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\textsubscript{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\textsubscript{2} emissions. We identify which household characteristics have significant influence on CO\textsubscript{2} emissions. Comparing the results with other studies reveal that national differences in production and energy technology imply major differences in contribution of CO\textsubscript{2} emissions from various commodity groups. Finally, the comparison demonstrates national differences in income and expenditure elasticities of both energy and CO\textsubscript{2}. This is due to differences in the disparity in CO\textsubscript{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 CO₂ 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 CO₂ emissions associated with the consumption of all Danish households, but CO₂ emissions at a single-household level; that is, the model is applied to various household types, making it possible to explore lifestyle effects on CO₂ 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 CO₂ emissions from household type *i* are defined as

\[ E_i = E_{ih} + E_{ip}, \]

where

- \(E_i\) is total CO₂ emissions from household *i*,
- \(E_{ih}\) is direct CO₂ emissions from household *i*, and
- \(E_{ip}\) is indirect CO₂ emissions from household *i*.

The analysis is carried out in two steps:

1. First, direct CO₂ emissions from household energy use are analysed using a simple energy-emission model
Second, indirect CO₂ emissions are analyzed using a generalized input-output model that also incorporates energy and emission matrices.

**Direct CO₂ Emissions**

Model (2) below estimates direct CO₂ 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:

\[ E_{ih} = Q_{ih} M_h F, \]  

(2)

where

- \( E_{ih} \) denotes a scalar of total direct CO₂ 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 CO₂ emission factors in units of kg CO₂/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 CO₂ 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 CO₂ Emissions**

Model (3) below estimates the indirect CO₂ emissions from household consumption by using the input-output model as used in Munksgaard et al (2000):
\[ E_{ip} = F (M_p \# R_p) (I-A)^{-1} C c_i \]  

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,

- \((I-A)^{-1}\) 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>
<thead>
<tr>
<th>Intermediates</th>
<th>Final demand</th>
<th>Other final demands</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Private consumption</td>
<td>Comm. #2</td>
</tr>
<tr>
<td>Commodity #1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Household type #1,…, Household type #n</td>
<td>H₁,…,Hₙ</td>
<td>H₁,…,Hₙ</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Domestic production</th>
<th>Commodity Flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreign production</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Value added</th>
<th>Production Factor Flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>Energy Flows</td>
</tr>
<tr>
<td>CO₂-emissions</td>
<td>Emission Flows</td>
</tr>
</tbody>
</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**

<table>
<thead>
<tr>
<th>Household member</th>
<th>Consumer Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>First person over 14 years</td>
<td>1</td>
</tr>
<tr>
<td>Other persons over 14 years</td>
<td>0.5</td>
</tr>
<tr>
<td>Children under 15 years</td>
<td>0.3</td>
</tr>
</tbody>
</table>

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:

  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

- *CO₂ 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, CO₂ emission factors for renewable energy types are considered to be zero, as it is assumed that CO₂ 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 CO₂ emissions. The inclusion of indirect CO₂ emissions enables us to estimate CO₂ 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 CO₂ intensities, in units of tonnes CO₂ per DKK1000 of total household consumption, listing the ten commodities with highest and lowest intensity in 1995. As appears from the Table, the most CO₂-intensive commodities are various types of foods and transportation. In contrary, the ten least CO₂-intensive commodities (Bottom 10) are mainly services and financial transfers.

<table>
<thead>
<tr>
<th>Number on list</th>
<th>Commodity</th>
<th>kg CO₂ per DKK 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Top 10</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Fruit and vegetables</td>
<td>112</td>
</tr>
<tr>
<td>2</td>
<td>Purchased transportation</td>
<td>110</td>
</tr>
<tr>
<td>3</td>
<td>Water</td>
<td>96</td>
</tr>
<tr>
<td>4</td>
<td>Package holidays</td>
<td>90</td>
</tr>
<tr>
<td>5</td>
<td>Butter</td>
<td>79</td>
</tr>
<tr>
<td>6</td>
<td>Sports and hobbies</td>
<td>78</td>
</tr>
<tr>
<td>7</td>
<td>Fish</td>
<td>75</td>
</tr>
<tr>
<td>8</td>
<td>Other foods</td>
<td>75</td>
</tr>
<tr>
<td>9</td>
<td>Dairy produces</td>
<td>72</td>
</tr>
<tr>
<td>10</td>
<td>Sugar</td>
<td>71</td>
</tr>
<tr>
<td><strong>Bottom 10</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Hospital care</td>
<td>23</td>
</tr>
<tr>
<td>9</td>
<td>Mail and telephone services</td>
<td>22</td>
</tr>
<tr>
<td>8</td>
<td>Medical services</td>
<td>19</td>
</tr>
<tr>
<td>7</td>
<td>Day care institutions for children</td>
<td>17</td>
</tr>
<tr>
<td>6</td>
<td>Insurance services</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>Cigarettes and tobacco</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>Financial services</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>Domestic services</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>Housing taxes</td>
<td>8</td>
</tr>
</tbody>
</table>
The large variation in intensities indicates that changes in consumption pattern may change CO\textsubscript{2} emissions substantially. Thus, different family types, having different lifestyles and consumption patterns, are likely to differ significantly with regard to CO\textsubscript{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\textsubscript{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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ emissions, i.e. emissions from household energy consumption, indirect CO₂ emissions, i.e. emissions in production sectors producing goods (other than energy) for private household consumption, and finally direct and indirect CO₂ intensities. P.T.O. (see other side)

As appears from Table 3, consumption of commodities other than energy accounts for 18.5 tonnes CO₂ per year, almost as much as household energy consumption, which accounts for 21.4 tonnes/year. In total, almost 40 tonnes CO₂ was emitted in 1995.

Furthermore, Table 3 shows that urban families living in flats have the lowest direct CO₂ emissions. Especially low income urban families, have direct CO₂ 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 CO₂ 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 CO₂ emissions increase with disposable household income. The type of accommodation, age and urbanity seem to have very little importance. High income
Table 3. CO₂ emissions for various household types, 1995. (Percentage deviation from the average Danish household in brackets).

<table>
<thead>
<tr>
<th>Household Type</th>
<th>Direct CO₂ Tonnes/Consumer-unit/year</th>
<th>Indirect CO₂ Tonnes/Consumer-unit/year</th>
<th>Total CO₂ Tonnes/Consumer-unit/year</th>
<th>Direct CO₂ Intensity (kg/DKK 1000)</th>
<th>Indirect CO₂ Intensity (kg/DKK 1000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low income</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young</td>
<td>Urban flat 2.9 (-51)</td>
<td>4.4 (-14)</td>
<td>7.4 (-33)</td>
<td>26.3 (-41)</td>
<td>39.5 (4)</td>
</tr>
<tr>
<td></td>
<td>Urban house 3.7 (-39)</td>
<td>4.0 (-23)</td>
<td>7.6 (-31)</td>
<td>34.9 (-22)</td>
<td>37.8 (0)</td>
</tr>
<tr>
<td></td>
<td>Rural house* 6.5 (9)</td>
<td>5.4 (5)</td>
<td>11.9 (8)</td>
<td>43.1 (-3)</td>
<td>35.9 (-5)</td>
</tr>
<tr>
<td>Middle aged</td>
<td>Urban flat 3.3 (-45)</td>
<td>4.5 (-12)</td>
<td>7.8 (-30)</td>
<td>27.5 (-38)</td>
<td>37.9 (0)</td>
</tr>
<tr>
<td></td>
<td>Urban house 5.3 (-11)</td>
<td>4.5 (-11)</td>
<td>9.8 (-11)</td>
<td>41.9 (-6)</td>
<td>36.0 (-5)</td>
</tr>
<tr>
<td></td>
<td>Rural house* 6.9 (17)</td>
<td>4.6 (-10)</td>
<td>11.6 (5)</td>
<td>54.0 (21)</td>
<td>35.9 (-5)</td>
</tr>
<tr>
<td>Elderly</td>
<td>Urban flat 2.9 (-51)</td>
<td>3.7 (-27)</td>
<td>6.7 (-40)</td>
<td>28.6 (-36)</td>
<td>36.5 (-4)</td>
</tr>
<tr>
<td></td>
<td>Urban house 5.9 (-1)</td>
<td>4.0 (-22)</td>
<td>9.9 (-11)</td>
<td>51.3 (15)</td>
<td>35.0 (-8)</td>
</tr>
<tr>
<td></td>
<td>Rural house* 6.9 (16)</td>
<td>3.7 (-27)</td>
<td>10.6 (-4)</td>
<td>63.2 (42)</td>
<td>34.2 (-10)</td>
</tr>
<tr>
<td>Middle income</td>
<td>Urban flat 3.6 (-39)</td>
<td>5.9 (14)</td>
<td>9.5 (-14)</td>
<td>25.0 (-44)</td>
<td>40.5 (7)</td>
</tr>
<tr>
<td>Young</td>
<td>Urban house 5.1 (-13)</td>
<td>5.6 (10)</td>
<td>10.8 (-3)</td>
<td>34.3 (-23)</td>
<td>37.5 (-1)</td>
</tr>
<tr>
<td></td>
<td>Rural house* 7.5 (27)</td>
<td>5.2 (2)</td>
<td>12.8 (15)</td>
<td>52.6 (18)</td>
<td>36.6 (-3)</td>
</tr>
<tr>
<td>Middle aged</td>
<td>Urban flat 3.6 (-40)</td>
<td>5.2 (2)</td>
<td>8.8 (-20)</td>
<td>26.8 (-40)</td>
<td>39.4 (4)</td>
</tr>
<tr>
<td></td>
<td>Urban house 6.0 (1)</td>
<td>5.8 (13)</td>
<td>11.8 (6)</td>
<td>40.3 (-10)</td>
<td>38.8 (2)</td>
</tr>
<tr>
<td></td>
<td>Rural house* 6.0 (2)</td>
<td>4.8 (-7)</td>
<td>10.8 (-2)</td>
<td>47.8 (7)</td>
<td>37.9 (0)</td>
</tr>
<tr>
<td>Elderly</td>
<td>Urban flat 4.1 (-31)</td>
<td>5.7 (11)</td>
<td>9.8 (-12)</td>
<td>27.9 (-38)</td>
<td>38.6 (2)</td>
</tr>
<tr>
<td></td>
<td>Urban house 6.4 (8)</td>
<td>5.9 (16)</td>
<td>12.3 (11)</td>
<td>40.1 (-10)</td>
<td>37.0 (-2)</td>
</tr>
<tr>
<td></td>
<td>Rural house* 8.2 (38)</td>
<td>6.1 (19)</td>
<td>14.3 (29)</td>
<td>50.2 (13)</td>
<td>37.1 (-2)</td>
</tr>
<tr>
<td>High income</td>
<td>Urban flat 2.1 (-65)</td>
<td>5.5 (7)</td>
<td>7.6 (-32)</td>
<td>13.4 (-70)</td>
<td>35.1 (-7)</td>
</tr>
<tr>
<td>Young</td>
<td>Urban house 7.2 (20)</td>
<td>7.2 (41)</td>
<td>14.4 (30)</td>
<td>38.5 (-14)</td>
<td>38.8 (2)</td>
</tr>
<tr>
<td></td>
<td>Rural house* 7.7 (30)</td>
<td>7.8 (52)</td>
<td>15.5 (40)</td>
<td>34.3 (-23)</td>
<td>34.6 (-9)</td>
</tr>
<tr>
<td>Middle aged</td>
<td>Urban flat 4.1 (-31)</td>
<td>7.1 (38)</td>
<td>11.2 (1)</td>
<td>22.6 (-49)</td>
<td>39.1 (3)</td>
</tr>
<tr>
<td></td>
<td>Urban house 6.4 (7)</td>
<td>7.2 (41)</td>
<td>13.6 (23)</td>
<td>34.3 (-23)</td>
<td>38.9 (3)</td>
</tr>
<tr>
<td></td>
<td>Rural house* 8.2 (39)</td>
<td>7.4 (45)</td>
<td>15.7 (42)</td>
<td>42.5 (-5)</td>
<td>38.4 (1)</td>
</tr>
<tr>
<td>Elderly</td>
<td>Urban flat 6.0 (1)</td>
<td>8.3 (63)</td>
<td>14.3 (29)</td>
<td>26.6 (-40)</td>
<td>37.1 (-2)</td>
</tr>
<tr>
<td></td>
<td>Urban house 6.6 (12)</td>
<td>6.9 (34)</td>
<td>13.5 (22)</td>
<td>30.8 (-31)</td>
<td>31.8 (-16)</td>
</tr>
<tr>
<td></td>
<td>Rural house* 10.6 (78)</td>
<td>7.4 (45)</td>
<td>18.0 (63)</td>
<td>50.6 (13)</td>
<td>35.6 (-6)</td>
</tr>
<tr>
<td>Average Danish Household</td>
<td>5.9 (0)</td>
<td>5.1 (0)</td>
<td>11.0 (0)</td>
<td>44.6 (0)</td>
<td>37.9 (0)</td>
</tr>
<tr>
<td>Total**</td>
<td>Mio tonnes/year</td>
<td>21.4</td>
<td>18.5</td>
<td>39.9</td>
<td></td>
</tr>
</tbody>
</table>

* Number of families living in rural flats is negligible and is not included
** This number includes families living in rural flats
families show in most cases indirect CO₂ emissions of more than 7 tonnes/consumer unit/year (or more than 40%) above the average of all families.

Thus, direct CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ intensity tells us how much CO₂ is emitted relative to total household consumption for each family type. Table 3 shows that the direct CO₂ intensity largely follows the pattern of direct CO₂ emissions, i.e. urban families living in flats have the lowest direct CO₂ 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 CO₂ intensity varies very little with family
types, and is not decreasing with disposable household income. Thus, indirect CO₂
emissions increase almost proportionally with total consumption.

CO₂ emissions can be broken down into broad commodity groups. Figure 2 shows
that the two largest contributors to CO₂ 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 CO₂ 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. CO₂ emissions from electricity and from food
consumption increases with disposable household income – as regards these
commodity groups, no other household characteristics have major influence. CO₂
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 CO₂ emissions are rather invariant with the type of accommodation and
urbanity. CO₂ emissions from consumption of purchased transportation, recreation
are highest in young families with high income. Finally, CO₂ emissions from
consumption of clothes and shoes are highest in high income families.
Figure 2. CO₂ emissions in 1995 by type of commodity and household (tonnes CO₂ 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 CO₂ requirements, the following features can be observed: Food accounts for an unusually large part of Australian emissions because of considerable non-energy CO₂ 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 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 CO₂ data, the category ‘Care’
was aggregated with ‘Other’.

Correlations of per-capita household energy and CO₂ 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 \( \varepsilon \) and household expenditure \( X \).

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

![](image)

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 \( \varepsilon \), for example, is defined as

\[
\eta_{X,\varepsilon} = \frac{\partial \varepsilon}{\partial X} \frac{\varepsilon}{X},
\]

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

\[
\varepsilon (X) = 1.74X^{0.80}
\]

\( R^2 = 0.75 \)
increases by only 90%. This elasticity can be calculated by regressing requirement data as a function

\[ \varepsilon(X) = kX^{\eta_{X,\varepsilon}}, \]  

(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 \( \chi \) 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

\[ \rho_\varepsilon = \frac{d\varepsilon}{\varepsilon \, dN}. \]  

(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 \( \rho_\varepsilon \), the functional relationship in Equation (6) requires a regression with an exponential function

\[ \varepsilon(N) = k \exp(\rho_\varepsilon N), \]  

(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 \( \varepsilon \) 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.
Table 4 shows values for $\eta_{I}$, $\eta_{X}$, $\eta_{X,I}$, and $\rho_e$ 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 ($\approx0.76$) than the income-energy/CO$_2$ regression ($R^2\approx0.47$), 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

Figure 5. Per-capita energy requirement and number of household members for 390 household types and regression according to Equation (7).
elasticities referring to CO₂, which indicates that the disparity between necessities and luxuries in terms of CO₂ intensities is larger than that in terms of energy. This is not the case for Denmark, where the CO₂ intensity is closely linked to the energy intensity, since there are no significant non-energy CO₂ emissions (such as from land clearing in Australia).

Table 4. Expenditure and income elasticities for per-capita energy and CO₂ requirements as well as relative changes in energy requirements with the number of household members for various countries.

<table>
<thead>
<tr>
<th>Reference</th>
<th>inc. elast. of energy</th>
<th>inc. elast. of CO₂</th>
<th>exp. elast. of energy</th>
<th>exp. elast. of CO₂</th>
<th>(\rho)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA 1960-61 Herendeen &amp; Tanaka 1976</td>
<td>0.87</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA 1972-73 Herendeen et al. 1981</td>
<td>0.81</td>
<td>-0.33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N 1973 Herendeen 1978</td>
<td>0.72</td>
<td>-0.27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NL 1990 Vringer &amp; Blok 1995</td>
<td>0.63</td>
<td>0.83</td>
<td>-0.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AUS 1993-94 Lenzen 1998</td>
<td>0.59</td>
<td>0.55</td>
<td>0.74</td>
<td>0.70</td>
<td>-0.16</td>
</tr>
<tr>
<td>DK 1995 this study</td>
<td>0.51</td>
<td>0.51</td>
<td>0.90</td>
<td>0.90</td>
<td>-0.20</td>
</tr>
</tbody>
</table>

Note: \(I\)=Income; \(X\)=expenditure; \(\varepsilon\)=per-capita energy requirement; \(\chi\)=per-capita CO₂ 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 CO₂ emissions are much more proportional to expenditure than in other countries. Again, this is caused by the fact that Danish energy and CO₂ 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 CO₂-intensive primary industries. Since for both countries, single-region models were employed, imports were treated assuming domestic technology. This circumstance may cause energy and CO₂ 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 CO₂ 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 CO₂-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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ intensities bear a closer relation to each other and to income than Australian intensities, because 1) in Denmark, there are no significant non-energy CO₂ emissions, and 2) Danish intensities appear to be more uniform across commodities.
References


