Household direct energy consumption and CO₂ emissions in European countries

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LIST OF ABBREVIATIONS

NL  The Netherlands
DE  Germany
CZ  Czech Republic
HU  Hungary
EU  European Union
ERE Energy Required for Energy
HDDs Heat Degree Days
R²  Coefficient of determination
WTT Well-To-Tank
IEA International Energy Agency
SUMMARY

Household direct energy consumption is often regarded as a given and determined using a top-down approach. Furthermore, research regarding household energy consumption tends to focus on western countries. This research uses a bottom-up approach to determine the direct energy consumption and CO$_2$ emissions in the West-European countries the Netherlands and Germany and the East-European countries Hungary and the Czech Republic. This was possible because of the availability of a dataset that contained data from a survey, which was performed in all four countries. The dataset enables a more detailed determination of the underlying variables (e.g. household size, infrastructure, region, climate, habits, etc.) that influence the energy consumption and CO$_2$ emissions per energy category (transport, heating and electricity). This should make it possible to answer the following research question: What are the differences in the direct energy consumption of households within and between European countries and their consequent CO$_2$ emissions and how will these patterns change in the future?

Household final energy consumption was converted to primary energy consumption using energy-required-for-energy ratios of national electricity sectors and fuels used. The CO$_2$ emissions were determined using data regarding the national electricity sector and fuel-specific CO$_2$ emissions from fuel burning. In addition, a model was used to forecast possible changes in the energy consumption patterns and related CO$_2$ emissions of households.

Households in the Netherlands and Germany consume, on average, 162 GJ and 174 GJ respectively. The average Czech household consumes 200 GJ of direct energy. This high consumption is primarily due to the rural households with their high heating and electricity consumption. The average Hungarian household consumes the least amount of direct energy with 115 GJ. The average CO$_2$ emissions related to the direct energy consumption in households is 10.2 tons in the Netherlands, 11.6 tons in Germany, 17.4 tons in the Czech Republic and 7.3 tons in Hungary.

In West-European households, the increase of a 1-person household to a 2-person household causes an increase in the direct energy consumption of around 33%. In East-European households, the same household size increase leads to a 102% or 176% increase in the direct energy consumption. The further addition of a third or fourth household member has no considerable effect on the household direct energy consumption.

The number of insulation measures taken in a house plays a major role in the energy consumption for heating. Houses with relatively few insulation measures in Hungary and the Czech Republic consume more energy than households in the Netherlands and Germany that have the same number of insulation measures. The type of insulation measures taken in these households is not the same and it is possible that the different insulation-types are not equally effective.

In 2030, the household direct energy consumption will see an increase in transport energy due to more passenger cars per household. Households in Germany and the Czech Republic will remain at the same energy consumption levels. A decline in the primary electricity consumption compensates the increase in transport in these countries. Households in the Netherlands and Hungary will see an increase in the direct energy consumption in all three consumption categories (transport, heating and electricity).

The energy source is often quite different and of importance in determining the direct energy consumption and related CO$_2$ emissions. Firstly, the electricity sectors in Hungary and the Czech Republic are less efficient than in the Netherlands and Germany. This can greatly increase the primary electricity consumption compared to the final consumption. Secondly, compared to households in the Netherlands and Germany, rural households in the Czech Republic and Hungary often use wood for household heating and when they use wood, the energy consumption is almost twice the energy consumption for households using a different fuel.
SAMENVATTING

Het directe energieverbruik van huishoudens wordt doorgaans behandeld als een gegeven en bepaald door middel van een top-down methode. Tevens is het zo dat onderzoek naar het energieverbruik van huishoudens zich focust op West-Europese landen. In dit onderzoek wordt een bottom-up methode gebruikt om het directe energieverbruik evenals de CO₂ uitstoot te bepalen van huishoudens in de West-Europese landen Nederland en Duitsland en de Oost-Europese landen Tsjechië en Hongarije. Dit was mogelijk vanwege de beschikbaarheid van een dataset, welke voortkwam uit een enquête die was afgenomen in deze landen. Met deze dataset is het mogelijk om een meer gedetailleerd beeld te krijgen van de onderliggende variabelen (bv. huishoudgrootte, infrastructuur, regio, klimaat, gewoontes enz.) welke verantwoordelijk zijn voor de verschillen in het primair energieverbruik en de CO₂ emissies per energieconsumptiecategorie (elektriciteit, warmte en transport). Hierdoor is het mogelijk om de volgende onderzoeksvraag te beantwoorden: *Wat zijn de verschillen in het directe energieverbruik en CO₂ emissies van huishoudens in en tussen Europese landen en hoe zal dit veranderen in de toekomst?*

Het eindverbruik van huishoudens is omgezet naar het primair energieverbruik door gebruik te maken van energie-noodzakelijk-voor-energie verhoudingen voor brandstoffen en nationale elektriciteitssectoren. De CO₂ emissies zijn bepaald met behulp van gegevens over de nationale elektriciteitssectoren en de brandstofspecifieke CO₂ emissies van verbranding. Voor een voorspelling van veranderingen in het energieverbruik en CO₂ emissies is een model gebruikt.

Huishoudens in Nederland en Duitsland consumeren gemiddeld genomen 162 GJ en 174 GJ directe energie. Het gemiddelde Tsjechische huishouden consumeert 200 GJ direct energie. Deze hoge consumptie komt voornamelijk door de landelijke huishoudens met een hoog energieverbruik voor warmte en elektriciteit. Een Hongaars huishouden consumeert gemiddeld de minste hoeveelheid direct energie met 115 GJ. De gemiddelde jaarlijkse CO₂ emissies van huishoudens is 10.2 ton in Nederland, 11.6 ton in Duitsland, 17.4 ton in Tsjechië en 7.3 ton in Hongarije.

In West-Europa is het zo dat bij een vergroting van een 1-persoons huishouden naar een 2-persoons huishouden het directe energie verbruik toeneemt met 33%. In Oost-Europese huishouden zorgt een zelfde huishoudsvergroting voor een toename van wel 102% tot 176% in het directe energie verbruik. In geen van de landen heeft de toevoeging van een derde of vierde bewoner aan een huishouden een grote invloed op het directe energieverbruik.

Het aantal geïnstalleerde isolatiemaatregelen en de manier van isolatie in een huis speelt een belangrijke rol in het bepalen van de hoeveelheid verwarmingsenergie. In Tsjechië en Hongarije gebruiken huishoudens met relatief weinig isolatiemaatregelen meer verwarmingsenergie dan huishoudens in Nederland en Duitsland met een zelfde aantal isolatiemaatregelen. Er zijn verschillen tussen de landen in welk type isolatie is geïnstalleerd in huizen met een zelfde aantal isolatiemaatregelen. Dit zou een verklaring kunnen zijn voor de waargenomen verschillen in de effectiviteit.

In het jaar 2030 zullen huishoudens, door een toename van het aantal auto’s per huishouden, in alle landen een toename zien in het primair energieverbruik voor transport. Huishoudens in Duitsland en Tsjechië zullen relatief stabiel blijven in de hoeveelheid energie die geconsumeerd zal worden. Door een daling van de primaire elektriciteitsconsumptie kan de toename van transportenergie gecompenseerd worden. Huishoudens in Nederland en Hongarije zullen een toename zien in alle drie de energieconsumptiecategorieën (transport, warmte en elektriciteit).

De bron van energie is vaak verschillend, maar belangrijk in het bepalen van de hoeveelheid directe energie die wordt geconsumeerd en de daarbij horende CO₂ emissies. Het eerste structurele verschil is dat de elektriciteitssectoren in Tsjechië en Hongarije minder efficiënt zijn dan die in Nederland en Duitsland. Dit is een belangrijke factor in de verhoging van
primaire elektriciteitsconsumptie vergeleken met het eindverbruik. Tevens is het zo dat
plattelandshuishoudens in Tsjechië en Hongarije meer hout gebruiken voor de verwarming
van de woning dan plattelandshuishoudens in Nederland en Duitsland. Daarnaast is het
energieverbruik, als ze hout gebruiken, ook nog eens bijna twee keer zo hoog als wanneer ze
een andere brandstof gebruiken.
1 INTRODUCTION

The total household energy consumption plays a large role in determining the CO\textsubscript{2} emissions of a country. The indirect and direct consumption of households contribute almost equally to the total CO\textsubscript{2} emissions of households. Estimates are that the total energy consumed by households, both the direct and indirect, can amount to 70-80\% of a country's national energy use and greenhouse gas emissions (Moll et al., 2005). Furthermore, in countries with a large import, the household-related CO\textsubscript{2} emissions can be more than 100\% of the national emissions (Bin and Dowlatabadi, 2005).

Several key factors determine the energy consumption of households. These factors include things like the household income, the size of the household, household behaviour, geographic location and climate conditions (Vringer and Blok, 1995). Furthermore, the energy supply network that is present in a country can also have a large influence on household-related energy consumption and CO\textsubscript{2} emissions (Munksgaard, 2000).

Comparisons of the energy consumption between households in different countries so far have focused on comparing the more developed (north-) western European countries (Moll et al., 2005; Kerkhof et al., 2009; Kok et al. 2003). These countries all share a more or less similar industry, climate and economic development. Comparing countries that do not completely share the same development could yield new insights. Moreover, country comparisons thus far mostly focused on the indirect energy consumption and regard the direct energy consumption just as a given. Whilst, within Europe the range of the share of direct energy consumption, of the total energy consumption, varies from 34\% to 64\% (Reinders et al., 2003). An in depth study of the underlying mechanisms that lead to a better understanding of the direct energy consumption, allows for finding new strategies and approaches that can contribute to reducing the overall energy use of households and to help create more sustainable households energy consumption patterns.

The information about the direct energy consumption is most often derived through expenditure data. This means that the direct energy consumption is determined through a top-down approach. This approach limits the possibility for a more detailed study of the determining consumption factors.

In addition, the information about the direct energy consumption of households in different countries often results from different surveys. Having the same survey taken in several countries could yield data that is more reliable for a direct comparison. Because then, any under- or overestimation due to the nature of the survey would be similar for each country. Moreover, having a more detailed survey will also enable a more detailed analysis of the determining factors of the direct energy consumption through a bottom-up approach.
1.1 Research questions

The goal of this research will be to compare and explain direct energy consumption of households in different countries, related CO₂ emissions and to predict possible changes in the near future. This research will focus on the direct energy consumption of households in four European countries. Each country contains an urban and a rural region. Differences within and between the four European countries will be analysed and explained. The direct energy consumption will be determined through a bottom-up approach. This will enable a detailed determination and description of the direct energy consumption and consequent CO₂ emissions. In this research, the following research questions and sub-questions will be answered:

**What are the differences in the direct energy consumption of households within and between European countries and their consequent CO₂ emissions and how will these patterns change in the future?**

1. What is the influence of the presence of resources and existing energy infrastructure in a country?

2. What is the influence of geographic and climate conditions?

3. Are there demographic differences that can explain the direct energy consumption?

4. What is the influence of housing conditions?

5. What is the influence of habits?

6. How will future changes influence the energy consumption of households and the CO₂ emissions?

Chapter 2 will be used to explain the methods and to elaborate on some of the data that are being used. Sub-questions 1-5 will be answered in chapter 3 and the related sub-sections. The answer to sub-question 6 will be found in chapter 4.
2 METHODS

The direct household energy consumption is expressed in primary energy. In order to do this, data regarding the energy supply of each country, as well as the energy content of several fuels were necessary.

The figures, tables and numbers used to answer sub-question 1 till 5 are all based on data from the dataset.

2.1 The dataset

The dataset has been made available from the research project “Governance, Infrastructure, Lifestyle Dynamics and Energy Demand: European Post Carbon Communities” (GILDED). This is a project that was funded through the European Union Framework Programme Seven. The Goal of GILDED is to identify socio-economic, cultural and political changes that could serve to reduce carbon-intensive energy demands from the household sector, in urban and rural communities across the EU (GILDED, 2012).

The data in the dataset were gathered through an extensive questionnaire. This questionnaire was taken in several European countries and covers the direct energy use of households as well as, household compositions, housing conditions and behavioural factors. The countries used in this research from the dataset are the Netherlands (NL), Germany (DE), the Czech Republic (CZ) and Hungary (HU). See Appendix A for a more detailed description of the type of questions in the questionnaire.

Within these countries, the survey was performed in one specific city and the surrounding rural regions of that city. In each case, the rural region was directly adjacent to the city. In the Netherlands, this was the city Assen, in Germany the city Potsdam, in the Czech Republic the city České Budějovice and in Hungary the city Debrecen (Figure 2-1).

Figure 2-1: The four countries (dark green) and the regions within these countries where the survey was performed (red dot).

With the data from the dataset, it is possible to determine the direct energy consumption and CO$_2$ emissions through a bottom-up approach. The data are analysed to determine the consequences of household differences and choices on the direct energy consumption and CO$_2$ emissions. Within each country, differences between household types (income, size, etc.) and region (urban or rural) were used to analyse the consequences on the direct energy consumption.
The data regarding the amounts of energy consumption that the respondents provided through the survey are in all cases based on consumptions in the year 2009 and/or 2010. Therefore, the use of additional data needed to determine the primary energy that could be time specific was from these years, if possible (e.g. the electricity sector). Because of the available data from the survey, the primary energy consumption for transport only accounts for the transport energy consumed by the passenger car.

2.1.1 Number of households and outliers

Because the original dataset did not provide information about the energy consumption for each household, such as the electricity readings, a selection was necessary. Only households that provided their electricity and heating consumption were used in the analysis. This initial selection reduced the number of households from 1735 to 602. Furthermore, because of the limited sample size outliers could have a large influence of the outcome of the analysis. Therefore, households with a direct energy consumption that varied more than three standard deviations of the mean were excluded from the analysis. These measures reduced the number of households to 593 households in total. See Table 2.1-1 for an overview of the number of households per country and region. However, not all of these households also answered all the other questions of the questionnaire. Therefore, the sample size used to obtain specific data can be different for each graph/table (see Appendix D for a sample size breakdown of each graph that is produced using data from the dataset).

Table 2.1-1: The number of households present in the dataset per region in each country.

<table>
<thead>
<tr>
<th></th>
<th>Number of households</th>
<th>Urban</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Netherlands</td>
<td></td>
<td>102</td>
<td>110</td>
</tr>
<tr>
<td>Germany</td>
<td></td>
<td>78</td>
<td>86</td>
</tr>
<tr>
<td>Czech Republic</td>
<td></td>
<td>33</td>
<td>56</td>
</tr>
<tr>
<td>Hungary</td>
<td></td>
<td>64</td>
<td>52</td>
</tr>
</tbody>
</table>

2.2 Energy efficiency and CO₂ emissions

2.2.1 Electricity sector

The electricity supply system of each country is analysed to determine energy-required-for-energy ratios, CO₂ emissions and the differences between countries. To determine the efficiency of the electricity sector data from the IEA (2010, 2012a) were used. The efficiency of the electricity sector was determined for the years 2009 and 2010, using the method from Graus (2007). The efficiency of the electricity sector in each country was determined using the following formula:

\[
E = \frac{P + H \times s}{I}
\]

Equation 2.2-1

\(E\) = the efficiency of the electricity generation
\(P\) = the amount of electricity generated by power plants and CHP plants
\(H\) = the amounts of heat generated by CHP plants
\(s\) = a correction factor for the reduction in electricity generated in favour of heat
\(I\) = the fuel input for power plants and CHP plants

The correction factor is set at \(s = 0.175\). However, this correction factor can vary between 0.15 and 0.2 depending on the infrastructure. For simplicity, the value of 0.175 was used. The energy-required-for-energy (ERE) ratios are equal to the inverse of the efficiency. This means that the lower the ERE ratio, the higher the efficiency of the electricity sector. To determine the primary energy from electricity consumption of the households, the average
ERE ratio of 2009 and 2010 was used. The efficiency of nuclear power plants was between 32 and 33%. For renewables, the efficiency of electricity generation was ±100%.

Data from the IEA (2011, 2012b) were used to determine the CO₂ emissions related to electricity consumption. The average CO₂ emissions of 2009 and 2010 per unit of primary energy were used to determine the CO₂ emissions related to electricity use on the household level (Table 2.2-1).

Table 2.2-1: ERE ratios of the electricity production sectors in each country and the CO₂ emissions per unit of primary energy of electricity consumed. The ERE ratios and CO₂ emissions are average values from the year 2009 and 2010. Values based on data from the IEA (2010, 2011, 2012a, 2012b).

<table>
<thead>
<tr>
<th>Country</th>
<th>ERE ratios of the electricity sector [MJ/MJ]</th>
<th>CO₂ emissions per unit of primary energy [kg/GJ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Netherlands</td>
<td>2.15</td>
<td>69.74</td>
</tr>
<tr>
<td>Germany</td>
<td>2.52</td>
<td>58.39</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>2.97</td>
<td>58.14</td>
</tr>
<tr>
<td>Hungary</td>
<td>2.81</td>
<td>37.60</td>
</tr>
</tbody>
</table>

In the Netherlands, the predominant way of generating electricity is by the use of gas turbines, this method accounts for almost 55% of the fuel consumption. This large use of gas makes generating electricity in the Netherlands a relative efficient process. However, due to the almost exclusive use of fossil fuels in the Dutch electricity sector, the related CO₂ emissions per primary unit of energy consumption are relatively high.

In the German electricity sector, the ‘coal and peat’ fuel category is the most used fuel category. In addition, nuclear fuel still had a large share in the German fuel consumption in 2010. Together, these two categories account for three-quarters of the fuel consumption.

In the Czech Republic, coal and nuclear fuel are predominantly used to generate electricity. Together these two fuel categories account for 95% of the fuel consumption in the Czech Republic. Because of the relative large share of nuclear fuel, the CO₂ emissions per primary unit of energy consumption are comparable to Germany. This is despite the relative larger share of coal-fired power plants to generate electricity.

In Hungary, the most used fuel category is nuclear. Although the use of nuclear fuel in Hungary is not a very efficient source of electricity, it does contribute largely to a lower CO₂ emission per unit of primary energy within Hungary (Figure 2-2,Table 2.2-1).

Figure 2-2: The fuel-mix of the electricity production sector for each country in 2010. Based on data from the IEA (2012a).
2.2.2 District heating

Some households in the dataset used district heating for space heating. In the countries in which these households were located, the ERE ratios and CO₂ emissions have been calculated. This was done using the same approach as for the electricity sector. However, to calculate the efficiency of the heat sector there was no need to use a correction factor (Table 2.2-2).

Table 2.2-2: ERE ratios of the heat production sectors in each country and the CO₂ emissions per unit of primary energy of heat consumed. The ERE ratios and CO₂ emissions are average values from the year 2009 and 2010. Values based on data from the IEA (2010, 2011, 2012a, 2012b).

<table>
<thead>
<tr>
<th></th>
<th>ERE ratios of the heating sector [MJ/MJ]</th>
<th>CO₂ emissions per unit of primary energy [kg/GJ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>1.40</td>
<td>65.35</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>1.62</td>
<td>92.10</td>
</tr>
<tr>
<td>Hungary</td>
<td>1.27</td>
<td>66.25</td>
</tr>
</tbody>
</table>

In Germany, the heat is produced using a mixture of coal (49%) and natural gas (41%), with the addition of some oil (8%) and other fuels (1%). In the Czech Republic, heat is predominantly produced using coal (84%). This could explain the higher CO₂ emissions per primary unit of energy. In Hungary, heat is produced using a mixture of natural gas (71%), coal (26%) and some oil (3%).

2.2.3 Energy and carbon content of fuels

The energy content of fuels and related CO₂ emissions from fuel combustion were obtained from the IPPC (2006). They are used to determine the primary energy use of forms of heating, the primary energy use of transport and the related CO₂ emissions. Fuel specific ERE ratios were used to incorporate the energy needed to obtain the fuel (extraction, processing, refining etc.), into the primary energy consumption. With the transport fuels (petrol, LPG and diesel), the Well-to-tank energy ratios were applied as ERE ratios. These ERE ratios were taken from literature (Edwards et al. 2011; Graus et al. 2007). In addition, the CO₂ emissions from fuel production were used for the total CO₂ emissions of the direct energy consumption (from Edwards et al. 2011) (Table 2.2-3).

Table 2.2-3: The energy content of various fuels, the CO₂ emissions from burning the fuel and the ERE values for each type of fuel. Data from Edwards et al. (2011), Graus et al. (2007) and the IPPC (2006).

<table>
<thead>
<tr>
<th></th>
<th>MJ/kg</th>
<th>ERE ratios</th>
<th>CO₂ emissions from fuel production [kg/GJ]</th>
<th>CO₂ emissions from burning [kg/GJ]</th>
<th>Total CO₂ emissions [kg/GJ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol</td>
<td>44.3</td>
<td>1.17</td>
<td>14.2</td>
<td>69.3</td>
<td>83.5</td>
</tr>
<tr>
<td>LPG</td>
<td>47.3</td>
<td>1.12</td>
<td>8</td>
<td>63.1</td>
<td>71.1</td>
</tr>
<tr>
<td>Diesel</td>
<td>43</td>
<td>1.19</td>
<td>15.9</td>
<td>74.1</td>
<td>90</td>
</tr>
<tr>
<td>Natural gas</td>
<td>48</td>
<td>1.05</td>
<td>2.9</td>
<td>56.1</td>
<td>59</td>
</tr>
<tr>
<td>Anthracite</td>
<td>26.7</td>
<td>1.17</td>
<td>30</td>
<td>98.3</td>
<td>128.3</td>
</tr>
<tr>
<td>Wood</td>
<td>15.6</td>
<td>1.097</td>
<td>7.7</td>
<td>100</td>
<td>107.7</td>
</tr>
<tr>
<td>Heating oil</td>
<td>42.6</td>
<td>1.121</td>
<td>15.9</td>
<td>73.6</td>
<td>89.5</td>
</tr>
<tr>
<td>Solid Biomass</td>
<td>11.6</td>
<td>1.097</td>
<td>5.7</td>
<td>100</td>
<td>105.7</td>
</tr>
<tr>
<td>Municipal waste</td>
<td>11.6</td>
<td>1.097</td>
<td>7.7</td>
<td>100</td>
<td>107.7</td>
</tr>
</tbody>
</table>

2.2.4 Transport energy

The transport energy consists of the energy consumed by driving the car. The use of public transport, airplanes and any other form of transport are excluded from the analysis. The data provided from the dataset for the other transport modes besides the car are inconsistent and undetailed.
2.3 Climate data

Temperature data for the years 2009 and 2010 were obtained from the NOAA (2012). For each city, the nearest weather station with measurements from the year 2009 and 2010 was chosen. Because temperature measurement locations are not widespread, it was not possible to make a distinction between urban and rural temperature measurements within a country. Therefore, it is only possible to use the temperature data for comparisons between countries.

Heat-degree-days (HDD) were used as a proxy of household heat demand. The HDD are based on daily average temperatures and calculated for the year 2009 and 2010 (Table 2.3-1). If the daily average temperatures were below $15\, ^\circ\text{C}$, the temperature is subtracted from 18, this would yield the HDD of that specific day. If the daily average temperature would be above $15\, ^\circ\text{C}$ then that specific day would have zero HDD. The daily HDD of a year are summed. This sum yields the HDD of a specific year.

Table 2.3-1: Yearly average HDD for 2009 and 2010 and the temperature correction factor.

<table>
<thead>
<tr>
<th>Assen (NL)</th>
<th>HDD 2009-2010 average</th>
<th>Temperature correction factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potsdam (DE)</td>
<td>3474</td>
<td>0.92</td>
</tr>
<tr>
<td>České Budějovice (CZ)</td>
<td>3352</td>
<td>0.96</td>
</tr>
<tr>
<td>Debrecen (HU)</td>
<td>2751</td>
<td>1.17</td>
</tr>
</tbody>
</table>

Because of the nature of the HDD, it is possible to use it as a correction factor for household heating demand. The temperature correction factor is obtained by dividing the HDD of a specific country with a ‘normalized’ HDD value. In this case, the normalized HDD value was the average of the HDD of the four countries. Through multiplying the energy consumption for heating with the temperature correction factor it creates an energy consumption for heating that is independent of the differences in temperature. In this way, it is possible to make a fairer comparison of the energy consumption for heating between countries, in terms of efficiency and energy wastage.
3 RESULTS

This chapter contains the results for sub-question 1 until 5. The results for each sub-question are found in the paragraphs with the same number as the sub-question.

3.1 Research question 1: Resource use and infrastructure

In this paragraph, the existing differences between countries in car ownership, travel distance and fuel use for heating are identified. Information about the source of electricity can be found in paragraph 2.2.

3.1.1 Transportation

Car ownership and use is highest in the Netherlands and Germany. In Hungary, the car ownership is the lowest of the four countries. However, if a Hungarian household owns a car they drive more than a household in the Czech Republic (15,458 vs. 13,420 km/year). The percentages of fuel types used for car transport is very similar between the countries. Hungary is an exception, here more petrol and less diesel is used to fuel the car. The average fuel efficiency of the cars is almost comparable. Contrary to expectations, the fuel efficiency of cars in the Netherlands is the lowest among the four countries. However, it is important to keep in mind that the sources of the data are surveys and thus, there could be a difference in the perceived fuel efficiency and the real efficiency.

Table 3.1-1: Average car ownership, driving distance, fuel use/economy and CO₂ emissions in the four countries.

<table>
<thead>
<tr>
<th>% households owning 1 or more cars</th>
<th>Number of cars per household</th>
<th>Average household driving distance per year [km]</th>
<th>Distance driven by car-owning households [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NL</td>
<td>94</td>
<td>1.48</td>
<td>16,174</td>
</tr>
<tr>
<td>DE</td>
<td>93</td>
<td>1.51</td>
<td>19,478</td>
</tr>
<tr>
<td>CZ</td>
<td>80</td>
<td>1.19</td>
<td>10,706</td>
</tr>
<tr>
<td>HU</td>
<td>60</td>
<td>0.72</td>
<td>8,529</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fuel used by percentage of total cars</th>
<th>Fuel efficiency [L/100 km]</th>
<th>CO₂ emissions [g/km]</th>
<th>CO₂ emissions inc. WTT emissions [g/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol</td>
<td>73 %</td>
<td>7.3</td>
<td>176</td>
</tr>
<tr>
<td>Diesel</td>
<td>25 %</td>
<td>6.9</td>
<td>171</td>
</tr>
<tr>
<td>LPG</td>
<td>2 %</td>
<td>6.5</td>
<td>161</td>
</tr>
<tr>
<td>HU</td>
<td>84 %</td>
<td>6.8</td>
<td>163</td>
</tr>
</tbody>
</table>
3.1.2 Household heating

The household heating within each country is heavily influenced by the availability of resources and existing infrastructure. In the Netherlands, gas is the only resource used for household heating. This holds for the urban and rural regions. This can be explained through the presence of the large Groningen gas field that was discovered at the end of the 1950s. This led to the nationwide implementation of gas as a heating fuel for households.

In Germany, the fuel use for household heating is more diverse. There is a large share of gas, both in urban (67%) and rural (57%) regions. However, in the urban region we also see the use of district heating (19%) and some heating oil (12%). The electricity and coal use for heating in the German urban region can be attributed to one household each. In the German rural region, there is a larger share of heating oil (35%) and there is some use of wood for household heating (7%). Again, the use of electricity can be attributed to one household in the dataset.

The Czech Republic has the lowest use of gas for household heating in urban (33%) and rural (7%) regions. In the urban regions, there is also a large share for district heating (58%) and some use of wood (9%). In the rural region, wood (63%) is the most used fuel for household heating. The second most used fuel is coal (29%). The share of district heating can be attributed to one household in the dataset.

In Hungary, most household heating systems use gas; this is true for urban (97%) and rural (75%) regions. However, in urban regions there is also some use of district heating (3%). In rural regions, the remaining households use wood (25%) to supply their heating demand (Figure 3-1).
### 3.1.3 Primary and final consumption

The type of fuel used and the efficiency of energy generation determine the difference between the final energy consumption and primary energy consumption. Because it is very difficult to determine the efficiency of the heating appliances in each household, the actual fuel consumption counts as the final energy consumption of heating. This means that the differences between the final and primary energy consumption for heating are less than in the case of electricity. Any difference between the final and primary consumption is due to the fuel specific ERE ratios that are used. Only in the case of district heating can the difference between the primary and final consumption be substantial (see ERE ratios in Table 2.2-2 and Table 2.2-3). The same principle applies to the difference in final and primary energy consumption for transport.

The difference between the final- and primary direct energy consumption can largely be attributed to differences in the electricity generating sectors and the relative amount of electric energy consumed compared to energy for heating and transport (Figure 3-2).

The amount of direct energy consumed in the Netherlands and Germany is comparable. In the Netherlands, the final energy consumption is equal to Germany. However, the primary energy consumption of the Netherlands is slightly lower than Germany. This difference in the final and primary consumption between Germany and the Netherlands is largely due to the more efficient electricity generation in the Netherlands.

The average household in the Czech Republic consumes more direct energy than in the Netherlands or Germany. This is despite the fact that the final electricity consumption is comparable and the energy used for transport is about half of that being used in the Netherlands and Germany. The energy consumption for household heating is about 1.5 times larger than in the Netherlands and Germany. This is largely due to the energy consumption in rural regions of the Czech Republic.

The average household in Hungary consumes the least direct energy when compared to the Netherlands, Germany and the Czech Republic. The final electricity consumption is about half of the other countries. The heat consumption is slightly less than in the Netherlands and Germany. The energy consumption for transport is half/more-than-half of that in the Netherlands and Germany and slightly below the consumption in the Czech Republic.

<table>
<thead>
<tr>
<th>Country</th>
<th>Final Transport</th>
<th>Final Heat</th>
<th>Final Electricity</th>
<th>Primary Transport</th>
<th>Primary Heat</th>
<th>Primary Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Netherlands</td>
<td>47</td>
<td>54</td>
<td>28</td>
<td>40</td>
<td>46</td>
<td>24</td>
</tr>
<tr>
<td>Germany</td>
<td>86</td>
<td>81</td>
<td>74</td>
<td>74</td>
<td>116</td>
<td>24</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>38</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>66</td>
<td>20</td>
</tr>
<tr>
<td>Hungary</td>
<td>29</td>
<td>13</td>
<td>15</td>
<td>15</td>
<td>71</td>
<td>66</td>
</tr>
</tbody>
</table>

Figure 3-2: The average annual household direct energy consumption as primary and final energy, for each country. The total direct energy consumption is composed of the direct energy required for transport, household heating and electricity consumption.
3.1.4 \textit{CO}_2\textit{ emissions}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3-3.png}
\caption{The average annual \textit{CO}_2\textit{ emissions from the direct energy consumption per household. The share of \textit{CO}_2\textit{ emissions for heating due to the use of wood are incorporated in the emissions from heating, as well as given as a negative value.}}}
\end{figure}

To show the impact of the wood burning on the total \textit{CO}_2\textit{ emissions, the \textit{CO}_2\textit{ emissions from wood burning are not only incorporated in the heat emissions, they are also given as a negative value in Figure 3-3. The average household \textit{CO}_2\textit{ emissions in the Netherlands and Germany are comparable. In the Netherlands, the direct energy consumption of households is responsible for 10.2 tons of \textit{CO}_2\textit{ per year. In Germany, households are responsible for 11.6 tons of \textit{CO}_2\textit{ per year. In the Czech Republic, the direct energy use of households is responsible for 17.3 ton of \textit{CO}_2\textit{ per year. This relative large amount is due to the large energy consumption for household heating and the high \textit{CO}_2\textit{ intensity of this heating energy (Table 3.1-2). This high \textit{CO}_2\textit{ intensity for household heating in the Czech Republic is due to the large share of wood and coal use in the rural households and the \textit{CO}_2\textit{ intense district heating system. A Hungarian household is responsible for 7.3 ton of \textit{CO}_2\textit{ emissions.}}}

Table 3.1-2: The \textit{CO}_2\textit{ emissions intensities of the direct energy consumption per energy consumption category, per country.}

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|}
\hline
& \textit{CO}_2\textit{ intensity electricity} & \textit{CO}_2\textit{ intensity heat} & \textit{CO}_2\textit{ intensity transport} \\
& [kg/GJ] & [kg/GJ] & [kg/GJ] \\
\hline
The Netherlands & 69.7 & 56.2 & 72.8 \\
Germany & 58.4 & 66.7 & 73.5 \\
Czech Republic & 58.1 & 99.7 & 73.1 \\
Hungary & 37.6 & 68.7 & 72.1 \\
\hline
\end{tabular}
\end{table}

3.2 \textbf{Research question 2: Geographic and climate conditions}

This paragraph is used to explore the differences in the energy consumption between urban and rural regions. In addition, this paragraph will be used to look at the influence of the climate combined with the size of the house on the energy consumption for heating.
3.2.1 Regional difference: Urban & Rural

Figure 3-4: The average annual household direct energy consumption in each country for rural and urban regions. The total direct energy consumption is composed of the direct energy required for transport, household heating and electricity consumption.

The difference between urban and rural households in their direct energy consumption varied between countries. In the Netherlands, there is almost no difference in the average direct energy consumption of urban and rural households. The energy use for transport is slightly lower in rural households than in urban households. The energy consumption for household heating in rural regions is somewhat higher (3%) than that of urban households. In Germany, there is a more visible difference between urban and rural households. Compared to the urban households the rural households consume less electric energy. However, the energy use for transport is 32% higher in rural households.

In the Czech Republic, there is a large difference in the direct energy consumption of urban and rural households. The rural households consume, on average, more than twice the amount of electric energy, twice the energy for heating and 37% more energy for transport. This amounts to a total energy consumption in rural households that is 99% higher than that of urban households.

In Hungary, the main difference in energy consumption between urban and rural households is in the energy used for heating. Rural households consume 35% more energy for heating than urban households. In addition, the energy used for transport is 30% higher in rural households.

Table 3.2-1: The average household size in urban and rural regions for each country.

<table>
<thead>
<tr>
<th>Country</th>
<th>Urban</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Netherlands</td>
<td>2.65</td>
<td>2.57</td>
</tr>
<tr>
<td>Germany</td>
<td>2.63</td>
<td>2.47</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>2.75</td>
<td>3.18</td>
</tr>
<tr>
<td>Hungary</td>
<td>2.66</td>
<td>3.10</td>
</tr>
</tbody>
</table>

Because households in urban and rural regions are not of the same size in terms of the number of household members (Table 2.3-1), energy consumption per person could be more insightful (Figure 3-5). In the Netherlands and Germany, rural households have fewer household members than urban households. In the Czech Republic and Hungary, the opposite is true.
The per person direct energy consumption of households in urban regions is nearly equal in Germany and the Netherlands. The same holds for the Czech Republic and Hungary. However, for Hungary and the Czech Republic the per person energy consumption is about 35% lower than in the Netherlands and Germany (Figure 3-5).

In rural regions the households direct energy consumption per person is higher than in urban regions. This holds for all four countries. However, there is a difference between rural regions in the different countries. Households in rural regions in the Netherlands have a lower per person energy consumption than in Germany. In the Czech Republic there is a large difference in the per person direct energy consumption in urban and rural regions. In rural regions the per person direct energy consumption is 83% higher. However, the 86 GJ per person is still comparable with the 85 GJ per person in Germany. Hungary has the lowest per person energy consumption in rural regions (Figure 3-5).

![Figure 3-5: The direct energy consumption of households per person, per region, for each country.](image)

3.2.2 Household heating and the effect of outdoor temperature

Household heating is quite dependent on the outside temperature, or the temperature difference between the inside and outside of a house. The average annual temperatures are not equal in the four countries. By correcting the energy use for household heating with a temperature correction factor, it is possible to compensate for the difference in the outdoor temperature (Chapter: 2.3, Table 2.3-1). With a higher than normal HDD the correction factor would be below one, if the HDD would be lower than normal the correction factor would be higher than one.

The temperature correction factors for the Netherlands (0.98) and the Czech Republic (0.96) deviate relatively little from one. In Germany it was on average slightly colder in 2009 and 2010, therefore the temperature correction factor was slightly lower (0.92). In Hungary, there were less cold days than in the other countries. This led to a correction factor of 1.17 (Table 2.3-1).

Figure 3-6 shows the household energy consumption for household heating, before and after temperature correction. The temperature corrected data show a different picture than the normal data. The urban energy consumption for heating now shows energy amounts that are closer together than before. With the exception of the Netherlands, here the urban energy consumption for heating is 8 GJ higher than the second highest. The other three urban regions are within a 5 GJ margin of each other.

The corrected heating energy consumed in rural regions show a wider range than before. The Hungarian rural energy consumption is now much higher than in the Netherlands and Germany. Even though the relative consumption in the Czech Republic lowered, it is still more than 50% higher than in the other countries (Figure 3-6).
Figure 3-6: Average household primary energy consumption for heating per region, per country. Top: before temperature correction. Bottom: after temperature correction.

3.2.2.1 House size

Houses within the four countries are not of the same size. There is some variation within and between the countries/regions. For example, the average urban house in the Netherlands is 202 m², whilst the average house in urban Hungary and the Czech Republic is much smaller, 79 m² and 84 m² respectively. The energy consumption for heating per square meter can be used to compensate for these differences (Figure 3-7).

Figure 3-7: Average household primary energy use for household heating per m² after temperature correction for the different countries per region.

From Figure 3-7, it is evident that households in the Netherlands and Germany use less energy for heating per square meter than in the Czech Republic and Hungary. In the Czech Republic and Hungary, the average house size in rural regions is larger than in urban regions (Table 3.2-2). Thus, by compensating the energy usage for household heating with the size of the house, the regional differences in energy usage become more similar (Figure 3-7).
Table 3.2-2: Average size of a house in square meters, in the four countries per region.

<table>
<thead>
<tr>
<th></th>
<th>Average house size [m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Urban</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>202</td>
</tr>
<tr>
<td>Germany</td>
<td>130</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>84</td>
</tr>
<tr>
<td>Hungary</td>
<td>79</td>
</tr>
</tbody>
</table>

3.2.3 $\text{CO}_2$ emissions

The $\text{CO}_2$ emissions of the different regions in the different countries (Figure 3-8) show a similar distribution as the actual energy consumption (Figure 3-4).

In Germany and the Netherlands, the urban and rural regions are similar. Only in the German rural region, the $\text{CO}_2$ emissions from household heating are slightly higher, mainly due to a difference in fuel use. The German rural regions have a larger share of heating oil and some wood use. These two fuels are relatively carbon intensive. In German rural regions, there is also a higher use of transport. Therefore, the $\text{CO}_2$ emissions for this category are also higher.

The difference in $\text{CO}_2$ emissions between urban and rural regions in the Czech Republic (144%) and Hungary (63%) becomes larger than the difference in direct energy consumption between regions (CZ: 99%; HU: 29%). In the Czech Republic, this effect is due to the large use of coal and wood for household heating in the rural region. In Hungary, this is due to the use of wood for household heating in the rural region.

Figure 3-9 shows the per person $\text{CO}_2$ emissions for the urban and rural regions. The relative differences between regions are similar as in Figure 3-8. Only in the Netherlands and Germany the difference between regions in $\text{CO}_2$ emissions is slightly larger on a per person basis. In the Czech Republic and Hungary, the difference between regions is now smaller after adjusting the $\text{CO}_2$ emissions for the number of household members in a household (Figure 3-9).
3.3 Research question 3: Demographic influences

3.3.1 Income
The average household income differs substantially between countries (Table 3.3-1). However, within countries household income has none and sometimes a weak correlation with the consumed amount of direct energy, electric energy, heating energy, transport energy and CO$_2$ emissions.

The highest coefficient of determination ($R^2$) is 0.35 for the Dutch CO$_2$ emissions from the direct energy consumption. Of course, this is similar to the relation between total direct energy consumption and household income ($R^2 = 0.334$). In addition, the Dutch energy consumption for transport shows a correlation of 0.318. This all means that these correlations are weak. Therefore, household income cannot fully explain the Dutch household direct energy consumption.

In the other countries, the correlation between energy consumption/CO$_2$ emissions and household income range from 0.13 to 0.001. This means that it is highly unlikely that household income has any effect on the amount of direct energy consumption of households in these countries (See Appendix C for more $R^2$ values).

Table 3.3-1: The average household incomes from the dataset of the years 2009/2010 in Euros.

<table>
<thead>
<tr>
<th></th>
<th>Average annual household income [Euro]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>36,483</td>
</tr>
<tr>
<td>Germany</td>
<td>32,766</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>13,379</td>
</tr>
<tr>
<td>Hungary</td>
<td>10,200</td>
</tr>
</tbody>
</table>

3.3.2 Household size
The number of people in a household influences the energy consumption of a household. In general, the energy consumption increases with household size. However, the increase in energy consumption with household size is not a linear relation. In addition, the relation between an increase in household size and the increase in energy consumption is different between countries. In Germany and the Netherlands, a 2-person household consumes only 30% more energy than a 1-person household, whilst in the Czech Republic and Hungary a 2-person household consumes more than twice the energy of a 1-person household (Figure 3-10; Table 3.3-2).
There is almost no difference in the energy consumption when comparing a 2-, 3- or 4-
person household within a country. Only in the Netherlands, a 3-person household
consumes 13% more energy than a 2-person household. Larger households (5-person or
more) do consume more energy than a 4-person household, with the exception of a 5-person
or larger household in Hungary. However, this ‘sharp’ increase in energy consumption is
possibly a side effect due to the aggregation of multiple household sizes into one category. In
the Czech Republic the sharp increase could also be due to the low sample size for the 5-
person or larger households (8 households).

### Table 3.3-2: The change in the direct energy consumption for the addition of an additional household member as a multiplication factor for the direct energy consumption.

<table>
<thead>
<tr>
<th>Shift in household size</th>
<th>NL</th>
<th>DE</th>
<th>CZ</th>
<th>HU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>1.32</td>
<td>1.33</td>
<td>2.76</td>
<td>2.02</td>
</tr>
<tr>
<td>2-3</td>
<td>1.13</td>
<td>1.02</td>
<td>1.06</td>
<td>0.98</td>
</tr>
<tr>
<td>3-4</td>
<td>1.00</td>
<td>1.03</td>
<td>0.95</td>
<td>1.07</td>
</tr>
<tr>
<td>4-5+</td>
<td>1.11</td>
<td>1.25</td>
<td>1.67</td>
<td>0.96</td>
</tr>
<tr>
<td>average</td>
<td>1.14</td>
<td>1.16</td>
<td>1.61</td>
<td>1.26</td>
</tr>
</tbody>
</table>

#### 3.3.3 Household composition

Besides the number of people in a household, the composition of the household is also of
importance to determining the direct energy consumption. There are differences for energy
consumption between households with one or two household members and the addition of
children. In addition, the energy consumption of different household compositions within
countries can differ between countries. Data regarding the household composition was only
available for the Netherlands, Germany and Hungary.
### 3.3.3.1 The Netherlands

![Bar chart showing energy consumption in the Netherlands.](image1)

Figure 3-11: Direct energy consumption of different household types in the Netherlands.

A household composed of two adults consumes 38% more energy than a single person household. The main difference is in the transport and electrical energy. The addition of children to a single-adult household increases the energy consumption by 46%. The largest increase is in the category transport (167%). The addition of children to a two-adult household increases the energy consumption by only 17%. The addition of children increases the energy consumption in all three consumption categories.

### 3.3.3.2 Germany

![Bar chart showing energy consumption in Germany.](image2)

Figure 3-12: Direct energy consumption of different household types in Germany.

The difference between a single- and two-adult households energy consumption is 37%. The differences are an increase in transport and electricity energy and a slight decrease in heating energy consumption. The addition of children to a single adult household increases the energy consumption by 43%. Adding children to a two adult household only increases the energy consumption by 7%.

In both single- and two-adult households the addition of children increases the consumption of transport energy by a large factor. In a single adult household with children this increase is more than 250%. In both single- and two-adult households with children the total direct energy consumption is equal.
3.3.3.3 Hungary

The difference in energy consumption between a single- and two-adult household is 129%. However, in both single- and two-adult households the addition of children only causes a small increase in the energy consumption, 12% and 7% respectively.

3.4 Research question 4: Housing conditions

3.4.1 Insulation

The ‘insulation degree’ is the scoring of the number of insulation measures taken in a house. These measures entail insulation of the loft, filling of cavity walls with insulation material, external or internal insulation of solid walls, any insulation of the underfloor, double glazing windows/two windows with single glasses and the insulation of windows against draught. Therefore, the higher the insulation degree the more insulation measures are installed in a house.

In Figure 3-14, it is visible that going from an insulation degree of 1 to 6 yields a downward trend in the amount of energy consumed for heating. However, this trend is not a smooth trend. This is likely due to the lower sample size for the high insulation degrees (5 and 6). In addition, the energy consumption for heating of households with the same degree of insulation is not always equal between counties. Poorly insulated houses in the Czech Republic and Hungary consume noticeably more energy than poorly insulated houses in the Netherlands and Germany. In addition, the type of insulation in the poorly insulated houses is quite different between the countries.
Appendix H). However, the difference in energy consumption for heating between countries becomes smaller with an increase in the insulation.

Table 3.4-1: The average degree of housing insulation in urban and rural regions per country.

<table>
<thead>
<tr>
<th></th>
<th>Average insulation degree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Urban</td>
</tr>
<tr>
<td><strong>The Netherlands</strong></td>
<td>3.22</td>
</tr>
<tr>
<td><strong>Germany</strong></td>
<td>2.65</td>
</tr>
<tr>
<td><strong>Czech Republic</strong></td>
<td>2.84</td>
</tr>
<tr>
<td><strong>Hungary</strong></td>
<td>2.26</td>
</tr>
</tbody>
</table>

The average degree of insulation of houses is highest in the Netherlands and lowest in Hungary. In the Netherlands and Germany, the insulation degree is higher in rural regions than urban. In contrast, in the Czech Republic and Hungary the insulation degree is higher in urban regions. The largest difference in the insulation degree between urban and rural regions is in Hungary. The average Hungarian urban house has almost one additional measure of insulation compared to a rural house (Table 3.4-1).

In the Netherlands, the age of the house has a weak correlation with the energy consumption for heating. The more recent built houses show a lower household energy consumption for heating than older houses. A similar trend is not observable in any of the other countries.

3.4.2 The type of house

![Graph showing energy consumption per house type](image)

Figure 3-15: The average annual direct energy consumption per house type.

The direct energy consumption differs between different house-types. The general trend is that the energy consumption increases the more detached a house is. The main consumption category that is responsible for this trend is the energy consumption for heating. However, the electricity and transport energy category also show an increase with a more detached house.

This trend does not seem to hold for Hungary. In Hungary, the household energy consumption appears independent of the house-type. In addition, the Hungarian dataset did not contain the same house-type categories as the other countries.
3.5 Research question 5: Habits

3.5.1 Temperature settings

The average in-house temperature settings are not equal between countries (Table 3.5-1). It is difficult to determine the effect of differences in the temperature settings between countries on the average energy consumption for heating. The difficulty most likely lies with the many factors that can determine the need for heating (e.g. outdoor temperatures, insulation degree, heating fuel use etc.) and their differences between the countries. Because of this, it is more sensible to look at the effect of temperature setting within countries. However, within each country there is no effect of the temperature setting on the direct energy consumption for heating (Highest $R^2 >0.01$).

Table 3.5-1: Average temperature setting in households.

<table>
<thead>
<tr>
<th>Average temperature setting [°C]</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>The Netherlands</td>
<td>19.8</td>
</tr>
<tr>
<td>Germany</td>
<td>21.1</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>21.7</td>
</tr>
<tr>
<td>Hungary</td>
<td>21.4</td>
</tr>
</tbody>
</table>

3.5.2 Self-reported energy saving behaviour

Respondents of the survey indicated whether and how often they performed energy saving behaviour. For each energy saving behaviour they had five possible options to indicate how often they performed this behaviour; 1= always 2=often 3=sometimes 4=seldom 5=never. By identifying and grouping the types of behaviour that could have an influence on the direct energy consumption it is possible to see if this behaviour actually influenced the energy consumption. There were four question regarding behaviour which has the potential to influence the direct energy consumption (lowering heating temperature in house, not leaving appliances on standby, replacing short car trips with the bike or foot and taking shorter showers).

The sum of the answers given in the survey are used as a score of the energy-saving effort of a household. This score could range from 4 till 20, with a score of 4 being a household that always performed the energy saving behaviours and a score of 20 being a household that would never perform any of the energy saving behaviours.

In none of the countries did the reported energy saving behaviour of a household influence the direct energy consumption (all $R^2 >0.02$) (See Appendix E). In addition, none of the single energy saving behaviours influenced the relevant energy consumption category (e.g. taking short trips by bike instead of the car on the transport energy).
4 FUTURE CHANGE

Future changes in the household direct energy consumption are dependent on several factors. In practice, the direct energy consumption is mostly determined through demand from the households (bottom-up). This demand is regulated by many factors within a household (e.g., energy efficiency of appliances, household size, size of house, etc.). Because of the impracticalities of predicting the household direct energy consumption through this approach, the choice was made to predict the direct energy consumption per household using a top-down approach.

4.1 Model design

The model is used to show change in the direct energy consumption and CO$_2$ emissions of households using the top-down approach and will try to forecast changes on the household level up to the year 2030. In order to predict changes in the average household direct energy consumption, four national components were used and translated to the household level. These four national components are trends in the electricity sector, the fuel used in the residential sector, the number of passenger cars/fuel type and changes in the population/household size (Figure 4-1).

Figure 4-1: A simplified graphical representation of the model design and the sources used for each of the future predictions. The diamond shape is used to indicate the source for the future change for each of model elements.

In the national energy-related categories of the model, ERE-specific fuel values and WTT CO$_2$ emissions are included. However, the ERE values and WTT emissions are assumed stable over time, with the exception of the ERE and WTT CO$_2$ values of the electricity produced.
The future changes in the electricity sector are based on the latest available IEA country-specific energy policies reports (Germany: IEA, 2007; The Netherlands: IEA, 2008a; Czech Republic: IEA, 2010a; Hungary: IEA, 2011a). This includes changes in the national share of electricity going to households. The IEA country-specific energy policy reports were chosen as the source for future changes because these are the only available reports describing the future change in the electricity sector that are from the same source (IEA) and they are available for all four countries.

Fuel use in the residential sector is assumed to be solely used for heating purposes. A trend analysis was performed for each type of fuel used in the residential sector using historical data from the IEA (IEA, 2004; IEA, 2006; IEA, 2008; IEA, 2010; IEA, 2012a). These trend lines were then extrapolated until 2030. In order to prevent the possible magnifying effect of percentage-based growth an incremental growth/decline was assumed for each type of fuel. The CO$_2$ emissions from biofuels used for household heating were included in the total emissions because it is unclear if the biofuels are derived from sustainable sources.

Changes in the passenger car sector are based on a trend analysis of the number of passenger cars present in a country (Eurostat, 2013). Eurostat provides the national numbers of six fuel-type passenger cars; these are petrol, diesel, LPG, natural gas, electric and other products. The car type in the ‘other products’ category is assumed bio-diesel fuelled cars. To predict future changes, incremental growth/decline is used. The car mileages and changes in mileages are based on data from the IEA/SMP Transport Model (2004). Because of technical improvements, the fuel consumption per km will decrease over time with an average decrease of -20% per 50 years. Because of limited possibilities in improving the mileage of electrical cars, the energy consumption of electrical cars per km is set to remain stable over time.

National average driving distances of passenger cars from Eurostat (2013) are used and assumed to remain stable over time. Detailed data about the average driving distance of passenger cars per fuel-type were only available for the Netherlands. The average driving distance between diesel and other fuel-type cars are not equal; for example, in the Netherlands the average driving distance of a diesel car is about twice as large as other fuel-type cars. The differences in the driving distance of diesel and other fuel-type cars against the normal average driving distance in the Netherlands was used to model this difference in the other countries as information about the average driving distance of cars per fuel-type was not available in these other countries. Therefore, the national average driving distances in the model are multiplied by 1.75 for (bio-)diesel cars and 0.81 for other fuel-type cars. These multiplication factors are derived from the Dutch data.

In order to translate the national total household direct energy consumption to household levels it was necessary to include the future change in population size and the number of households in a country. Population growth was derived from historical data from Eurostat (2013) and, if necessary, corrected to match UN (2011) population predictions. Changes in the household size and the number of households where obtained through a trend analysis using historical data from Eurostat (2013) and matched with national predictions, if available (CBS, 2013; DESTATIS, 2013).

4.2 Model results

The results displayed in this paragraph are the model results per average household in the specific countries. Appendix F shows more model results on the national level for the population size, number of households, electricity production and mix, CO$_2$ emissions from electricity production, fuel use for heating, CO$_2$ emissions from heating fuel use, number of passenger cars, passenger car fuel use and passenger car CO$_2$ emissions.
4.2.1 The Netherlands

The Netherlands will face a population growth. Combining this with a decrease in the number of household members will lead to a fast growth in number of households. In the IEA (2008) report, the Netherlands plan to expand the number of coal-fired power plants. This plan has an enlarging effect on the household electric energy consumption and especially on the CO$_2$ emissions. The heating demand per household will increase by almost 23% in 20 years. Because of a large role for biofuels and district heating in the household heating demand, the CO$_2$ emissions will increase by about 29%. The growing number of passenger cars owned increases the transport energy, despite improvements in the mileage of the cars. However, this will increase the transport energy consumption per household by only 7.5%. The increase in CO$_2$ emissions from transport is a bit larger than the increase in energy consumption. The reason for this is the growing share of diesel cars owned (Figure 4-2; Table 4.2-1).

Table 4.2-1: Household direct energy consumption and CO$_2$ emissions per consumption category in the Netherlands in the year 2010, 2030 and the percentage change between these years.

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2030</th>
<th>% change</th>
<th></th>
<th>2010</th>
<th>2030</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transport [GJ]</strong></td>
<td>35</td>
<td>38</td>
<td>7.5 %</td>
<td><strong>Transport [t]</strong></td>
<td>2.5</td>
<td>2.7</td>
<td>8.4 %</td>
</tr>
<tr>
<td><strong>Heating [GJ]</strong></td>
<td>52</td>
<td>64</td>
<td>22.9 %</td>
<td><strong>Heating [t]</strong></td>
<td>3.1</td>
<td>3.9</td>
<td>28.9 %</td>
</tr>
<tr>
<td><strong>Electricity [GJ]</strong></td>
<td>27</td>
<td>48</td>
<td>78.9 %</td>
<td><strong>Electricity [t]</strong></td>
<td>1.8</td>
<td>4.7</td>
<td>157.1 %</td>
</tr>
<tr>
<td><strong>Total [GJ]</strong></td>
<td>113</td>
<td>149</td>
<td>31.3 %</td>
<td><strong>Total [t]</strong></td>
<td>7.4</td>
<td>11.4</td>
<td>53.7 %</td>
</tr>
</tbody>
</table>

Figure 4-2: Household direct energy consumption (left) and CO$_2$ emissions (right) in the Netherlands from 2010 until 2030.
4.2.2 Germany

The German population is currently declining and will continue to do so in the future. Because the average household size will decline at a faster rate than the population, the number of households shall increase with time. The primary electricity consumption per household decreases in 2030 with almost 24% compared to 2010. This decrease is partially because of the switch to renewables and the more energy-efficient gas-fired power plants instead of nuclear power plants and partially because of the smaller households whom consume less electricity. The demand for heating energy also decreases with time. In the heating fuel use, there is a sharp reduction in the use of heating oil and some growth in the use of biofuels, geothermal energy and district heating. This change in the fuel use causes the CO₂ emissions from heating to decrease even further than the heating energy itself. The total number of passenger cars in Germany increases from 42.3 million in 2010 to 52.4 million in 2030 with the largest increase coming from diesel cars. This will increase the transport energy consumption of households by almost 29% and the related CO₂ emissions by 30% (Figure 4-3; Table 4.2-2).

Table 4.2-2: Household direct energy consumption and CO₂ emissions per consumption category in Germany in the year 2010, 2030 and the percentage change between these years.

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2030</th>
<th>% change</th>
<th></th>
<th>2010</th>
<th>2030</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport [GJ]</td>
<td>60</td>
<td>78</td>
<td>28.9 %</td>
<td>Transport [t]</td>
<td>4.4</td>
<td>5.7</td>
<td>30.3 %</td>
</tr>
<tr>
<td>Heating [GJ]</td>
<td>58</td>
<td>51</td>
<td>-12.0 %</td>
<td>Heating [t]</td>
<td>4.0</td>
<td>3.4</td>
<td>-14.7 %</td>
</tr>
<tr>
<td>Electricity [GJ]</td>
<td>38</td>
<td>29</td>
<td>-23.7 %</td>
<td>Electricity [t]</td>
<td>2.6</td>
<td>2.2</td>
<td>-14.0 %</td>
</tr>
<tr>
<td>Total [GJ]</td>
<td>156</td>
<td>157</td>
<td>1.0 %</td>
<td>Total [t]</td>
<td>11.0</td>
<td>11.4</td>
<td>3.5 %</td>
</tr>
</tbody>
</table>
4.2.3 Czech Republic

In the Czech Republic the population will grow. Together with a decrease in the number of household members this will result in an increase in the number of households from 4.2 million in 2010 to almost 4.9 million households in 2030. The electricity consumption per household is expected to decrease, and because of the installation of a new nuclear power plant in favour of coal-fired power plants the CO$_2$ emissions from electricity consumption will decrease by over 50%. In the current model, the energy consumption of households for heating is increasing with time. The increase is mainly a consequence of an increase in the use of biofuels for household heating. The number of passenger cars will grow. The growth of the number of passenger cars is mainly found in the number of diesel cars. This leads to an increase of the household transport energy consumption of over 34% and transport-related CO$_2$ emissions of over 35%. Overall, the household direct energy consumption will increase by 8.1% from 2010 until 2030 and the CO$_2$ emissions will increase by only 1.7% (Figure 4-4; Table 4.2-3).

Table 4.2-3: Household direct energy consumption and CO$_2$ emissions per consumption category in the Czech Republic in the year 2010, 2030 and the percentage change between these years.

<table>
<thead>
<tr>
<th>Category</th>
<th>2010</th>
<th>2030</th>
<th>% change</th>
<th>2010</th>
<th>2030</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport [GJ]</td>
<td>42</td>
<td>57</td>
<td>34.2%</td>
<td>3.1</td>
<td>4.2</td>
<td>35.7%</td>
</tr>
<tr>
<td>Heating [GJ]</td>
<td>60</td>
<td>73</td>
<td>20.2%</td>
<td>4.9</td>
<td>6.1</td>
<td>24.8%</td>
</tr>
<tr>
<td>Electricity [GJ]</td>
<td>52</td>
<td>37</td>
<td>-27.5%</td>
<td>4.1</td>
<td>2.0</td>
<td>-51.2%</td>
</tr>
<tr>
<td>Total [GJ]</td>
<td>154</td>
<td>167</td>
<td>8.1%</td>
<td>12.1</td>
<td>12.3</td>
<td>1.7%</td>
</tr>
</tbody>
</table>
The Hungarian population size is declining. The household size, however, is declining faster. This gives a small rise in the number of households in Hungary. Currently, there is no policy for the electric sector in Hungary. Therefore, a linear growth of all fuels used to generate electricity was assumed in order to meet the expected 24% growth per 10 years in electricity demand. On the household level, this will lead to a 48.8% increase of the electricity consumption and an equal increase in the CO\textsubscript{2} emissions. Household heating will see an increase in the use of biofuels in favour of coal and oil. In addition, the heating energy consumed per household will increase slightly. The number of passenger cars is growing in Hungary and the main growth is coming from diesel cars. This increases the energy consumption for transport by 35.5% (Figure 4-5; Table 4.2-4).

Table 4.2-4: Household direct energy consumption and CO\textsubscript{2} emissions per consumption category in Hungary in the year 2010, 2030 and the percentage change between these years.

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2030</th>
<th>% change</th>
<th></th>
<th>2010</th>
<th>2030</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transport [GJ]</strong></td>
<td>29</td>
<td>39</td>
<td>35.5 %</td>
<td><strong>Transport [t]</strong></td>
<td>2.1</td>
<td>2.9</td>
<td>37.1 %</td>
</tr>
<tr>
<td><strong>Heating [GJ]</strong></td>
<td>55</td>
<td>60</td>
<td>8.7 %</td>
<td><strong>Heating [t]</strong></td>
<td>3.6</td>
<td>4.2</td>
<td>15.3 %</td>
</tr>
<tr>
<td><strong>Electricity [GJ]</strong></td>
<td>22</td>
<td>33</td>
<td>48.8 %</td>
<td><strong>Electricity [t]</strong></td>
<td>0.9</td>
<td>1.3</td>
<td>48.8 %</td>
</tr>
<tr>
<td><strong>Total [GJ]</strong></td>
<td>106</td>
<td>132</td>
<td>24.4 %</td>
<td><strong>Total [t]</strong></td>
<td>6.6</td>
<td>8.4</td>
<td>26.8 %</td>
</tr>
</tbody>
</table>
The energy consumption for transport will increase in all countries. The largest increases in the direct energy consumption are in the Netherlands and Hungary. For these countries, the increase in the energy consumption happens in all three energy consumption categories. German and Czech households will remain relatively stable in their direct energy consumption (Figure 4-6).
5 CONCLUSION

The factors that can determine the direct energy consumption of a household are: the energy efficiency and type of fuel use, the number of insulation measures and climate, the type of house and if the households consist of 1 or 2+ people. Whether a household is located in an urban or rural region also influences the energy consumption. In general, rural households have a higher per person energy consumption compared to urban households in the same country.

The amount of direct energy consumption in the west-European countries the Netherlands and Germany is comparable. However, small differences do exist. In total, a Dutch household uses more heating energy than a German household does. This is even true after correcting for the size of the house and the HDDs. In this regard it is notable that a Dutch household has a lower average temperature setting than a German household and that a Dutch house has more insulation than a German house. The reason for the higher Dutch consumption of energy for heating remains unknown.

Another difference is the fact that an average German household consumes more energy for transport than a Dutch household does. This is primarily due to the high transport use of a rural German household. Despite the differences between these two countries, the final energy consumption is the same. The more efficient electricity sector and the use of only gas for heating, causes a lower primary energy consumption of households in the Netherlands than in Germany.

Compared to households in the two West-European countries, a Hungarian household consumes less direct energy. However, the energy consumption for heat is relatively high after correcting for the size of a house and the HDDs. This could very well be a consequence of the low insulation level of a Hungarian house. The average Czech household consumes more direct energy than the two western-European countries. However, after adjusting for the number of household members in a household, the per person energy consumption in rural Czech becomes similar to rural Germany and the urban Czech household consumption becomes similar to that of a Hungarian household.

There is a large difference between the Czech urban and rural households. The rural households consume twice the amount of energy than urban households. The consumption of energy for heat and electricity are the largest contributor to this difference. The energy consumption in these two categories is twice as large in rural regions. There is only a partial explanation for the higher energy consumption in Czech rural households and that is the fact that households that use wood for heating consume twice the amount of heating energy than households that use a different kind of fuel (Appendix G). A more valid explanation for the higher electricity consumption in Czech rural households has not been found.

The direct energy consumption for heating, after house-size and temperature correction, is higher in Hungary and the Czech Republic than in the Netherlands and Germany. In the Czech Republic, the main cause for this is the use of inefficient district heating in the urban regions and the fuel use in the rural regions. In rural Czech households, the use of wood and coal for heating is still normal. These means of heating in the Czech Republic also give relative high CO₂ emissions. In rural Hungarian regions, the cause for the high energy consumption for heating appears to be due to the low number of insulation measures taken in the houses. There is no good explanation as to why the relative energy consumption for heating is so much higher in urban Hungarian regions, as the number of insulation measures and fuel use is near equal to the urban German region. However, despite the equal number of insulation measures, the type of insulation could still be different.

Household income within countries do not relate to the direct energy consumption. This suggests that there is a certain necessity for direct energy. The exceptions are the Dutch households, where an increase in income has a weak correlation with an increase in the
transport energy. This means that households with a higher income travel more. Lenzen et al. (2006) have seen this effect before in Brazil, where high income households tend to travel further for their work.

An increase in the size of a household leads to an increase in the energy consumption. This is similar as the results from Kok et al. (2003). The difference in the direct energy consumption of 1- and 2-person households in all countries leads to the largest difference (a 32% to 176% increase in the energy consumption). A further increase in the household size results in only small changes in the direct energy consumption. An exception to this trend is the addition of one or more children to a 1-person household in Hungary, because then the increase in direct energy consumption is less than 15%.

The amount of CO$_2$ emissions from the direct energy consumption of households almost directly related to the amount of energy consumed. However, the type of fuel is important in determining the amount of CO$_2$ being emitted. The Czech rural household is evidence of this. Due to the use of fuels with high carbon content, the CO$_2$ emissions compared to the other countries are higher than the actual differences in the direct energy consumption.

**Future change**

The future change in household energy consumption is not the same in all counties. The energy consumption in the transport category, however, will increase in all countries.

The Netherlands and Hungary show the largest increase in the household energy consumption. In the Netherlands, this can be explained through the sharp increase in electricity consumption from 2020 until 2030 because of the planned instalment of multiple coal-fired power plants, as described in the Dutch IEA energy policy report (IEA, 2008a). This increase in electricity consumption is expected to be fulfilled using coal-fired power plants. This dramatically increases the household CO$_2$ emissions due to electricity consumption.

The Hungarian growth in energy consumption is the result of growth in all three energy categories. This growth brings Hungary closer to the energy consumption range as the other countries. However, Hungary will remain the lowest energy-consuming country.

German and Czech households will only have a minor change in the total direct energy consumption. However, there is a shift in the amount of energy being consumed within consumption categories because the energy consumption for transport will increase. In Germany, this increase in transport energy is compensated by a decrease in the energy consumption for heating and electricity. The primary reason behind this is the sharp decline in the number of household members, thus households require less heat and electricity. In addition, the switch to more efficient electricity-producing sources lowers the primary electricity consumption and CO$_2$ emissions more than the final electricity consumption decreases. In the Czech Republic, the electricity consumption and CO$_2$ emissions from electricity go down tremendously. This is the result of a decrease in the final electricity consumption as well as a decrease in inefficient coal-fired power plants in favour of low-carbon-intense nuclear power. Household heating will still be dependent on the inefficient district heating and there will be a growth in the use of biofuels, increasing the energy consumption and CO$_2$ emissions in this category in 2030.
6 DISCUSSION

The selection of households from the original dataset for the usability in this research reduces the number of households considerably. This even led to the exclusion of Scotland, because here the households that did fill in their energy consumption for heat and electricity numbered in the low twenties. In some instances, it is possible that the low number of respondents affected the validity of some of the findings in this report. Although there are 593 households selected that provided the appropriate data for heating and electricity, these households did not necessarily answer all the other questions. There are several cases where the average energy consumption of a group of households with similar characteristics is composed of less than ten households (see Appendix D). Despite the sometimes low sample sizes, the findings can still help in understanding some of the factors that determine the direct energy consumption.

The dataset is comprised of only one specific city and its rural region per country. It is likely that this city is not representative for the entire country. For example, the reported energy consumption for household heating in the dataset is considerably higher than the national average heating energy consumption per household in 2010 (Figure 6-1). A likely explanation is the difference in house size, with the average house from the dataset being 18-55% larger than the national average house.

![Figure 6-1: Household direct energy consumption per country. Using the top-down approach in 2010 (model) and the bottom-up approach (dataset).](image)

In addition, the data provided in the dataset regarding the energy consumption, and specifically the energy for heating, are consumption periods in the years 2009 and 2010. It turns out that the year 2009 was an unusual warm year and 2010 an unusual cold year. Hence, if the reported periods of energy consumption for heating in the survey in one country had more households reporting their heating energy consumption from the year 2009 compared to the other countries, this could have affected the findings.

6.1 Transport

The real transport energy is likely higher than shown in the survey. In the questionnaire, there was room to provide data on the car use for only two cars per household. However, 7.4% of the households report to have more than two cars. In addition, 10% of the
households in the Netherlands and Hungary reported to have one or more cars but did not provide any information about the mileage. The energy consumed by these missing cars is not taken into account, leading to a possible underestimation of the transport energy.

6.2 Fuel and CO₂ emissions

The EU averages of the energy content of fuels, ERE ratios and CO₂ emissions from fuel manufacturing are used in this research. Although all countries in this report are part of the EU, there can still be substantial differences. For example, when fuels are extracted or manufactured domestically the ERE ratios for fuel in this country can be substantially lower because of the shorter distribution distances then compared to the EU level.

Throughout chapter 3, the CO₂ emissions from wood burning are, in addition to being incorporated in the total CO₂ emissions, separately depicted as a negative value to illustrate their contribution to the total CO₂ emissions. The importance of the CO₂ emissions from wood burning lies in the origin of the wood. If the wood originates from sustainable sources, the net effect of burning the wood on CO₂ emissions would be almost zero (not accounting for emissions from wood harvesting). This would lower household-related CO₂ emissions tremendously in some countries. However, if the wood does not come from sustainable sources the CO₂ emissions should be added to the total. An answer on whether the wood that is being used by households in this dataset is from a sustainable source or not, is not possible given the available data. Therefore, the choice was made to present the data ‘as is’ with the addition of a negative bar for CO₂ emissions from wood.

6.3 Behaviour

Because the self-reported energy saving behaviour did not show any relation between the energy consumption and reported behaviour, it does not necessarily mean that there is no effect of the behaviour. It is possible that consumers that are more conscious of their energy consumption and try to save energy are still consuming an amount of energy that is close to the average. However, they would have consumed more than the average household, without their energy saving effort. In addition, it is also possible that the people are unable to assess their behaviour correctly and the self-reported behaviour might not be their real behaviour.

6.4 The model

The choice to use the same source for the energy policies of the four countries had its consequences on the outcome of the model. The most recent IEA energy policies reports for each country are not all as recent as the real policies being implemented right now. This is especially true for the four-year-old Dutch energy policy report (IEA, 2008a). In this report there is a large addition of coal-fired power plants from 2020 onwards (hence the steep growth of CO₂ emissions in the model). This growth in coal-fired power plants was planned under the assumption that by that time carbon capture and storage (CCS) technology would be an economically and technologically feasible option to reduce the CO₂ emissions. However, recent developments in the feasibility and negative public attitude towards CCS have already changed the current policies towards building less coal-fired power plants than previously planned. This harms the accuracy of the model outcomes.

In addition, the change in future household energy consumption is modelled using a relatively ‘conservative’ approach. Consequently, there is relatively little room for big changing effects. Using a less conservative approach to model change can give more room to bigger changes in the outcome than otherwise would occur.

Furthermore, the outcome of the model is sometimes in conflict with national energy policies and/or EU policies. For example, the Dutch outcome of the model shows an increase of the
energy consumption for household heating and consequent CO₂ emissions. However, the outlook of the ECN (2012) on 2030 predicts a reduction of the household CO₂ emissions. This discrepancy in the predictions could be due to several factors. Firstly, the household heating consumption in the model relies on a trend analysis from 2002 until 2010 to predict the future change. The year 2010 was an exceptional cold year and thus increased the heating energy consumption considerably for this year. This affected the trend line by showing an increase in the gas consumption, whilst excluding 2010 from the trend analysis would have yielded a more stable trend line in the gas consumption. Currently, the year 2010 is included because similar cold winters can also happen in the future. Secondly, the CO₂ emissions in the model incorporate the emissions of biofuels into the total emissions, whereas the ECN (2012) predictions include the emissions from biofuels is unknown.

Despite the aforementioned remarks regarding the reliability of some of the findings, the research was still useful for uncovering the differences in the household direct energy consumption. The bottom-up approach yielded a more detailed analysis of the underlying factors that contribute to determining the energy consumption than would have been possible using a top-down approach.
REFERENCES


Vringer, K., Blok, K., 1995. The direct and indirect energy requirements of households in the Netherlands. Energy Policy 23 (11), 893-910
APPENDICES

Appendix A
The questionnaire exists of five sections with 52 main questions. These main questions could contain multiple sub-questions.

1 At Home
This section is about:
- Household size
- House (type, age and size)
- Insulation of the house
- Household heating (boiler type, fuel type, age of equipment, additional heating sources, hot water usage, living room temperature settings and habits)
- Electricity use (energy saving measures, energy efficiency and age of major household equipment
- Behavioural elements

2 Mobility
This section is about:
- Number of vehicles in household
- Cars (type, km/year, fuel consumption, fuel type)
- Transport behaviour (taking public transport, car sharing, commuting behaviour)
- Transport modes
- Flights (distance, frequency)

3 Nutrition
This section is about:
- Type of food eaten (amount of meat)
- Origin of the food (regional, seasonal, own production)
- Shopping behaviour

4 Electricity and heating demand
This section is about:
- Electricity demand (amount, timeframe, unit)
- Heating demand (fuel type, amount, timeframe, unit)
- Difference in consumption with previous years
- Intention of lowering consumption (heating, electricity, transport, food, water)

5 Socio-demographics
This section is about:
- Age/gender of questioner
- Education level
- Employment status
- Household type
- Household income
Appendix B
Direct household energy consumption for different household sizes in all four countries.

The Netherlands

![Graph showing annual energy consumption for different household sizes in the Netherlands.]

Germany

![Graph showing annual energy consumption for different household sizes in Germany.]

Czech Republic

![Graph showing annual energy consumption for different household sizes in the Czech Republic.]

48
Hungary

Annual energy consumption [GJ]

Household size

0 50 100 150 200 250 300 350

Transport
Heat
Electricity
Appendix C

The coefficient of determination ($R^2$) for various forms of energy consumption and CO$_2$ emissions against household income.

<table>
<thead>
<tr>
<th></th>
<th>The Netherlands</th>
<th>Germany</th>
<th>Czech Republic</th>
<th>Hungary</th>
</tr>
</thead>
<tbody>
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<td>CO$_2$ emissions</td>
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<td>+0.069</td>
<td>+0.047</td>
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**Appendix D**

Number of households represented in each figure with a short description of the figure. In orange are the sample sizes with fewer than 10 households.

<table>
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<th>Figure</th>
<th>Description</th>
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Appendix E
The Energy saving Effort (EE) plotted against the direct energy consumption.

**Netherlands - total vs EE score**

![Graph showing the relationship between Primary energy consumption and EE score for the Netherlands. The R² value is 0.0161.]

**Germany - total vs EE score**

![Graph showing the relationship between Primary energy consumption and EE score for Germany. The R² value is 0.003.]

[52]
Appendix F

The Netherlands
Appendix G

The average primary energy consumption for household heating per fuel type in the four countries. Above each bar is the numbers of households given that are represented in the average.
Hungary - Primary heat

Annual energy consumption [GJ]

- Natural Gas
- Heating oil
- District heating
- Electricity
- Wood
- Coal

Urban HU
Rural HU
Appendix H
Insulation type occurrence in households with the same number of insulation measures per country.