Linking Environmental Effects to Consumption Pattern and Lifestyle - an Integrated Model Study

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Abstract:

We combine several data sources and apply them in an integrated modeling framework. Using input-output tables, energy flow matrices, CO_2 *emissions factors, and national consumer survey statistics, we are able to relate differences in household types to differences in private consumption and again to differences in* CO_2 *emissions. We identify which household characteristics have significant influence on* CO_2 *emissions. Comparing the results with other studies reveal that national differences in production and energy technology imply major differences in contribution of* CO_2 *emissions from various commodity groups. Finally, the comparison demonstrates national differences in income and expenditure elasticities of both energy and* CO_2*. This is due to differences in the disparity in* CO_2 *intensities amongst commodities and to the models' assumptions on foreign technology.*

1. Introduction

During the last decade, there has been an increasing focus on the importance of family lifestyle for the sustainable development of household consumption. The main part of these studies concentrates on socio-cultural factors from a sociological perspective, and stresses the importance of attitudes, values, the individual's need for expressing its identity through consumption of goods, a.o. (e.g. Giddens, 1990; Beck, 1992, Maffesoli, 1991).

During the same period, a number of studies focussing on demand for energy from an economic point of view have emerged. These studies apply quantitative models explaining changes in consumption patterns with changes in income and relative prices, often supplemented by technical information on electrical household equipment, improvements in thermal performance of housing or energy production technology etc. (cf. e.g. the review in Moroney, 1997 or Madlene, 1996). Most often, behavior is described in a simplified way and preferences are assumed constant over time.

The economic and the sociological approach supplement each other, but have so far benefited little from each other. Recently, however, several attempts to link household consumption choices and lifestyle with input-output modeling and energy and emission flow analysis in one integrated modeling framework have emerged (cf. Weber and Perrels, 2000; Munksgaard et al, 2000, Duchin, 1998, Lenzen, 1998). The main idea behind these studies is that information on household characteristics such as the level of education, the presence of children, urbanity, socio-economic status and others are included in the analysis and utilized as explanatory variables in quantitative modeling. These studies do not only consider residential energy consumption and derived emissions, but also energy and emissions embodied in commodities other than energy.

In the present study, we combine several data sources and apply them in an integrated modeling framework following the tradition of the studies described above. This type of analysis has not been carried out for Danish data before, and the study benefits from recent and detailed data on production sectors, commodities, energy types and household characteristics. In the present paper, we consider only CO_2 emissions from energy. However, the analysis may easily be extended to other types of emissions.

2. Model

The model relevant for our analysis is an extension of the model used by Munksgaard et al. (2000). Contrary to that study, we do not focus on total CO_2 emissions associated with the consumption of all Danish households, but CO_2 emissions at a single-household level; that is, the model is applied to various household types, making it possible to explore lifestyle effects on CO_2 emissions.

As in Munksgaard et al. (2000), we distinguish between direct and indirect emissions. The *direct emissions* are emissions associated with the consumption of energy commodities in the households, i.e. electricity, gas, oil, gasoline and other heating. The *indirect emissions* are emissions associated with the production of all other commodities for households (such as furniture, clothes, foods, services), i.e. emissions that occur in the industry producing these commodities.

Total CO_2 emissions from household type *i* are defined as

$$E_i = E_{ih} + E_{ip} \quad , \tag{1}$$

where

E_i is total CO_2 emissions from household *i*,
E_{ih} is direct CO_2 emissions from household *i*, and
E_{ip} is indirect CO_2 emissions from household *i*.

The analysis is carried out in two steps:

$ First, direct CO_2 emissions from household energy use are analysed using a simple energy-emission model

$ Second, indirect CO_2 emissions are analyzed using a generalized input-output model that also incorporates energy and emission matrices.

Direct CO_2 Emissions

Model (2) below estimates direct CO_2 emissions from household energy use as the product of total energy consumption and the composition of energy types in the household and energy supply sectors:

$$E_{ih} = Q_{ih} \; M_h \; F, \qquad (2)$$

where

E_{ih} denotes a scalar of total direct CO_2 emissions from household *i*,

Q_{ih} is a 1 x 5 vector including the consumption of five types of energy in household *i*, i.e. electricity, gas, oil, gasoline and other heating (primarily district heating, coke and coal) in units of GJ,

M_h is a 5 x 40 matrix of fuel mix in the household sector, i.e. demand for 40 energy types per unit of total energy demand for five energy consumption categories, and

F is a 40 x 1 vector of CO_2 emission factors in units of kg CO_2/GJ for 40 energy types. The emission factors are constant for 37 of the 40 types of energy, as they solely depend on the carbon content of the fuel. For three types, however, (electricity, district heating and gas from gasworks) the CO_2 emission factor depends on fuel mix in the energy supply sector, and consequently is changing over time.

Note that only the exogenous variable Q_{ih} (the absolute level of five categories of energy consumption) is specific to household *i*, whereas M_h and F are general figures based on national data.

Indirect CO_2 Emissions

Model (3) below estimates the indirect CO_2 emissions from household consumption by using the input-output model as used in Munksgaard et al (2000):

$$E_{ip} = F\ (M_p \# R_p)\ (I\text{-}A)^{-1}\ C\ c_i \tag{3}$$

where

- $\#$ denotes element-wise multiplication,
- E_{ip} denotes a scalar of total indirect CO_2 emissions from production sectors as a consequence of production of goods and services used by household *i*,
- F is a 1 x 40 vector of CO_2 emission factors as above,
- M_p is a 40 x 130 matrix of fuel mix in the production sectors, i.e. demand for 40 energy types per unit of total demand for energy for all production sectors,
- R_p is a 1 x 130 vector of energy intensities, i.e. total energy consumption per unit of production in all 130 sectors, in units of GJ,
- $(I\text{-}A)^{-1}$ is the 130 x 130 Leontief inverse matrix,
- C is a 130 x 72 matrix of the composition of consumption commodity aggregates, i.e. 72 private consumption commodity aggregates apportioned by production sectors,
- c_i is 72 x 1 vector including consumption of 72 commodities in household *i*, in units of Danish Crowns (DKK) 1000.

The integrated model

The integrated model, which is illustrated in Figure 1, is extended in two ways: First, matrices of energy consumption and emissions are added, and second, final demand has been sub-divided to a detailed level. Hence, private consumption is given for 72 commodity groups and these groups are all given for various household types. The number *n* of household or family types is open. In the present study, we apply 390 family types.

Figure 1. The integrated model system

<table>
<tr><td rowspan="4"></td><td rowspan="4">Interme-diate commo-dities</td><td colspan="5">Final demand</td></tr>
<tr><td colspan="4">Private consumption</td><td>Other final demands</td></tr>
<tr><td>Commodity #1</td><td>Comm. #2</td><td></td><td>…Comm. #72</td><td></td></tr>
<tr><td>Household type #1,…, Household type #n</td><td>H_1…..$H_{n.}$</td><td></td><td>H_1…..$H_{n.}$</td><td></td></tr>
<tr><td>Domestic production</td><td colspan="6" rowspan="2">Commodity Flows</td></tr>
<tr><td>Foreign production</td></tr>
<tr><td>Value added</td><td colspan="6">Production Factor Flows</td></tr>
<tr><td>Energy</td><td colspan="6">Energy Flows</td></tr>
<tr><td>CO_2-emissions</td><td colspan="6">Emission Flows</td></tr>
</table>

Consumer Units

When comparing various household types, it is often enlightening to adjust for differences in household size by applying *consumer units*, which is relevant, because there may be economies of scale in consumption in larger families, as several commodities can be shared and as item prices may decrease with purchased amount. Therefore, the second household member counts less than the first. In addition, children should count less than adults, as their consumption is lower. In the Danish consumer survey, consumer units are defined by the *modified OECD scale*, as reported in Table 1 below.

Table 1. The modified OECD Scale of Consumer Units

Household member	Consumer Units
First person over 14 years	1
Other persons over 14 years	0.5
Children under 15 years	0.3

Source: Statistics Denmark, 1999

3. Data

All data used in this study are compatible, as they apply identical classification of goods and activities, making it possible to utilize the data in an integrated model. The data used for the present analysis are:

- Danish *input-output tables* for the year 1995 from Statistics Denmark, (tables documented in Statistics Denmark, 1986).

  These tables comprise 130 production sectors and 9 categories of final demand. One of the latter is private consumption, which is divided into 72 components, 5 of which are direct energy consumption by households

- *Energy-flow matrices* for the year 1995 from Statistics Denmark containing energy consumption for the 130 production sectors as well as for 5 categories of household consumption (documented in Statistics Denmark, 1983).

  Energy demand is reported for 40 types of energy in both monetary, physical and calorific terms. The latter is used in the present study as emission factors are given relative to calorific terms

- *CO_2 emission factors* for the 37 primary fuels are part of the European CORINAIR database (Fenhann et al., 1997).

  The factors are calculated on the basis of the carbon content of the fuels. Emission factors for the converted energy types (electricity, district heating and gas) have previously been calculated from the primary emission factors and the energy inputs to the energy production sector (Munksgaard et al., 1998). Finally, CO_2 emission factors for renewable energy types are considered to be zero, as it is assumed that CO_2 emissions from e.g. straw and wood are absorbed in new biomass production

- The *consumer survey* from Statistics Denmark (Statistics Denmark, 1999).

  The survey comprises the consumption of 1334 commodities of 3438 representatively selected households. The latest survey is based on data from 1995-97. The households characteristics registered are various economic, financial and demographic characteristics e.g. number and age of children and adults, type of accommodation, urbanity, socio-economic status, education and type and level of disposable household income and expenditure. Data is collected through registration of household purchases on a daily basis, supplemented by personal interviews and information from the registrars. The respondent rate is 68,5% and the. As a final step in the calculation procedure, the data is adjusted for the proportion of non-respondents, in order to give each household type the appropriate weight.

4. Results

As already described, the study considers direct as well as indirect CO_2 emissions. The inclusion of indirect CO_2 emissions enables us to estimate CO_2 contributions from commodities other than energy and thus to estimate the importance of differences in consumption pattern for various family types.

Table 2 illustrates the large variation in CO_2 intensities, in units of tonnes CO_2 per DKK1000 of total household consumption, listing the ten commodities with highest and lowest intensity in 1995. As appears from the Table, the most CO_2- intensive commodities are various types of foods and transportation. In contrary, the ten least CO_2-intensive commodities (Bottom 10) are mainly services and financial transfers.

Table 2: Indirect CO_2 intensity: Top 10 and Bottom 10, 1995

Number on list	**Commodity**	**kg CO_2 per DKK 1000**
Top 10		
1	Fruit and vegetables	112
2	Purchased transportation	110
3	Water	96
4	Package holidays	90
5	Butter	79
6	Sports and hobbies	78
7	Fish	75
8	Other foods	75
9	Dairy produces	72
10	Sugar	71
Bottom 10		
10	Hospital care	23
9	Mail and telephone services	22
8	Medical services	19
7	Day care institutions for children	17
6	Insurance services	16
5	Cigarettes and tobacco	12
4	Financial services	11
3	Domestic services	10
2	Housing taxes	8

1	Gross rent	8

Source: own calculations

The large variation in intensities indicates that changes in consumption pattern may change CO_2 emissions substantially. Thus, different family types, having different lifestyles and consumption patterns, are likely to differ significantly with regard to CO_2 emissions. This is examined in the following.

In the present study, we focus on the following household characteristics:

- Level of education of main income supplier (college/other),
- Number of children under 18 years,
- Age of oldest child under 18 years,
- Number of adults,
- Age of main income provider,
- Disposable household income (6 intervals of DKK 100,000),
- Urbanity (rural/urban),
- Type of accommodation (flat/house (detached or terraced house)),
- Employment status (employed/non employed (including students, job-seeking and retired persons)).

In the analysis, we apply consumer units (cf. Section 2) whenever possible, in order to provide at better basis for comparing the different household types, i.e., we consider differences in tonnes of CO_2 emissions *per year and per consumer unit* for each household type. In addition, we adjust each household characteristic for differences in disposable household income level.

Several of these household characteristics were found to have major importance. The most significant variables are disposable household income, type of accommodation, urbanity, and finally age of the household's main income supplier. Unexpectedly, the level of education, employment status, the presence and age of children nor the number of adults (1, 2, 3 or more) living in the household makes any noteworthy difference – the deviations from the average Danish family are mostly below 6%. This is remarkable, since most of these variables, having minor importance, are assumed to be related to lifestyle and socio-cultural variables like consumer attitudes and values (see e.g. Bourdieu, 1989, 1990; Turner, 1988). However, there are exceptions to this rule: the presence of children is important in the case of rural families, as families with children have lower direct CO_2 emissions per consumer unit. Also, households with more than two adults exhibit small economies of scale in their direct energy consumption. Finally, employed families have somewhat lower direct CO_2 emissions per consumer unit, due to a lower demand for heating. These findings were obtained for households located within the same income brackets.

Table 3 below presents the CO_2 emissions for various household types, described by the variables found to be most significant in the present study: disposable household income, type of accommodation, urbanity and finally age of the household's main income supplier. The table shows direct CO_2 emissions, i.e. emissions from household energy consumption, indirect CO_2 emissions, i.e. emissions in production sectors producing goods (other than energy) for private household consumption, and finally direct and indirect CO_2 intensities. P.T.O. (see other side)

As appears from Table 3, consumption of commodities other than energy accounts for 18.5 tonnes CO_2 per year, almost as much as household energy consumption, which accounts for 21.4 tonnes/year. In total, almost 40 tonnes CO_2 was emitted in 1995.

Furthermore, Table 3 shows that urban families living in flats have the lowest direct CO_2 emissions. Especially low income urban families, have direct CO_2 emissions which are approximately 3 tonnes/consumer unit/year (more than 50%) below the average of all Danish families. In contrary, rural families, especially high income families, have the highest direct CO_2 emissions – up to more than 10 tonnes/consumer unit/year (or 78%) above the average of all Danish families. Families living in single-family houses in urban areas have lower emissions than similar families in rural areas. The age of the main income contributor seems to have minor importance, compared to the type of accommodation and the disposable household income.

Indirect CO_2 emissions increase with disposable household income. The type of accommodation, age and urbanity seem to have very little importance. High income

Table 3. CO_2 emissions for various household types, 1995. (Percentage deviation from the average Danish household in brackets).

			Direct CO_2 Tonnes/ Consumer-unit/year		Indirect CO_2 Tonnes/ Consumer-unit/year		Total CO_2 Tonnes/ Consumer-unit/year		Direct CO_2 Intensity (kg/DKK 1000)		Indirect CO2 Intensity (kg/DKK 1000)	
Low income												
	Young											
		Urban flat	2.9	(-51)	4.4	(-14)	7.4	(-33)	26.3	(-41)	39.5	(4)
		Urban house	3.7	(-39)	4.0	(-23)	7.6	(-31)	34.9	(-22)	37.8	(0)
		Rural house*	6.5	(9)	5.4	(5)	11.9	(8)	43.1	(-3)	35.9	(-5)
	Middle aged											
		Urban flat	3.3	(-45)	4.5	(-12)	7.8	(-30)	27.5	(-38)	37.9	(0)
		Urban house	5.3	(-11)	4.5	(-11)	9.8	(-11)	41.9	(-6)	36.0	(-5)
		Rural house*	6.9	(17)	4.6	(-10)	11.6	(5)	54.0	(21)	35.9	(-5)
	Elderly											
		Urban flat	2.9	(-51)	3.7	(-27)	6.7	(-40)	28.6	(-36)	36.5	(-4)
		Urban house	5.9	(-1)	4.0	(-22)	9.9	(-11)	51.3	(15)	35.0	(-8)
		Rural house*	6.9	(16)	3.7	(-27)	10.6	(-4)	63.2	(42)	34.2	(-10)
Middle income												
	Young											
		Urban flat	3.6	(-39)	5.9	(14)	9.5	(-14)	25.0	(-44)	40.5	(7)
		Urban house	5.1	(-13)	5.6	(10)	10.8	(-3)	34.3	(-23)	37.5	(-1)
		Rural house*	7.5	(27)	5.2	(2)	12.8	(15)	52.6	(18)	36.6	(-3)
	Middle aged											
		Urban flat	3.6	(-40)	5.2	(2)	8.8	(-20)	26.8	(-40)	39.4	(4)
		Urban house	6.0	(1)	5.8	(13)	11.8	(6)	40.3	(-10)	38.8	(2)
		Rural house*	6.0	(2)	4.8	(-7)	10.8	(-2)	47.8	(7)	37.9	(0)
	Elderly											
		Urban flat	4.1	(-31)	5.7	(11)	9.8	(-12)	27.9	(-38)	38.6	(2)
		Urban house	6.4	(8)	5.9	(16)	12.3	(11)	40.1	(-10)	37.0	(-2)
		Rural house*	8.2	(38)	6.1	(19)	14.3	(29)	50.2	(13)	37.1	(-2)
High income												
	Young											
		Urban flat	2.1	(-65)	5.5	(7)	7.6	(-32)	13.4	(-70)	35.1	(-7)
		Urban house	7.2	(20)	7.2	(41)	14.4	(30)	38.5	(-14)	38.8	(2)
		Rural house*	7.7	(30)	7.8	(52)	15.5	(40)	34.3	(-23)	34.6	(-9)
	Middle aged											
		Urban flat	4.1	(-31)	7.1	(38)	11.2	(1)	22.6	(-49)	39.1	(3)
		Urban house	6.4	(7)	7.2	(41)	13.6	(23)	34.3	(-23)	38.9	(3)
		Rural house*	8.2	(39)	7.4	(45)	15.7	(42)	42.5	(-5)	38.4	(1)
	Elderly											
		Urban flat	6.0	(1)	8.3	(63)	14.3	(29)	26.6	(-40)	37.1	(-2)
		Urban house	6.6	(12)	6.9	(34)	13.5	(22)	30.8	(-31)	31.8	(-16)
		Rural house*	10.6	(78)	7.4	(45)	18.0	(63)	50.6	(13)	35.6	(-6)
Average Danish Household			5,9	(0)	5,1	(0)	11,0	(0)	44,6	(0)	37,9	(0)
Total**		Mio tonnes/year	21,4		18,5		39,9					

* Number of families living in rural flats is negligible and is not included

** This number includes families living in rural flats

Source: own calculations

families show in most cases indirect CO_2 emissions of more than 7 tonnes/consumer unit/year (or more than 40%) above the average of all families.

Thus, direct CO_2 emissions vary with type of accommodation, urbanity and to some extent disposable household income. Type of accommodation and urbanity turn out to be especially important for CO_2 emissions associated with energy demand for heating and petrol, as families living in urban flats have a much lower demand for individual transportation and heating. In contrary, indirect CO_2 emissions increase with disposable household income, as these emissions are associated to total private consumption. It is remarkable, that differences in consumption patterns due to differences in socio-cultural variables like education or employment status are negligible. The most significant variables are income, housing characteristics, and age. Thus, according to the results of this study, it seems that an explanation of the consumption pattern should be based on economic variables and housing characteristics and to some extent age, rather than socio-cultural variables.

The fact that the level of education and knowledge about environmental problems bears no relation to CO_2 emissions was also demonstrated in a study on households in Melbourne, Australia (Stokes et al. 1994). As regards Danish studies, these results are in agreement with the findings of Pedersen (1997, 2000) and Jensen (1999). Based on Danish survey data, Pedersen and Jensen conclude that consumers' environmental consideration and concern have no influence on consumption on electricity (Pedersen's study) and petrol (Jensen's study) – even though Pedersen found that environmental concern was positively correlated to consumption of organic foods, according to the same survey.

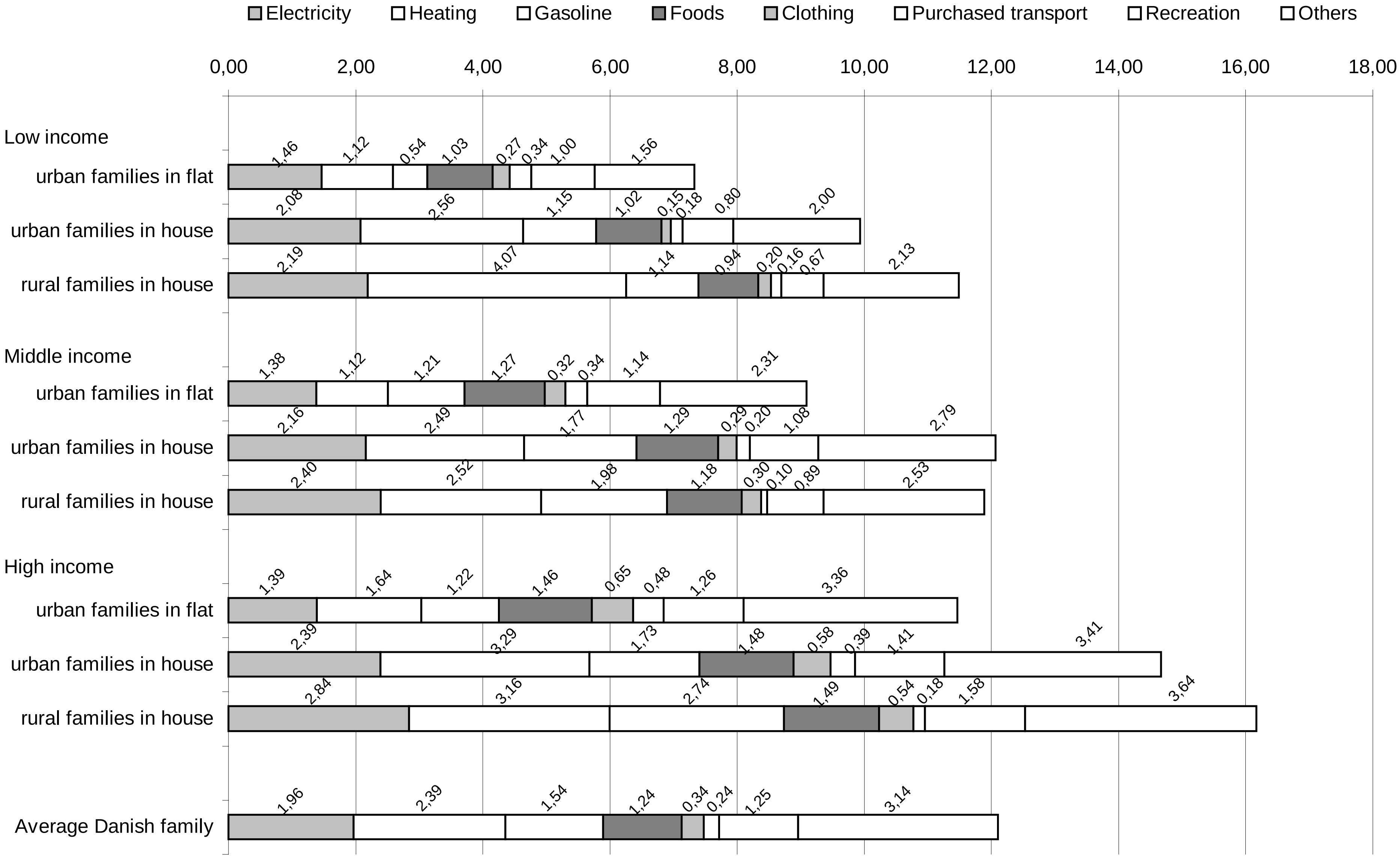
The CO_2 intensity tells us how much CO_2 is emitted relative to total household consumption for each family type. Table 3 shows that the direct CO_2 intensity largely follows the pattern of direct CO_2 emissions, i.e. urban families living in flats have the lowest direct CO_2 intensity. However, looking at intensities, it is clear that high income families have the lowest emissions – not low income families. The reason for that is that high income families have the highest household consumption, and the direct energy consumption constitutes a smaller part of that the higher the consumption level. In contrary, indirect CO_2 intensity varies very little with family types, and is not decreasing with disposable household income. Thus, indirect CO_2 emissions increase almost proportionally with total consumption.

CO_2 emissions can be broken down into broad commodity groups. Figure 2 shows that the two largest contributors to CO_2 emissions are the consumption of energy for heating and electricity, contributing with 2.4 tonnes and almost 2.0 tonnes respectively per consumer unit in 1995. Third largest contributor is the consumption of gasoline, contributing 1.5 tonnes, followed by food consumption (1.2 tonnes) and recreation (1.3 tonnes) constitutes the fifth largest contributor.

Looking at family types, it is clear that CO_2 emissions from consumption of energy for heating is increasing with disposable household income, and also that it is much higher in rural than urban areas. CO_2 emissions from electricity and from food consumption increases with disposable household income – as regards these commodity groups, no other household characteristics have major influence. CO_2 emissions from petrol consumption also increase with income, but moreover, they vary with type of accommodation, as emissions are much higher for families living in single-family houses.

Indirect CO_2 emissions are rather invariant with the type of accommodation and urbanity. CO_2 emissions from consumption of purchased transportation, recreation are highest in young families with high income. Finally, CO_2 emissions from consumption of clothes and shoes are highest in high income families.

Figure 2. CO_2 emissions in 1995 by type of commodity and household (tonnes CO_2 per consumer unit per year)



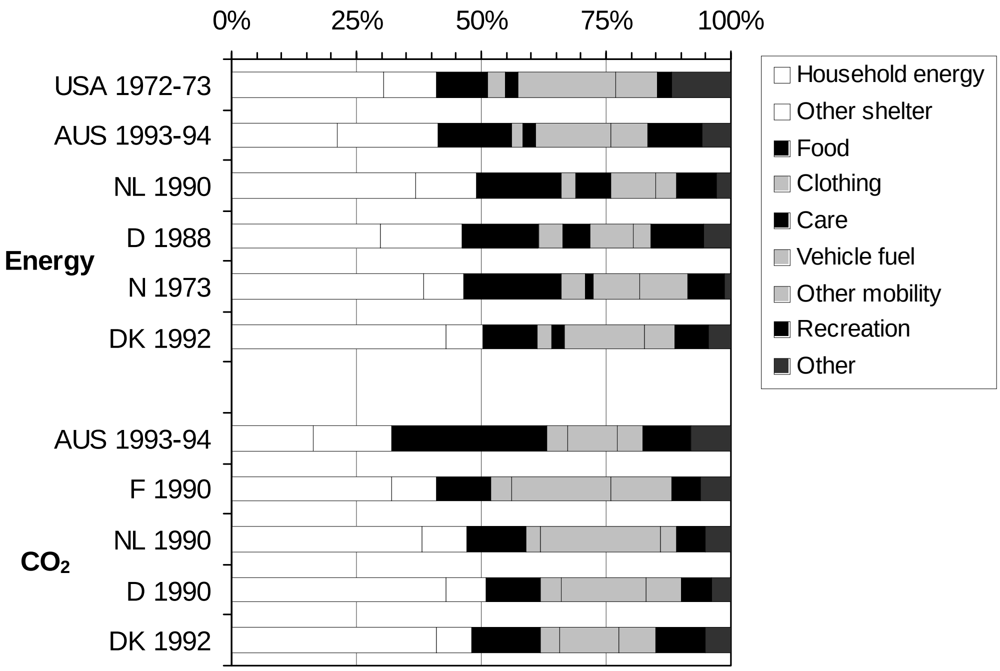
5. Comparison with previous studies

The method of combining household expenditure data with input-output-based energy intensities was developed by Robert Herendeen already in the early 1970s, and first applied to the US economy of 1960-61 (Herendeen and Tanaka 1976), the Norwegian economy of 1973 (Herendeen 1978), and again the US economy of 1972-73 (Herendeen et al. 1981). Even though these are the first studies of this kind, they already consider a range of theoretical issues such as the energy intensity of renewable energy, taxes and subsidies (the 'valuation problem'), the allocation of government consumption, changes in household assets (problem of income definition), and investment. Herendeen also covers various demographic factors influencing household energy requirements such as expenditure (related to income), number of household members, and regional population density. The main results of these early studies was that (1) a substantial part of a household's energy requirements is constituted by non-energy commodities, (2) total energy requirements increase less than proportional with income, that is, total energy intensity decreases with income, (3) per-capita energy requirements decrease with the number of household members, and (4) urban households exhibit a lower energy intensity than rural households.

These results were confirmed in similar studies on other countries, such as the Netherlands (Vringer and Blok 1995, and Biesiot and Noorman 1999), Germany (Weber and Fahl 1993), and Australia (Lenzen 1998). In the following, we will quantitatively compare the results obtained in this study for Denmark with findings from the studies mentioned above with regard to points (1)-(3).

Figure 3 shows a comparison of breakdowns of household energy and CO_2 requirements into nine commonly used categories of human need. The data was extracted from the references mentioned above as well as Munksgaard et al. (2000) and Weber and Perrels (2000). The portion of direct requirements (vehicle fuel and household energy) in the total is around 55% for European countries and about 30% for Australia. Munksgaard et al (2000b) and Biesiot and Noorman (1999) have reported that, in the case of Denmark and the Netherlands, respectively, this portion has been decreasing steadily since 1950 and since 1980, respectively. The most striking differences between the energy requirements of households in different countries are the following: Household energy accounts for the smallest part of the total in Australia, followed by the USA and Germany, and finally the Netherlands, Norway, and Denmark, reflecting these countries' climates. In contrast, mobility comprises a larger part in Australia and the USA, since these countries are larger and more sparsely settled. In the remainder of the countries, energy requirements are fairly similar, given differences in category definition and base year. Within CO_2 requirements, the following features can be observed: Food accounts for an unusually large part of Australian emissions because of considerable non-energy CO_2 emissions due to land clearing in Queensland for the purpose of beef cattle grazing. Again, Australian emissions from household energy use are comparatively small. Emissions from household energy in France are relatively small, because French households are an important user of nuclear electricity. Once again, the remainder of countries shows a similar emissions structure, with

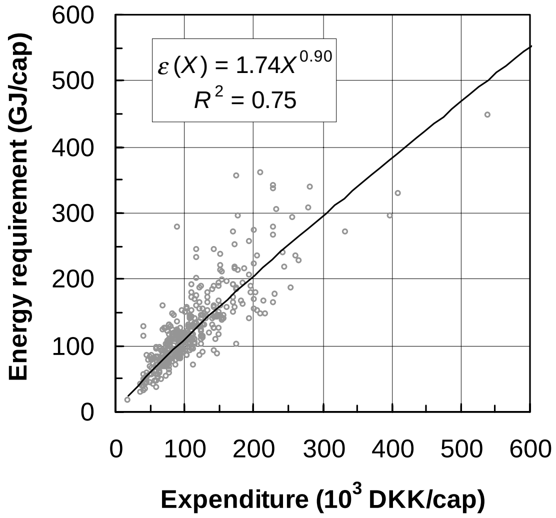
Figure 3. Comparison of household energy and CO_2 requirement (breakdown as percentages of the country total)



differences possibly be caused by discrepancies in category definition. Note that all categories are subject to slight discrepancies in definition. 'Vehicle fuel' contains requirements for 'Recreation' (holiday trips) in the case of the USA, and but does not contain trips to and from work in the case of Germany. For all CO_2 data, the category 'Care' was aggregated with 'Other'.

Correlations of per-capita household energy and CO_2 requirements with expenditure or income can conveniently be analysed by using the concept of expenditure and income elasticities. As an example, Figure 4 shows the relation between per-capita energy requirement ε and household expenditure X.

Figure 4 Per-capita energy requirement and expenditure for 390 household types and regression according to Equation (5).



It can be seen that the relationship is not proportional, but flattens out towards high expenditure. Thus, the expenditure elasticity $\eta_{X,\varepsilon}$ of the per-capita energy requirement ε, for example, is defined as

$$\eta_{X,\varepsilon} = \frac{\partial\varepsilon / \partial X}{\varepsilon / X} \quad , \tag{4}$$

where X is household expenditure. A value of $\eta_{X,\varepsilon} = 0.9$, for example, means that, for a 100% increase in household expenditure, the per-capita energy requirement increases by only 90%. This elasticity can be calculated by regressing requirement data as a function

$$\varepsilon(X) = kX^{\eta_{X,\varepsilon}} \quad , \tag{5}$$

where k and $\eta_{X,\varepsilon}$ are constant. The R^2 value in Figure 4 reveals whether the regression function is closely correlated with the initial data (R^2 close to 1) or not (R^2 close to 0). Formulas for the per-capita CO_2 requirement χ or household income I can be derived in the same way.

The dependence of the per-capita energy requirement, for example, on the number of household members N can be characterised by the relative change

$$\rho_\varepsilon = \frac{d\varepsilon}{\varepsilon\, dN} \quad . \tag{6}$$

A value of $\rho_\varepsilon = -0.1$, for example, means that for each additional household member, the per-capita energy requirement decreases by 10%. In order to obtain ρ_ε, the functional relationship in Equation (6) requires a regression with an exponential function

$$\varepsilon(N) = k\exp(\rho_\varepsilon N), \tag{7}$$

where k is a constant. Note that, apart from having an intuitive meaning, the approach in Equations (6) and (7) has also proven to yield a better correlation with the underlying observations than power, logarithmic, or polynomial functions. As an example, Figure 5 shows the relation between per-capita energy requirement ε and the number of household members N. Note than N is not adjusted for consumer units, in order to make the results of this study and other studies comparable.

Figure 5. Per-capita energy requirement and number of household members for 390 household types and regression according to Equation (7).

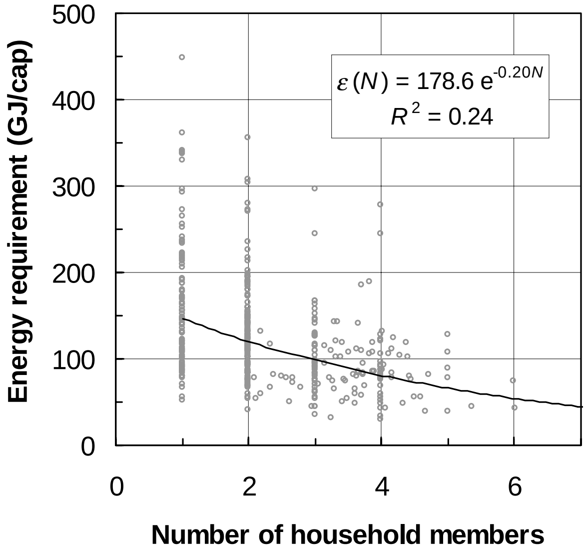


Table 4 shows values for $\eta_{I,\varepsilon}$, $\eta_{I,\chi}$, $\eta_{X,\varepsilon}$, $\eta_{X,\chi}$, and ρ_ε derived from five previous and this study. It can be seen that all elasticities are smaller than 1. This circumstance describes a saturation in the energy or CO_2 requirements of households with increasing expenditure or income. Apparently, 1 DKK of consumption at the upper end of the expenditure or income scale does not require as much energy to be consumed or CO_2 to be emitted as 1 DKK of consumption at the lower end. This is due to the fact that, at the lower income end, mostly 'necessities' such as food or fuel are consumed, which are energy- or CO_2-intensive, while at the upper end, remaining disposable income is spent for 'luxuries' such as services or entertainment, which are not energy- or CO_2-intensive. This effect is observed for all countries. Moreover, it can be seen that income elasticities are smaller than expenditure elasticities, which is due to the fact that progressive income taxes and economies of scale in the prices of household purchases introduce an additional rigidity into the income-energy/CO_2 relationship. The expenditure-energy/CO_2 regression also has a higher R^2 value (≈0.76) than the income-energy/CO_2 regression (R^2≈0.47), which again indicates that expenditure is a better proxy for energy consumption and CO_2 emissions than income. In the case of Australia, elasticities with regard to energy are larger than elasticities referring to CO_2, which indicates that the disparity between necessities and luxuries in terms of CO_2 intensities is larger than that in terms of energy. This is not the case for Denmark, where the CO_2 intensity is closely linked to the energy intensity, since there are no significant non-energy CO_2 emissions (such as from land clearing in Australia).

Table 4. Expenditure and income elasticities for per-capita energy and CO_2 requirements as well as relative changes in energy requirements with the number of household members for various countries.

	Reference	inc. elast. of energy $\eta_{I,\varepsilon}$	inc. elast. of CO_2 $\eta_{I,\chi}$	exp. elast. of energy $\eta_{X,\varepsilon}$	exp. elast. of CO_2 $\eta_{X,\chi}$	ρ_ε
USA 1960-61	Herendeen & Tanaka 1976			0.87		
USA 1972-73	Herendeen et al. 1981			0.81		-0.33
N 1973	Herendeen 1978			0.72		-0.27
NL 1990	Vringer & Blok 1995	0.63		0.83		-0.33
AUS 1993-94	Lenzen 1998	0.59	0.55	0.74	0.70	-0.16
DK 1995	this study	0.51	0.51	0.90	0.90	-0.20

Note: I=Income; X=expenditure; ε=per-capita energy requirement; χ=per-capita CO_2 requirement.

Furthermore, the Danish expenditure elasticity is larger than the Dutch and the American, which are in turn larger than the Australian expenditure elasticity. It seems that in Denmark, energy consumption and CO_2 emissions are much more proportional to expenditure than in other countries. Again, this is caused by the fact than Danish energy and CO_2 intensities exhibit a relatively small disparity amongst commodities. Assuming that Danish household consumption is not too different from Australian, this finding is somewhat surprising, and could in fact be an effect of the input-output modeling. While in Denmark, secondary and tertiary industries dominate, Australia receives a considerable part of its national income from energy and CO_2-intensive primary industries. Since for both countries, single-region models were employed, imports were treated assuming domestic technology. This circumstance may cause energy and CO_2 embodied in Danish imports to be underestimated, and hence Danish intensities to be too uniform. In contrast, Danish income elasticities are smaller than Dutch and Australian, which is probably due to a strong progression in the Danish tax rate.

It should finally be pointed out that the method employed in this work does not distinguish between commodities produced within one sector, that is, a piece of furniture of 10,000 DKK is assumed to have the same energy and CO_2 intensity as a piece of furniture of 200 DKK. Some expensive products, however, incorporate a large proportion of manual labor, and are hence less energy- and CO_2-intensive. Since high-income households are likely to buy more expensive products, all elasticities are likely to be smaller than indicated in Table 4.

Finally, increasing the number of household members always reduces the per-capita energy requirement. The relative change in energy requirement is large for the Netherlands and the USA, but relatively small for Australia. Under the assumption that the commodity mix of households does not change with size, this indicates that large households in the Netherlands and in the USA shared a great deal more than in Australia. ρ_E is, however, also influenced by the proportion of children in the household, and again, by economies of scale in the prices of household purchases, so that at this stage, a thorough analysis cannot be provided.

6. Conclusions

The study shows that different family types may have different CO_2 emissions. These differences are primarily due to differences in the type of accommodation, urbanity, age and disposable household income. Our analysis reveals that the consumption of most commodities is correlated with the household budget. Furthermore, transportation needs resulting from differences in distance between work and home, are correlated with urbanity, while differences in demand for heating are correlated with the type of accommodation. Finally, age appears to have some importance, as young families have lower direct CO_2 emissions.

Variables such as education, number and age of children, employment status, number of adults (adjusted for number of consumer units) appear to have only minor influence. Remarkably, most of these variables are assumed to be related to socio-cultural variables e.g. consumer attitudes and values. Moreover, the variables that strongly influence CO_2 emissions are economic parameters, housing characteristics, and age. Thus, according to the results from this study, it seems that the explanation of the consumption pattern preferably should be based on economic variables and housing characteristics and to some extent on age, rather than on socio-cultural variables.

A Comparison with results on other countries shows that, with regard to breakdowns of energy and CO_2 requirements into broad commodity groups, Denmark, the Netherlands, Germany, and Norway are similar. Due to differences in climate and population density, the USA and Australia show a comparably low contribution from household energy, but a larger contribution from mobility. Danish energy and CO_2 intensities bear a closer relation to each other and to income than Australian intensities, because 1) in Denmark, there are no significant non-energy CO_2 emissions, and 2) Danish intensities appear to be more uniform across commodities.

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