COMPARISON OF CO_2-EMISSIONS OF HOUSEHOLDS HEATED BY NATURAL GAS AND FIREWOOD

MÓNIKA PALÁDI

University of Debrecen, Department of Lanscape Protecition and Environmental Geography
Hungary, 4032, Deberecen, Egyetem tér 1.
E-mail: paladimonika@gmail.com

Received 3 november 2013, accepted in revised form 19 december 2013

Abstract
In terms of climate protection, one of the most important questions is the reduction of the GHG emission. In this study, I compared CO_2-emission of households heated by natural gas and firewood, which had similar heated area and volume of air, considering the carbon-dioxide absorbing of forests of the households heated by firewood. Natural gas is a fossil fuel; however, the firewood (solid biomass) is a renewable energy resource. One of the main features of renewable energy sources is to get into the atmosphere less CO_2 than fossil fuels. The renewable energy resources emit into the air just as much CO_2 as they absorb during their life cycle.

Keywords: CO_2-emission, Hungary, firewood consumption, natural gas consumption

1. Introduction

Nowadays fossil fuels play an important role in energy supply. Coal, oil and natural gas are the most responsible for the air pollution and the global warming which generates an increasing problem. Human activities have increased the atmospheric concentrations of greenhouse gases (GHG), including carbon dioxide (CO_2), primarily through the combustion of fossil fuels, agricultural production and land use change (Tamás – Szabó 2001; Xiaozhi et al. 2012). Increasing levels of greenhouse gas emissions contribute to climate change (Szabó 2002). In 2011, global CO_2 emission from fossil fuel combustion reached 31.6 Gt (IEA 2012). The use of renewable energy sources can reduce the greenhouse gas emissions and can mitigate the risks of climate change. During recent years, the use of wood for bioenergy purpose has become an interesting alternative to fossil fuels (Eriksson et al. 2002; Raymer 2006). The use of the biomass is suitable to replace fossil fuels (Paré et al. 2011; Manomet 2010; Börjesson 2008). The European Union has set an aim to increase the proportion of renewable energy resources (including biomass). The European Council adopted the “Energy and Climate” package in 2007. The EU is committed to the “20-20-20” initiative, in which undertook that by 2020 the GHG-emission will be reduced by 20%; the proportion of renewable energy in the energy consumption will be increased from 8.5% to 20%; as well as the energy efficiency will be improved by 20% (Energy Roadmap 2011).

In Hungary, the most important application area of the renewable energy sources is heat consumption for heating purposes. In my study, I demonstrated the benefits of the use of biomass for heating purposes. The ancient utilization of biomass is the utilization of heat generated during the burning of firewood. As a consequence of burning, carbon which had absorbed in the living plants, gets into the atmosphere in the form of carbon-dioxide; oxidative energy is generated in the closed carbon cycle, thus more carbon does not released into the atmosphere than the plant absorbed from there. In contrast, the fossil energy accumulated in the earth's crust over millions of years, so their carbon content gets into the air in form of carbon-dioxide by burning; increasing the amount of greenhouse gases (Kerényi et al. 2003). Fossil fuel burning emitted >9 Gt carbon (C) to the atmosphere in 2010 (Peters et al. 2011). If these emissions were to be absorbed by trees to form wood of density 500 kg m^{-3}, where half of this mass is C, annual tree growth to produce a solid wood cube of 36 billion m^3, over four times the height of Mt. Everest, would be needed. To offset these emissions through reforestation, assuming an average tree wood growth rate of 10 m^3 ha^{-1} y^{-1}, an area of 36 million km^2 of plantations, over four times the area of Australia or continental USA, would be needed (Morony 2013).

In the energy consumption of households, these two fuels are dominant, (the natural gas was 47%, the firewood was 27% in 2008), and in the recent years the proportion of firewood is increasing.

During my work, I studied CO_2-emissions of households heated by natural gas and firewood in the 2011/2012 heating season. My aim was to compare CO_2-emission of households heated by natural gas and firewood, which had similar heated area and volume, considering the carbon dioxide absorbing of forests of the households heated by firewood.

2. Methods

2.1. Location of study area and data collection

In the 2011/2012 heating season I examined the CO_2-emission from heating of 30 households, in Milota. 30 households were chosen by random walk method in the village. Households were representative regarding the building stocks and families of the village. 22 households were heated by firewood and 8 were heated by natural gas. The amount of burnt wood was measured in every day in 22 households. However, in the other 21 households the total firewood consumption of this heating season was measured; thus, in these households cumulative data were available. Each house in the village was heated by acacia wood.

The location of the households heated by natural gas (piece of 9) is shown in Figure 1, which are located in Borsod-Abaúj-Zemplén county (Miskolc), Hajdú-Bihar county (Debrecen) and Szabolcs-Szatmár-Bereg county (Nyíregyháza, Nagydobos, Fehérgyarmat, Szatmárcseke, Tiszabecs). This measurement is based on daily measurements, so the gas consumption was recorded by residents in every heating day.

Fig. 1. The location of the studied settlements

2.2. The calculation

The calculation of the amount of emitted CO_2, which is get into the air during the firewood heating, I have presented in details the previous paper (Paládi et al. 2014). The theoretical basis of the calculation was a chemical equation describing the oxidation of carbon content of the wood using for heating, considering atomic mass of carbon and oxygen. In addition, the average moisture content of firewood used for heating was determined by warming methods beside of the carbon content of dry matter of firewood. The fresh cut and dried in determined period black locust wood samples were dried to constant weight on 105 °C in a drying oven, the measurements were carried out 0.2% accuracy in tare balance (Paládi et al. 2014). Drying of wood is necessary to obtain the amount of maximum energy, as net

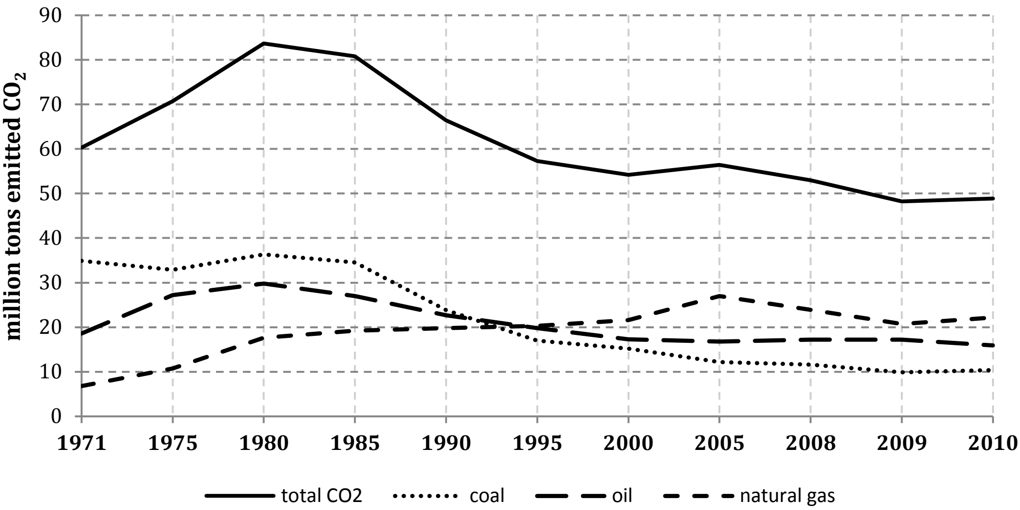

Fig. 2. Changes of carbon dioxide emissions in Hungary between 1971-2010
Source: IEA, World Energy Outlook, 2012.

obtainable energy depends on the moisture content. The heating value of firewood is inversely related to moisture content. The amount of unburnt carbon, which remained in the ash, was determined by potassium dichromate method (Zboray – Szalai 2012). With these data, we calculated the amount of CO_2 generated during the combustion of 1 kg dry firewood, and then the CO_2-emission of whole heating season (Paládi et al. 2014).

The natural gas mainly contains hydrocarbon gases. The higher the proportion of non-combustible (inert content CO_2, N_2) in gas is, the smaller its heating value is (Szemmelveiszné 1998). Approximately 10 m^3 air is needed for combustion of one unit natural gas (1 m^3), during its perfect combustion smoke, soot and ash are not generated.

The typical composition of natural gas is as follows: methane (97%), ethane (0.919%), propane (0.363%), butane (0.162%), carbon dioxide (0.527%), oxygen (0-0.08%), nitrogen (0.936%), noble gases (as trace element) [2].

At perfect combustion of 1 m^3 room temperature (SATP-state gas) natural gas, the CO_2-emission of natural gas is calculated as follows:

- SATP-state gas is 298.15 K (25°C) temperature and 1 bar (100 000 Pa) pressure.
- Molar volume of SATP-state perfect gas is Vm = 24.790 l * mol-1.
- 1 m^3, i.e. 1000 litre SATP-state CO_2 contain 1000 [l]/24.790 [l*mol-1] = 40.338 mol.
- For this reason 1 m^3 SATP-state CO_2 40.338 [mol] * 44 [g/mol] = 1774.909 g i.e. 1.775 kg.

Thus, at total combustion of 1 m^3 SATP-state methane 1.775 kg CO_2 generated (Atkins 2002). So, in my further calculations this value was taken as basis.

3. Results

3.1. CO_2-emission of Hungary

According to the latest available IEA database (2012) the CO_2-emission of Hungary was 48.9 million tons in 2010, that is 26.3% less than in 1990. 16 Mt CO_2 derived from electricity and heat production, 11.6 Mt CO_2 came from transport, 5.9 Mt CO_2 from manufacturing industries and construction industry, 1.6 Mt CO_2 from communal sector, and 13.8 Mt CO_2 from other sources, of which 62% (8.6 Mt CO_2) is related to the population. In 2010, the emissions per capita are 4.89 tonnes CO_2, that is 23.6% less than in 1990.

Based on the curve it can be concluded

that a very intensive growth can be observed in CO_2-emission of Hungary to 1980. After 1985, however, a similar intensity decrease occurred. This decline is explained by the regime change, when the industrial, agricultural and energy performance have declined significantly (Kerényi – Szabó 1999). In addition, important technical or technological change has taken place, as new energy production methods have appeared. The dominant heavy industry decreased significantly, natural gas has been more and more widespread and supplanted the fossil fuels.

3.2. Natural gas consumption of Hungary

The primary energy sources can be found in nature. Earlier, under the primer energy sources mainly fossil fuels and fuels with nuclear power were understood. The spread of natural gas utilization increased slightly because of the growth of proven supply and due to the development of combustion plants it can be used more effectively. Use of natural causes slightly less environmental load than petroleum. However, the delivery of natural gas to consumers is expensive (e.g. liquefaction, building of long pipelines).

According to the distribution of household energy use, the most frequently used energy is the natural gas, the second is electricity, followed by biomass in third place (Energy Centre Non-profit Ltd 2009). From 2005, realignment began on the energy market. Between 1995 and 2011 number of settlements connected to the piped gas network, thus the increasing was nearby doubled. By 2011, 2895 settlements had been linking into the network. The number of household customers was increased by 42% during the mentioned period. The rate of growth has considerably slowed in recent times. The popularity of natural gas seems to break. This is explained by a drastic change in the price of natural gas, which were increasing 8.5-fold between 1995 and 2011. Between 2006 (83.32 Ft/m^3) and 2011 (134.04 Ft/m^3) a 60% of rising was in gas price. At the same time the proportion of biomass starts to increase, which is not only the power but also the private consumption can be attributed.

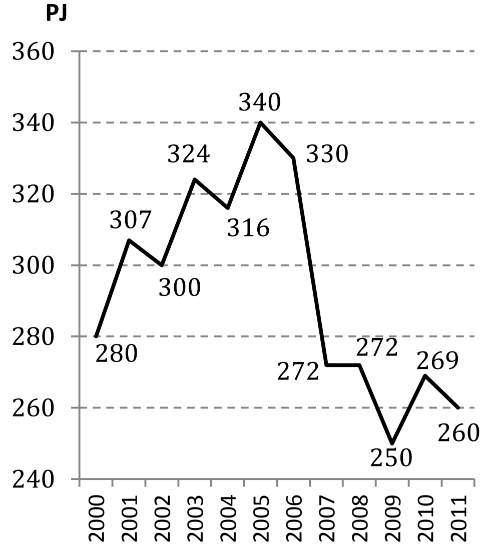

Fig. 3. Changes in natural gas consumption
Source: MEKH

In 2011, the proportion of natural gas production was 18.88% in the primary energy generation. Domestic natural gas production was about. 25% of domestic consumption, thus a significant amount of natural gas was imported. In 2011, the domestic natural gas protection was 2640 Mm^3, so 8019 Mm^3 natural gas was imported (MEKH). The proportion of natural gas import was 39.04% of energy source import. In 2011, the amount of natural gas sold in Hungary was 10 975 Mm^3, of which 3591 Mm^3 (33%) was consumed by households (MEKH).

3.3. Biomass utilization in Hungary

Solid biomass is one of the most important renewable energy sources in Hungary. Energy was extracted from solid biomass by burning for district heating, heating, and electricity generation purpose. The easiest way of energetic utilization of biomass is firing. The heat resulting from the combustion is usually sold in heat supply.

The combustion of biomass has several advantages. Biomass is natural origin and renewable energy sources (Dinya 2010).

Biomass can be considered a carbon-neutral resource. Carbon-dioxide was generated by biomass utilization, then it is absorbed in their life. During combustion it emits less greenhouse gas than fossil fuels.

In Hungary, the use of renewable energy is mostly traditional. Renewable energy sources, as Figure 4 shows, is mostly used for heating / cooling.

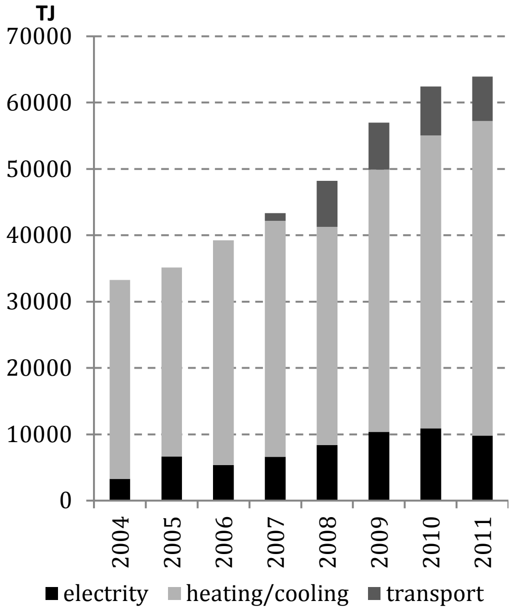

Fig. 4. Development of renewable final energy consumption by industries Source: MEKH

Of renewable energy sources, the biomass represents the greatest potential within the heating, and the proportion of effective utilization is outstanding as well. Based on data of 2011, biomass is 90% within the renewable energy resources, which is followed by geothermal energy (5.6%). The characteristics of the essential combustion technology of solid biomass are the following: the heating value is 15-18 MJ/kg in air-dry state (~10% moisture content); content of combustible volatile oil is high (60-70% of heating value), and ash content is favourably low (1-7%) (Gyulai 2009).

3.4. CO_2-emissions of households heated by natural gas and firewood

Similar heated area and volume households heated by natural gas (piece of 4) and firewood (piece of 4) were chosen for comparison of CO_2-emission. The four wood-fired household is located in (12, 13, 17 and 20) Milota, while gas-fired household can be found in Nagydobos (24), in Nyíregyháza (25), in Tiszabecs (28) and in Debrecen (29). On the basis of OMSZ in 2011/2012 heating season the average temperature (3-4 C°) of heating season does not show large differences in the studied settlements. The comparisons were carried out as follows: CO_2-emission of 12 No. wood-burning household was compared with emission of 24 No. gas-heated household. CO_2-emission of 13 No. wood-heated household was compared with 25 No. gas-fired household; the 17 No. wood-burning with 28 No. gas-heated household; the 20 No. wood-heated with the 29 No. gas-heated household.

The CO_2-emission of 12 No. (heated area: 70 m^2) household heated by firewood was 4800 kg. On the contrary, the CO_2-emission of 24 No. (heated area: 66 m^2) household heated by natural gas was only 2106.9 kg which is less than half as it would be in case of household with almost the same area heated by firewood. If we compared the CO_2-emission of 13 No. (heated area: 100 m^2) heated by firewood with 25 No. (heated area: 100 m^2) household heated by natural gas, we can see that the wood-fired household emitted more than three times CO_2 into the

Table 1. The significant combustion technology characteristics of arboreal biomass (Source: Hutkainé et al. 2013)

Biomass	Elemental composition (m/m %)					Heating value (MJ/kg)	Ash (%m/m)	Volatile (%m/m)
	C	H	O	N	S			
Tree	47	6.3	46	0.16	0.02	18.5	0.5	85
Tree bark	47	5.4	40	0.4	0.06	16.2	7.2	76

Table 2. CO_2-emissions of households heated by firewood in 2011/2012 heating season

Home	Heated area (m^2)	Heated volume (m^3)	Conbusted wood (kg)	CO_2-emmission (kg)	CO_2 (kg)/ person	CO_2/volume (kg/m^3)
12.	70	196	4000	4800	1600	20
13.	100	275	8000	7360	3680	30
17.	138	372.6	15000	18170	4540	50
20.	80	232	15000	14280	3570	60
Average	97	268.9	10500	11152.5	3347.5	40

Table 3. CO_2-emissions of households heated by natural gas in 2011/2012 heating season

Home	Heated area (m^2)	Heated volume (m^3)	Conbusted wood (kg)	CO_2-emmission (kg)	CO_2 (kg)/ person	CO_2/volume (kg/m^3)
24.	66	178.2	1187	2106.9	526.72	10.11
25.	100	270	1353	2401.6	600.40	8.89
28.	130	351	232	4139.3	885.5	10.9
29	87	234.9	1821.9	3233.9	1616.95	11.77
Average	95.75	258.52	1673.47	2970.42	907.39	10.42

Table 4. Changes in CO_2 balance of households heated by firewood depending on the forest area

Home	CO_2 - emission	Forest area (ha)	Absorbed CO_2 (kg)	CO_2 balance (kg)
13.	7360	0.25	1830	5530
17.	18170	3.2	23460	-5290
20.	14280	1.2	8800	5480
Average	13270	1.55	11363.3	1906.6

atmosphere than gas-fired household.

The CO_2-emission of 17 No. household was 18170 kg. However, the 28 No. gas-fired household, which has similar heated area, got into 4139.3 kg CO_2. Thus, the household heated by firewood emitted into the atmosphere four times more CO_2, than the household heated by natural gas. If we compared the 20 No. wood-heated household with 29 No. gas fired household, we can get similar results.

According to the data we clearly state, significantly less CO_2 was emitted into the atmosphere by the gas-fired household, than wood-fired household. If we consider the CO_2 absorbing capacity of forest area of households heated by firewood, we can state the CO_2-balance of wood-fired households change. Each household has forest area, except 12 No. household. The 13 No. household has 0.25 hectare, the 17 No. has 3.2 hectare, the 20 No. has 1.2 hectare forest area.

The CO_2-emission of 13 No. household decreased by 1830 kg considering the CO_2 absorbing capacity of forest area (0.25 hectare) belonging to the households. If we consider again the 13 No. wood fired with the 25 gas-fired household, we can see that the wood-fired household gets into the air still twice more CO_2.

Since the 17 No. household has 3.2 hectare forest, which has absorbed 23460 kg CO_2, thus the total emission of household was absorbed, even it is able to absorb further 5290 kg CO_2.

The 20 No. household has 1.2 hectare forest area, which is able to absorb 8800 kg CO_2, thus the CO_2-balance of household decreased by 5480 kg. If we compare the emission of the 20 No. household with the emission of 29 No. household, it can be stated one and a half times more CO_2 gets into the air during wood heating.

The four selected wood-fired households got into the air 44610 kg CO_2. If we consider the CO_2 absorbing capacity of forest area belonging to households, then this amount is significantly reduced, as according to my calculation 4.65 hectare forest area was able to absorb 34090 kg CO_2. Thus the CO_2-emission of households heated by firewood reduced by 10520 kg.

The CO_2-emission of four gas-fired households was 11881.7 kg.

4. Discussion

In the carbon cycle, forests help to slow down the build-up of atmospheric CO_2 by absorbing GHG, thereby mitigating climate change (Xiaozhi et al. 2012). Forests are linked to climate change in several important ways. For example, forest destruction and degradation result in increased CO_2 emissions, contributing to climate change (Canadell et al. 2007). Forests can also capture large amounts of CO_2 from the atmosphere and store carbon in living trees, litter, soils, and forest products (Powers et al. 2011). In these instances, forests can act to mitigate climate change and forests are thus affected by climate change (Pete et al. 2013).

One of the main arguments of the plant (wood based) biomass utilization is that it emits less GHG compared to the fossil fuels. It is considered that the combustion of biomass is CO_2 neutral, since in this case they emit into the air just as much CO_2 as they absorb during their life cycle (Hutkainé et. al. 2013).

My aim was to compare CO_2-emissions of households heated by natural gas and firewood, which have similar heated area and cubic meter of air, considering the carbon dioxide absorbing of forests of the households heated by firewood.

If we locally examine CO_2-emission and absorbing connected to heating, it can be stated these two are in balance. As CO_2, which was gotten into the air by biomass combustion, was absorbed by forest area of households wholly or partly. However, if we examine the whole atmosphere, it can be concluded that every burned wood increases the CO_2 content of air, as the CO_2 adsorption capacity decreases globally due to the deforestation. Forests absorb CO_2 from the atmosphere as they grow, incorporating the carbon into organic matter, and return carbon to the atmosphere via vegetation respiration, decomposition or combustion (Morony 2013). However, during the natural gas combustion, plus carbon-dioxide is gotten into the air.

Acknowledgement

This research was supported by the European Union and the State of Hungary, co-financed by the European Social Fund in the framework of TÁMOP-4.2.4.A/ 2-11/1-2012-0001 'National Excellence Program'.

5. References

Börjesson, P. (2008): Bioenergy systems—which are the most efficient? In B. Johansson (ed). Bioenergy—for what and how much? Stockholm: Forskningsradet Formas. ISBN 978-91-540-6006-1. pp. 133–148.

Canadell, J. G. – Le, Quere, C. – Raupach, M. R. – Field, C. B. – Buitenhuis, E. T., Ciais, P. – Conway, T. J. –Gillett, N. P. – Houghton, R. A. – Marland, G. (2007): Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. Proc Natl Acad Sci USA. 104:18866–18870.

Dinya, L. (2010): Biomassza alapú energiatermelés és fenntartaható energiagazdálkodás. Biomass-based energy production and sustainable energy management (in Hungarian). Magyar Tudomány, A Magyar Tudományos Akadémia folyóirata. http://www.matud.iif.hu/2010/08/03.htm (downloaded in 2013)

Energy Centre Nonprofit Ldt. (2008): Háztartási energiafogyasztás energiafajtánként hőmennyiségben. Household energy consumption by energy resources in heat quantity (in Hungarian). Internetes kiadvány. ISBN 978-963-235-284-8. 33 p. http://www.ksh.hu/docs/hun/xftp/idoszaki/pdf/haztartenergia08.pdf (downloaded in 2013)

Eriksson, H. – Hall, J. – Helynen, S. (2002): Rationale for forest energy production. In: J. Richardson, R. Bjo¨rheden, P. Hakkila, A. T. Lowe & C. T. Smith (eds.), Bioenergy from sustainable forestry: Guiding principles and practice, pp. 1-17, The Netherlands: Kluwer Academic Publishers.

Energy Roadmap 2050 (2011): Impact assessment and scenario analysis. Europen Commission. Brusseles. http://ec.europa.eu/energy/energy2020/roadmap/doc/roadmap2050_ia_20120430_en.pdf (downloaded in 2013)

FAO 2006. Global Forest Resources Assessment (2005): Rome: Food and Agricultural Organization of the United Nations. 378 p. http://www.fao.org/docrep/008/a0400e/a0400e00.htm (downloaded in 2013)

Gyulai, I. (2009): A biomassza-dilemma. The biomass dilemma (in Hungarian). Magyar természetvédők szövetsége. Budapest. ISBN-10: 963-86870-8-8, ISBN-13: 978-963-86870-8-1. 72 p. http://www.mtvsz.hu/dynamic/biomassza-dilemma2.pdf (downloaded in 2014)

Hutkainé Göndör, Zs. – Koós, T. – Szűcs, I. (2013): Faalapú biomassza energiacélú hasznosításának globális és helyi levegőkörnyezeti hatásai. Local and global air-environmental impact of utilization of wood-based biomass for energy purposes (in Hungarian). Anyagmérnöki tudományok, 38: (1) (2013), pp. 137-146. http://www.matarka.hu/koz/ISSN_2063-6784/38k_1_2013/ISSN_2063-6784_38k_1_2013_137-146.pdf (downloaded in 2013)

IEA (International Energy Agency). Newsroom and Events 24 May 2012. www.iea.org/newsroomandevents/news/2012/may/name,27216, en.html; 2012 (downloaded in 2012)

IEA (International Energy Agency) (2012): CO_2 emissions from fuel combustion p. 126 http://www.iea.org/publications/freepublications/publication/CO2emisionfromfuelcombustionHIGHLIGHTS.pdf (downloaded in 2013)

Kerényi, A. – Szabó, Gy. (1999): Main Environmental Problems in East Central Europe with Special Reflect to Hungary - Papers of the 3rd Moravian Geographical Conference CONGEO '99, Slavkov u Brna, Czech Republic Sept. 6-10. pp. 111-118.

Kerényi, A. – Szabó, Gy. – Fazekas, I. – Szabó, Sz. (2003): Környezeti problémák és megoldási lehetőségek – A Tisza és vízrendszere II. kötet. Environmental problems and possible solutions - The Tisza and its water system II. volume (in Hungarian) – szerk. Telpák I., MTA Társadalomkutató Központ, Budapest, pp. 179-202.

Magyar Energetikai és Közműszabályozási Hivatal. Hungarian Energy and Utilities Regulatory Authority (in Hungarian) homepage http://www.mekh.hu

Manomet Center for Conservation Sciences. (2010): Massachusetts Biomass Sustainability and Carbon Policy Study: Report to the Commonwealth of Massachusetts Department of Energy Resources. T. Walker (ed.). Natural Capital Initiative Report NCI-2010-03, Brunswick, ME.

Morony, M. T. (2013): Simple models of the role of forests and wood products in greenhouse gas mitigation, Australian Forestry, 76: (1) pp. 50-57.

Paládi, M. – Szabó, Sz. – Megyeri-Runyó, A. – Kerényi, A. (2014): Determination of CO_2-emission in the case of country houses heated by firewood. Carpathian Journal of Earth and Environmental Sciences. ISSN: 1842-4090) 9: (1) pp. 199-208.

Paré, D. – Bernier, P. – Thiffault, E. – Titus, B.D. (2011): The potential of forest biomass as an energy supply for Canada. The Forestry Chronicle 87(1):71-76.

Pete, B. – Jacek S. – Krista, M. (2013): Forest management planning technology issues posed by climate change, Forest Science and Technology, 9: (1), 9-19.

Peters, G. P. – Marland G. – Le Quéré, C. – Boden, T. – Canadell, J. G. – Raupach, M. R. (2011): Rapid growth in CO_2 emissions after the 2008–2009 global financial crisis. Nature Climate Change. Published online 4 December 2011 doi:10.1038/nclimate1332 (2, 2–4, 2012).

Powers, M. – Kolka, R. – Palik, B. – McDonald, R. – Jurgensen, M. (2011): Long-term management impacts on carbon storage in Lake States forests. Forest Ecol Manag. 262: 424–431.

Atkins, P. W. (2002): Fizikai kémia. I. kötet. Physical chemistry. Volume I. (in Hungarian) Nemzeti tankönyvkiadó, Budapest. 360 p.

Raymer, A. K. P. (2006): A comparison of avoided greenhouse gas emissions when using different kinds of wood energy. Biomass and Bioenergy, 30, 605-617.

Szabó, Gy. (2002): A globális klímaváltozás – a XXI. század kihívása. Global climate change - The challenge of the XXI. century (in Hungarian) – Debreceni Szemle, X. évf. 4. sz. pp. 599-613.

Szemmelveiszné Hodvogner, K. (1998): Energiahordozók. Energy resources (in Hungarian). Miskolci Egyetem, p. 256.

Tamás, A. – Szabó, Gy. (2001): Nemzetközi egyezményekkel a globális klímaváltozás ellen. International agreements against global climate change (in Hungarian). A földrajz tanítása. MOZAIK Oktatási Stúdió, Szeged, IX. évf. 4. sz. pp. 21-24.

Xiaozhi (Jeff), C. – Mihyun S. – Youn Yeo, C. (2012): An exploratory study on forest carbon markets in Asia In: Forest Science and Technology 8: (1) pp. 34-37.

Zboray, N. – Szalai, Z. (2012): Quantitative determination of soil organic matter (comparative study) (in Hungarian) In: Horvath, E.; Mari, L. (eds.) Research on Physical Geography in Hungary in the XXIth century, Institute of Geosciences, ELTE TTK, Budapest, pp. 163-168.