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# FIREWOOD CONSUMPTION AND $CO_2$ EMISSION OF DETACHED HOUSES IN RURAL ENVIRONMENT, NE-HUNGARY

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**Abstract:** We aimed to study the $CO_2$ emissions of detached houses using firewood for heating, using the example of a Hungarian village (Milota). We presented Hungary's $CO_2$ emission structure and discussed the increasing ratio of firewood heating in households in relation to the increasing level of poverty in the population and the increasing price of natural gas. The annual firewood consumption of 22 households in an eastern Hungarian village in a rural environment was measured and the associated $CO_2$ emissions were calculated. We found that the material of the walls was relevant; however, age structure was not important in the volume of the burnt firewood. Outdoor temperature determined significantly the amount of combusted wood and the analyses also revealed that heating habits (considering the daily routines of weekdays and weekends) can also influence $CO_2$ emissions. It is argued that using firewood for heating is beneficial at both local and national levels since the absorption capacity of forests in Hungary can keep pace with firewood combustion emissions; although, they can absorb only 48.6% of total household $CO_2$ emissions. At a global level, however, firewood combustion increases the $CO_2$ content of the atmosphere.

**Keywords:** firewood consumption, $CO_2$ emission, woodlands, climate protection, family habits, Hungary

## 1. INTRODUCTION

The European Union has undertaken to achieve a significant target in order to reduce global climate change: it will increase the ratio of renewable energy resources in the total energy consumption of the member states by 2020 so that $CO_2$ emissions will be reduced by 20% (European Union Committee 2012). Regarding Hungary, the value accepted for $CO_2$ emissions reduction by 2020 is 13%. Considering renewable energy resources, Hungary is relatively rich in solar energy, geothermal energy and energy extracted from biomass. The so-called technical potential, which refers to the real potential of utilization, is relatively small for solar energy (3.6 PJ/year), somewhat larger for geothermal energy (50 PJ/year) and the greatest potential is attributed to the utilization of biomass, with around 200 PJ/year (Faragó & Kerényi, 2003). Biomass, especially wood, has traditionally been an important source of energy and is particularly attractive nowadays because it is inherently both environmentally friendly and renewable (Grioui et al., 2006). It is clear, therefore, that among renewable energy resources, biomass offers Hungary the greatest potential for successful use. However, forestry experts draw attention to the fact that the sustainable potential is only around the half of the technical potential (Varga et al., 2011). Of the various forms of biomass, firewood produced from forests makes up the greatest amount of biomass used in Hungary.

A major issue arising from the burning of the wood produced from forests is increased $CO_2$ in the atmosphere. According to Cannel et al., (1999), deforestation and associated land-use changes contribute 80% to the total carbon emissions related to land-use. Most of the remaining 20% is released into the atmosphere from agricultural lands where woodlands have been previously cleared. Deforestation is generally carried out by burning. This technology oxidises the coal content of the burnt wood and enables the rapid oxidising of the humus content of the forest soil as well; thus coal accumulated in the soil over a long period is released into the atmosphere in large quantities.

Natural woodlands (and natural terrestrial ecosystems in general) are slow carbon accumulators (Bolin et al., 2000). Forests are significant stores of carbon (C) (Byrne, 2010). Modern forests, however, differ from this quasi-equilibrium state mainly because of anthropogenic changes in the woodlands and in their environment. According to Kuusela (1994), between 1950 and 1990 the wood stock of forests in Europe increased by 43%. Spiecker et al., (1996) and Somogyi (1998) detected a significant acceleration in the growth rate of trees in Europe's forests. Model experiments revealed that European wood species bind around 1.5 times more coal at double $CO_2$ concentrations in the short-term (Medlyn et al., 2000). The limits of this $CO_2$ fertilising effect, however, and the effects of other factors (e.g. the limited amount of nutrients in the soil) are not yet clear; therefore this $CO_2$ accumulation cannot be taken into consideration in the long-term.

Considering the $CO_2$ emissions of buildings, attempts to model the future rate of $CO_2$ emissions from heating and air conditioning have been widespread recently. The global $CO_2$ emissions model of Isaac & van Vuuren (2009) showed that the value of emissions from the air conditioning of buildings will exceed that of $CO_2$ emissions from heating (reference scenario: in 2100 the global surface temperature change since the preindustrial age will be 3.7°C).

Others investigate the process of urbanization regarding the increase in building density in towns and the increasing $CO_2$ emissions per capita (Güneralp & Seto, 2012). It must be noted, however, that almost half of the population of our planet live in rural environments (villages, farms) where air conditioning and other modern types of heating spread at much slower rates than in towns; therefore characteristic features of $CO_2$ emissions also differ from those in urban areas.

This paper aims to study one form of $CO_2$ emission - wood heating, because households in poor countries make extensive use of this heating method. Fuelwood consumption is a particularly important problem, since approximately half of the world's population uses fuelwood in their daily lives (He et al., 2009). Furthermore, poverty levels are increasing in developed countries like Hungary and wood heating is becoming dominant especially in more underdeveloped rural areas. Vajda (2004) shows that among renewable sources wood heating accounted for 78.7%.

The household $CO_2$ emissions resulting from burning wood can be assessed realistically if we consider whether or not the household owns woodland, and if it does, we also take into account the size, wood species and $CO_2$ accumulation. With increasing prices of fossil fuels the number of households using firewood is increasing.

In this paper, the structure of Hungary's $CO_2$ emissions is presented as it is reflected in the change in the energy consumption structure of Hungarian households since the second half of the 1990s. We reveal a possible method, based on mass measurement, of estimating the $CO_2$ emissions (and thus the firewood consumption) of households within a case study of a typical village (Milota) in north-eastern Hungary. We developed and applied a method based on mass measurement to determine the $CO_2$-emissions of firewood. Emissions of households that own woodland and those that do not were assessed regarding $CO_2$ increases in the atmosphere. Results were evaluated from local, national and global perspectives. Finally, the role of outdoor temperature and family habits in $CO_2$ emissions was studied and, based on this, the possibilities for $CO_2$ emissions reduction are assessed.

## 2. METHODS

### 2.1. Study site

The eastern and north-eastern regions are Hungary's most underdeveloped areas and the ratio of houses using firewood in villages is over 50%. Considering Hungarian settlements, 55.1% of the country's 3152 settlements have less than 1000 inhabitants. This size is especially relevant and representative in the studied region, therefore a village - Milota - with 880 inhabitants was chosen for the investigation. The village of Milota is located in the vicinity of the Ukrainian-Hungarian border (Fig. 1).

Figure 1. Geographical location of the study site (Milota, Hungary)

The number of inhabitants of working age is 620, 19.7% of whom live on unemployment benefit. This ratio is much higher than the national average (10.8%) but similar to that of the county (Szabolcs-

Szatmár-Bereg County). The unemployment rate and the average income (about 160 Euros per month) of these villagers is representative of the north-eastern region of the country.

There are 320 houses in the village. However, each house can be considered as one household from the point of view of heating. The average size of households is 2.7 people. Around 30% of the buildings have a floor area of less than 70 $m^2$ and are built of adobe (although there are a few larger adobe houses in the village as well), while 70% are built of brick or silicate blocks. Doors and windows are traditional, with old wooden frames; well-sealed plastic windows are not widespread. 18% of the houses can be heated solely by solid fuel, while 80% are technically suited for the use of both natural gas and solid fuel. The increasing price of natural gas in recent years has resulted in gas being used only for cooking. As a result, more than 90% of the houses in the village are heated by the cheapest fuel available today, firewood.

The annual firewood consumption of 22 households out of the 320 in the village was measured, and the $CO_2$ emissions from burning were calculated based on this figure. Households chosen randomly constitute an accurate representative sample of the buildings and the households found in the village. The average ground-floor area of the adobe houses is 68 $m^2$. Brick houses are significantly larger (121 $m^2$ on average) and more recent (5-30 years old).

## 2.2. Data collection and calculations

Data collection and analysis was conducted on a national and local level. National data was used to demonstrate firewood consumption in Hungary and its relevance in the heating structure. Local data collection was divided into two stages: firstly, a survey of 22 households focusing on the data for heating; subsequently a detailed analysis of a typical household.

Gomez & Watterson (2006) suggested an equation to calculate households' global GHG-emissions. However, our method led to more concrete results. The above-mentioned authors pointed out that "Emission can be also estimated as the product of fuel consumption on a mass or volume basis." During our work we chose the mass-based calculation for the studies at the local level.

### *2.2.1. The national level*

We evaluated the data of the Hungarian Central Statistics Office from the perspective of changes in the energy structure of Hungarian households between 1990 and 2010.

### *2.2.2. The local level*

Annual firewood consumption of the 22 households chosen randomly in Milota was measured in the heating season of 2010–2011. We applied a questionnaire survey to collect data from households (heated area, age of residents etc.), and the details of firewood consumption. We determined the floor space with local measurements. 12 out of the 22 households had private woodlands, the size of which varied between 0.025 ha and 6.3 ha.

The annual $CO_2$ absorption of each woodland was calculated, based on the PC model of Somogyi et al., (2010a). According to this simulation model the average carbon accumulation of one hectare of a Hungarian acacia woodland over 40 years is 80 tons, i.e. 2 t/ha per year (Somogyi et al., 2010b). Converting this to $CO_2$, 1 ha of acacia woodlands accumulates 7.33 t of $CO_2$ over a 1 year period. This value was applied when the ratio between carbon emissions and accumulation was studied.

The average moisture content of the firewood used in the households was determined by heating: wood samples were dried until weight balance in a desiccator at 105°C. Measurements were carried out using a tare balance with an accuracy of 0.2%.

The quantity of emitted $CO_2$ was calculated based on the average carbon content of the absolute dry firewood and the atomic mass ratio of the firing reaction $C + O_2 = CO_2$. As the firewood was acacia in more than 90% of cases, we estimated the $CO_2$ emissions based on this tree species. The carbon content of the dry firewood varies between 38 m/m % and 42 m/m % depending on the wood species (Vajda, 2004). In the case of acacia an average value of 40% of C content was used in the calculations. In addition, we determined the carbon content of the collected ash by using the Tyurin method (Buzás, 1988). Ash samples were digested in cc. $K_2Cr_2O_7$ and then the suspension was titrated with Mohr-salt (ammonium-iron (II)-sulphate) in the presence of Ferroin indicator (Zboray & Szalai, 2012). This method is used in soil science to determine the humus content; however, as all the organic compounds are oxidised during the process, it reflects the carbon content of the ash, too.

In our calculations we considered that, on the basis of our measurements, there was 1.1 kg C remaining in the ash after burning 1000 kg firewood. Consequently, the carbon content of the wood transformed into $CO_2$ at 99.7%. The method used for the subsequent calculations is as follows. Knowing the moisture content of the combusted wet wood (dried to various extents beforehand) the mass of the dry wood was calculated:

$M_d = M_w – M_{H2O}$, where

$M_d$ = mass of dry wood (kg),

$M_w$ = mass of wet firewood (kg),

$M_{H2O}$ = water content of firewood (kg).

Following this, the quantity of $CO_2$ produced by firewood combustion was calculated on the basis of the following equations:

$M_c = 0.4\ M_d$, where (kg),

$M_c$ = carbon content of firewood (kg).

Then: $\Sigma CO_2 = M_c + 2.666\ M_c$ (kg).

The factor 2.666 is obtained from the mass ratio of the two oxygen atoms and the carbon atom (32:12).

#### *2.2.3. Data collection of a typical household*

In household No. 22 under detailed analysis, the mass of the combusted wood was measured for all of the 223 heating days (average is about 180-210 days in Hungary) and those habits of the family of five members which were significant in terms of heating were noted: they heat 2 more rooms at the weekends than on weekdays. There were five rooms in the building of 148 $m^2$ floor area. A dining room, a kitchen, toilets and bathrooms were also found in the building. The height of the rooms is 280 cm. The family consisted of five adults; three of them studied at university (in Debrecen), and thus they only spend the weekends at home. At these times the whole house (148 $m^2$) is heated.

The residents of the house use 107 $m^2$ of floor area continuously during the heating season, i.e. this area was heated every day. The outer walls are made of silicate blocks; doors and windows were of wooden structure and their heat conductivity factor was $k = 3\ W/m^2$. Heating was provided by a dual fuel boiler in which the owners had been combusting wood for years. A gas boiler had been installed as well and so the building can also be heated using gas; however, gas heating was not in use for financial reasons. Firewood had been dried – before use – for one year, so its water content was only 11.2%.

The indoor temperature of house No. 22 was measured at 7 a.m. and 7 p.m. every day. Diurnal outdoor temperature data in the heating season were provided by the National Meteorological Survey. In further calculations the daily mean temperatures were used.

### 2.3. Statistical analysis

In the course of statistical analysis the average, standard deviation, standard error and relative standard deviation (RSD) was calculated. Most variables were of normal distribution according to the Shapiro-Wilk test. The relationship between the $CO_2$ emissions calculated on the basis of the quantity of wood combusted daily and its moisture content, and the outdoor daily average temperature was studied by correlation calculation (Pearson correlation coefficient) while an analysis of the differences between the given time periods was performed on the basis of the Mann-Whitney test. Our dataset involving the households contained 22 data items, so we applied permutation with the Monte-Carlo method with 10,000 random assignments to control the significance level (Sokal & Rohlf, 1969). Apart from the significance level the effect size was given as well. Effect size (as statistical power) quantifies the magnitude of difference between two groups in standardized (i.e. comparative) form (Cohen, 1992). Effect sizes were evaluated following Field (2009). Bivariate regression analysis was applied to quantify the dependencies of the combusted firewood based upon the predictors (heated volume, etc). In the case of regression analysis the normal distribution of the residuals was considered important, and homoscedasticity was controlled graphically as well as with the Shapiro-Wilk test. We divided the whole dataset into smaller groups in order to obtain detailed results. Clusters were defined considering the type of wall material and the age of the owners. Using these clusters we were able to carry out a deeper analysis and to reveal more precise consequences. Statistical analyses were carried out with PAST (Hammer et al., 2001) and SPSS (Statistical Package for the Social Sciences, 2007) software.

## 3. RESULTS

### 3.1. $CO_2$ emission structure in Hungary and the energy consumption structure of the households

$CO_2$ emissions in Hungary decreased from 72.5 million tons to 57.8 million tons between 1990 and 2007, a reduction in which the change in the economic structure at the time of the political transformation played a significant role. Numerous energy-intensive heavy industry factories were closed, while the share of the service sector increased significantly. 14.4% of $CO_2$ emissions were produced by fossil fuel combustion in households in the structure of carbon dioxide emissions in 2007 (whereas the ratio of energy industries was 35%, transport 21% and industry 19%).

Hungarian households turned increasingly to natural gas during the 1980s and 1990s due to the subsidies provided: by 2008 76.5% of households were connected to the natural gas network, although many families prepared for combined heating. Especially in rural settlements natural gas was used only for cooking and hot water, while heating was provided by solid fuel, mostly firewood. The ratio of district heating (i.e. heat fed in from a central heating plant) in the energy consumption structure of households was significantly reduced: from 18% in 1996 to 10% in 2008.

The share of solid fuels in the energy consumption of households was 29.1% in 1996 and 30.3% in 2008. This was not a significant change but the internal structure changed significantly: firewood, with its 27.1% share, became the second most important household energy resource following natural gas (Table 1). In villages 97.1% of households with no natural gas supply used firewood for heating.

The correlation between family income and heating methods can be clearly observed: regarding households with no natural gas supply, 92% of those belonging to the lower fifth income category used firewood or coal for heating (with the latter much less used) while in the third fifth income category (i.e. in the middle of the income distribution) this ratio was 71.5%. In the upper fifth this value was only 32.5%.

### 3.2. Milota's $CO_2$ production

#### 3.2.1. Firewood consumption and $CO_2$ emissions of the studied households in one heating season

The quantity of combusted wood can be compared only roughly with the floorspace (due to the varying height of the ceilings); we therefore considered the size of the heated volume to be more significant regarding the quantity of combusted wood and, consequently, the $CO_2$ emissions (Table 2). Annual firewood consumption was around 4000–7000 kg for small adobe buildings.

The sole exception was household No. 1 where the elderly residents lived in relatively better financial conditions than those in other houses and, as they particularly needed warmer conditions, they kept temperatures significantly higher (27–29°C) than the average. This was also reflected in their annual firewood consumption (13.000 kg). The opposite example was provided by households Nos. 7 and 12 where firewood was saved as much as possible: they kept temperatures in the heated rooms lower (19°C on average) and did not heat the whole house. A particularly economical consumption of firewood in household No. 12 was provided by a modern and effective boiler.

The $CO_2$ emissions of the houses were influenced by the moisture content of the firewood, and this can be divided into two groups (Table 2): in 8 households the moisture content of firewood varied between 11.2% and 18.2% (the drier wood belonging to the woodland owning households), in the rest, the moisture content varied between 27.7% and 38.2%. Lower values were the result of careful drying for one year. Higher values were characteristic when the purchased wood was burnt at once or within a few months. Households No. 20 and 22 were good examples of the $CO_2$ emissions caused by heating with two types of wood. In these households an almost identical mass of firewood was burnt (12.0 t and 11.9 t respectively) but the water content of the firewood in household No. 20 was 34.1%, while that in household No. 22 was 11.2%. Accordingly, the carbon content of the firewood was 3.16 t and respectively 4.23 t, while the emitted $CO^2$ was 11.59 t and 15.50 t respectively 107 m$^2$ was heated with drier wood at a higher mean temperature while with the wetter firewood only 80 m$^2$ was heated at practically similar temperatures (21–22°C) inside the flats (Table 2). In conclusion, a larger flat can be heated with the same amount of drier wood, thus drier wood is more economical. When analysing the heated volume of houses and the amount of combusted wood, we found a strong relationship ($R^2$=0.606; $p<0.01$). This means that the size of the house can explain 58.6% of the variance in heating.

Table 1. Energy consumption of household by energy types in quantities of heat (Hungarian Central Statistical Office, 2008)

| Energy resources | Quantity of heat (TJ) | | Distribution (%) | | Change % 2008/1996 |
|---|---|---|---|---|---|
| | 1996 | 2008 | 1996 | 2008 | |
| Natural gas | 117608 | 135980 | 38.9 | 45.1 | 115.6 |
| Electric energy | 31913 | 39830 | 10.5 | 13.2 | 124.8 |
| Propane/butane gas | 8676 | 2961 | 2.9 | 1.0 | 34.1 |
| Fuel oil | 872 | 8 | 0.3 | 0.0 | 0.9 |
| District heating | 55500 | 31398 | 18.3 | 10.4 | 56.6 |
| Black coal | 4954.4 | 7125 | 1.6 | 2.4 | 143.8 |
| Cokery coal | 1156.8 | 48 | 0.4 | 0.0 | 4.1 |
| Firewood | 51370 | 81806 | 17.0 | 27.1 | 159.2 |
| Other solid fuel | 30580.5 | 2487 | 10.1 | 0.8 | 8.1 |
| Out of this: pellet | - | 119 | - | 0.0 | - |
| Wood chips | - | 2368 | - | 0.8 | - |
| Total | 302630 | 301642 | 100.0 | 100.0 | 99.7 |

a) Under other solid fuel we mean pellet, wood briquette, wood chips, brushwood and twigs.

Table 2. $CO_2$ emission of investigated households in Milota (Hungary) within a heating season 2010-2011 (a: adobe; b: brick; $M_d$: mass of dry wood; $M_c$: carbon content of dried wood)

| House | | $M_d$ (kg) | $M_c$ (kg) | $CO_2$-emission (kg) | Forest area (ha) | Absorbed $CO_2$ (kg) | $CO_2$ budget* | $CO_2$ (kg) / person | $CO_2$ / heated volume (kg/m$^3$) |
|---|---|---|---|---|---|---|---|---|---|
| No. | wall material | | | | | | | | |
| 1 | a | 9400 | 3760 | 13780 | | 0 | 0 | 6890 | 130 |
| 2 | b | 7450 | 2980 | 10920 | | 0 | 0 | 2730 | 40 |
| 3 | a | 4910 | 1960 | 7200 | 2.000 | 14660 | -7460 | 3600 | 86 |
| 4 | b | 12900 | 5160 | 18910 | | 0 | 0 | 4720 | 71 |
| 5 | a | 8070 | 3230 | 11830 | 0.550 | 4030 | 7800 | 1480 | 45 |
| 6 | b | 18540 | 7420 | 27190 | 0.750 | 5500 | 21690 | 13600 | 46 |
| 7 | b | 3440 | 1376 | 5040 | 1.250 | 9160 | -4120 | 2520 | 36 |
| 8 | b | 6280 | 2510 | 9210 | | 0 | 0 | 4600 | 33 |
| 9 | a | 3690 | 1476 | 5410 | 0.025 | 180 | 5230 | 5410 | 117 |
| 10 | a | 2770 | 1108 | 4060 | | 0 | 0 | 2030 | 56 |
| 11 | b | 4140 | 1656 | 6070 | | 0 | 0 | 6070 | 90 |
| 12 | b | 2510 | 1000 | 3680 | | 0 | 0 | 1230 | 19 |
| 13 | a | 4130 | 1650 | 6050 | 0.250 | 1830 | 4220 | 3030 | 22 |
| 14 | a | 3270 | 1308 | 4790 | | 0 | 0 | 4790 | 100 |
| 15 | a | 5450 | 2180 | 7990 | | 0 | 0 | 2660 | 32 |
| 16 | b | 8280 | 3310 | 12140 | | 0 | 0 | 4050 | 27 |
| 17 | b | 17260 | 6900 | 25310 | 3.200 | 23460 | 1850 | 6330 | 68 |
| 18 | b | 11470 | 4590 | 16830 | 6.300 | 46180 | -29350 | 8420 | 57 |
| 19 | a | 2790 | 1116 | 4090 | 1.200 | 8800 | -4710 | 4090 | 61 |
| 20 | b | 7910 | 3160 | 11590 | 1.200 | 8800 | 2790 | 2900 | 50 |
| 21 | b | 12710 | 5080 | 18630 | 5.000 | 36650 | -18020 | 9320 | 57 |
| 22 | b | 10570 | 4230 | 15500 | 6.300 | 46180 | -30680 | 3100 | 54 |

If we divide the dataset according to wall material, we can see that in the cases of adobe-walled houses this relationship did not exist (the equation was not significant). In the case of houses with brick walls the correlation was similar to the analysis of the whole dataset, at $R^2$=0.607 ($p<0.01$). The error in the estimation was 4,700 kg. This separation can be justified by the fact that the difference was significant ($p<0.01$) in terms of heated volume in the two kinds of houses and this variable had the largest effect on separating the characteristics of the houses. The mean value of brick houses was more than double that of adobe houses (Table 3). Due to this fact, the amount of combusted wood was significantly different ($p<0.01$) in these clusters, too.

The insulating efficiency of adobe and brick is dissimilar, and this should be reflected in the amount of combusted wood. This effect was indicated in the difference in combusted wood consumed (Table 3), however, the moderate value (r=-0.41) of this difference showed that the other parameters had an influence on the results.

We applied another type clustering of the dataset, this time from the perspective of the age of the householders, focusing on retirement. The probability of a retired person staying at home all day is higher, unlike those who go to work and start heating their house after working hours.

Age did not seem to have significant effects on the results (Table 4); none of the variables showed significant differences due to these clusters. However, the correlation of combusted wood and heated volume gave important additional information. This separation of the data and the application of regression analysis revealed that if we examined only houses belonging to non-retired owners, we could explain 64% of the variance ($R^2$=0.640; $p<0.01$; N=14). At the same time, in the case of a cluster of retired owners the correlation was non-significant ($R^2$=0.403, p=0.09; N=8). These analyses and the separation of the dataset into clusters helped to establish the reasons for the moderate strength of the obvious connection between the heated volume and combusted wood. We revealed that brick houses and houses with younger owners could provide relevant and reliable information about these relationships. The other important factor influencing wood consumption and $CO_2$ emissions was the family's financial situation.

The firewood consumption of poorer families and those living alone (households Nos. 7, 9, 10, 11, 14, and 19) was a half, or a third, of the average. $CO_2$ emission per capita of the 22 households was 4 tons (3970 kg). The lowest $CO_2$ emission per capita was found in household No. 12 (1230 kg/person) while the highest value (1360 kg/person) was in household No. 6 with 2 members.

Table 3: Average of the relevant parameters of houses considering the material of the walls (arithmetical mean ± standard error; **p<0.05**)

| parameters | adobe | brick | Significance (effect size) |
|---|---|---|---|
| heated volume ($m^3$) | 134.2 ± 32.5 | 290.2 ± 36.4 | **0.001 (-0.72)** |
| heated area ($m^2$) | 52.6 ± 12.1 | 105.1 ± 13.1 | **0.006 (-0.51)** |
| height of ceiling (m) | 2.49 ± 0.05 | 2.76 ± 0.02 | **0.004 (-0.58)** |
| retired owners (%) | 66.6 | 38.4 | - |
| combusted wood (kg/year) | 7060 ± 1220 | 12840 ± 200 | **0.050 (-0.41)** |

Table 4. Average of the relevant parameters of houses considering the age of the owners (arithmetical means ± standard error; **p<0.05**)

| Parameters | 60 years > | 60 years < | Significance (effect size) |
|---|---|---|---|
| heated volume ($m^3$) | 233.4 ± 43.8 | 214.1 ± 33.1 | 0.664 (-0,09) |
| heated area ($m^2$) | 86.1 ± 15.5 | 79.2 ± 11.9 | 0.664 (-0,10) |
| height of ceiling (m) | 2.63 ± 0.05 | 2.68 ± 0.05 | 0.815 (-0,05) |
| combusted wood (kg/year) | 10600 ± 2100 | 10100 ± 1200 | 0.920 (-0,03) |
| preferred temperature ($^oC$) | 22.5 ± 0.5 | 22.2 ± 1.0 | 0.815 (-0.05) |

It is worth noting, however, that the $CO_2$ emission per $m^2$ of the heated area was somewhat lower than the average (103 kg/$m^2$, average: 150 kg/$m^2$). This was related to the large floor area of the flat and the good quality of the heating system. The highest emission per $m^2$ of heated area was found in the strongly overheated household No. 1.

$CO_2$ emissions are reduced by the woodlands owned by the households in the case of half of the households studied. The $CO_2$ emission of some flats was fully compensated by the $CO_2$ accumulation of the woodlands owned by the families. The highest $CO_2$ absorption in an absolute value was provided by the woodlands of households Nos. 18 and 22 (46,180–46,180 kg). These households had significant reserves regarding $CO_2$ absorption (Table 2; negative values represent the $CO_2$ absorption reserve per household). Six households out of the 22 had this kind of reserve.

The difference between the total $CO_2$ emissions of the 22 households and the $CO_2$ absorption of all the woodlands of the families is 40,790 kg, i.e. the net $CO_2$ emission of the 22 households in a year is 40,790 kg. This also means that 83.4% of the gross emissions of the households are accumulated by their woodlands, and thus the net emission is 16.6% of the total $CO_2$ produced.

### 3.3. Habits influencing $CO_2$ emission

Average firewood consumption of the households presented in Table 2 was 10,400 kg annually, while for household No. 22 it was 11,900 kg. This is somewhat over the average but at the start of the analysis the average value of consumption of household No. 22 was not known.

As a first step in the analysis the correlation was studied between the daily mean temperatures and $CO_2$ emissions. Fig. 2 represents the correlation between the outdoor temperature and the $CO_2$ emissions. We revealed a strong negative correlation (r =-0.83; p<0.01; N=223) between the two factors.

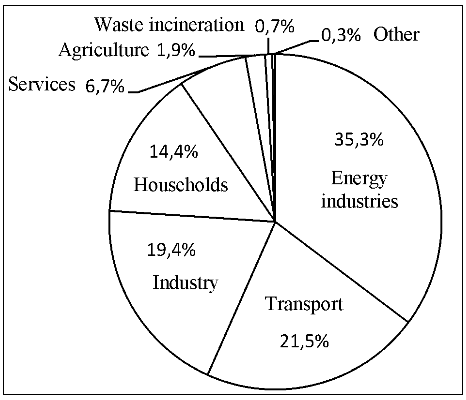


Figure 2. Structure of emission of carbon dioxide in Hungary, 2007 (Hungarian Central Statistical Office, 2008)

Variations in $CO_2$ emissions in winter months (December, January, February) were greater than in months in the transitional seasons (September, October, November), being 9,488±2,355 kg (RSD=32%) and 4,955±1,665 kg (RSD=24%), respectively. This was partly caused by the family's habit of heating the whole area of the house at weekends, and in colder outdoor conditions heating required more fuel than in warmer outdoor conditions. At weekends and on weekdays the morning outdoor and indoor temperatures did not differ significantly (p<0.05), although evening temperatures did. Even though this difference was small the change in the heating habits was reflected clearly, i.e. not only was a greater area heated but weekend evening indoor temperatures were generally higher. The quantity of combusted firewood at the weekends was on average 4 kg more than on weekdays; however, the difference was not significant.

The quantity of fuel used was significantly influenced by the family's habits and daily routine, as well as the daily mean temperature values. The quantity of combusted wood depended on whether the analysed day was a weekday or weekend, as the size of the heated area and volume, the number of family members at home, the time heating started and the hours of heating differ in the two periods. Weekdays were characterised by lower firewood consumption than weekends (Table 4). On weekdays only 107.2 $m^2$ of the 148 $m^2$ area of the house was heated as only 2 family members were at home out of the 5 who arrived home only late in the afternoon after work; the time the heating was switched on was adjusted to this fact. As a result the house was heated for 3-4 hours less than it was at weekends. At weekends the total area of the house was heated and so the heated volume increased from 394 $m^3$ to 493 $m^3$. At these periods every member of the family was at home and heating was turned on earlier than on weekdays. The habits of the family influenced the weekend heating pattern the most. If the mean temperatures at weekends were higher than on weekdays the house was heated up more due to the family's habits. The measurement at 7 p.m. revealed that temperatures around 2°C higher than on weekdays were typical (Table 5). This can be explained by the fact that the 3 members of the family arriving home for the weekend like higher indoor temperatures.

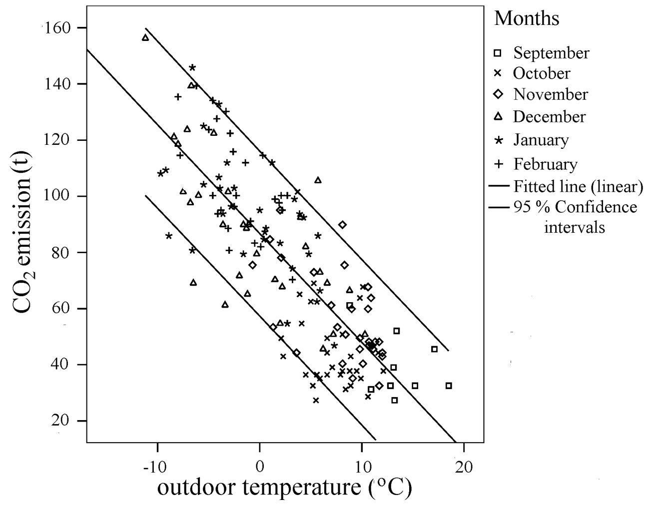


Figure 3. $CO_2$ emission (t) and outdoor temperature (°C) based on daily measurements ($R^2$=0.669; p<0.001)

Examining each month's data individually we can observe that the habits of the family influence the amount of burnt wood to different degrees. In October 2010, there were more weekends when, in spite of the higher outdoor temperature, heating was more intensive than on colder weekdays (Fig. 3). In this month, the correlation was not significant, due to the heating habits: r=-0.28 (p>0.05; N=31). Besides, in December the temperature was colder and wood consumption was only slightly biased by heating habits (Fig. 4). Because of the low temperature on each day of the week, strong heating was needed. The correlation was the highest over the period investigated in monthly clusters: r=-0.72 (p<0.05; N=31). Consequently, family habits influenced the consumption of firewood when the outdoor temperature was 7.2±2.7°C (October) and had no effect on heating when the temperature was under zero (-0.8±5.8). We revealed similar results in the case of other transitional (November, March, April) and cold (January, February) months.

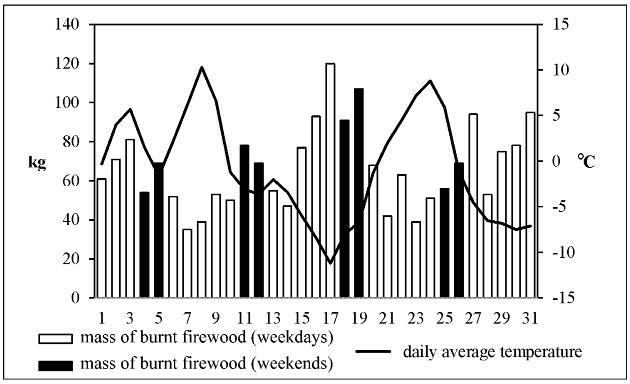


Figure 4. Relations of firewood consumption (kg) and outdoor temperature (°C) in December 2010

## 4. DISCUSSIONS

As a result of the financial-economic crisis that started in 2008 the ratio of firewood heating in the energy consumption of households was expected to increase, since levels of poverty had been increasing in Hungary for years and no beneficial change was expected in the near future. Currently firewood is the cheapest and most easily available of the energy resources used by Hungarian households. This also means that $CO_2$ emissions from wood combustion were expected to increase. The question was whether the $CO_2$ accumulation capacity of Hungarian forests can keep pace with this increase or not. Therefore, studying the climatic effects of firewood heating is highly justified (Szabó 2002).
Based on our measurements, it can be stated that 83.4% of the $CO_2$ emissions of the households heated by firewood we studied was absorbed by the woodlands owned by the house owners.

This indicates a significantly more advantageous situation than exists nationally. The $CO_2$ accumulation capacity of all forests in Hungary amounts to 48.6% of the total household emissions, i.e. the net emission is 51.4% (Hungarian Central Statistical Office 2008). Both forested areas and the reserve of living trees is increasing in Hungary but the country's ratio of forested areas is relatively low compared to European conditions (in Hungary the spatial ratio is 20%). It is important that the quantity of cut wood (6.8 million $m^3$) is less than the annual growth of woodlands (13.8 million $m^3$) (Schiberna 2011). The difference between the two figures is significant and planned new forestation may increase the $CO_2$ absorption capacity of woodlands even further. However, even the long-term target (a forest area ratio of 25%) would not be sufficient to accumulate the total emission of households.

The application of methods requiring significant investment (plastic doors and windows with good insulation, wood insulation) in regions where households have low incomes, like our study area, is very limited: only relatively wealthy families can afford them. However, the indoor temperature could be reduced by 2–3°C in several households and in some cases even the size of the heated space could be reduced as well. This latter is especially justified in the case of houses with a large heated area if only a small number of residents live in them. Households Nos. 1 and 6 are good examples of extreme overheating, and large $CO_2$ emissions associated with large heated volume, respectively. Relative overheating (mean temperatures above 20°C) is characteristic of 73% of the households.

The applied method of calculation of $CO_2$ emissions led to sufficiently precise results at local level. Gomez & Watterson (2006) emphasized that calculations which are based on country-specific data provide more accurate results than global $CO_2$ emission calculations. We believe many of the data used in these calculations are estimated. In our method all data are based on measurements and can thus be assumed to be sufficiently accurate. However, the disadvantage is that it is labour-intensive and requires further basic information (e.g. the carbon content of different tree species) if we intend to do calculations for the whole country or several regions.

## 5. CONCLUSIONS

In this study, we analyzed the annual firewood consumption and $CO_2$ emissions of 22 households in a village in eastern Hungary (Milota). From the viewpoint of atmospheric $CO_2$ increase, we evaluated the emissions of the woodland-owning and woodland-free households.

The firewood consumption and $CO_2$ emissions are significantly influenced by the moisture content of firewood, the lifestyle and daily routine of the residents, as well as their financial situation. We calculated the $CO_2$ absorption of the forests belonging to households. It can be stated that the $CO_2$ emissions are reduced by the forests owned by the residents. Some households manage to produce a $CO_2$-reserve.

The investigation revealed that 83.4% of the total gross output of the households is absorbed by their own forests. Consequently the net emission is 16.6% of the total generated $CO_2$.

Compared with the national situation this indicates a considerably more favourable situation. The $CO_2$ absorption capacity of Hungary's forests is 48.6% of the total emissions of the country's households, which means that the net emission is 51.4% (Central Statistical Office, 2008).

However, at a global level more $CO_2$ is emitted into the atmosphere by forest clearing, by firing and firewood consumption than the absorption capacity of the Earth's forests. The carbon surplus entering the atmosphere in the form of $CO_2$ as the result of wood firing is estimated to be at least 1 billion tons. In a global context using firewood contributes to the intensification of the green-house effect although to a much lesser extent than combustion of fossil energy resources (around 8 billion tons carbon/year).

Thus, the reduction of $CO_2$ emissions related to heating with firewood contributes to climate protection.


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