Greenhouse Gas Emissions by Cooking With Different Fuels and the Reduction Potential of Solar Cookers

- Preprint -
13/09/2002

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Abstract

Available data on greenhouse gas (GHG) emission by the use of fuelwood and other cooking fuels are compiled.

"Meal portion" analysis, based directly on experimental data, shows that per capita GHG emissions are lowest for biogas, followed by agricultural waste, LPG, Kerosene and dung, whereas electricity and wood cause the highest GHG emissions.

On the average, close to 50% of the CO_2 emitted by fuelwood for cooking is recycled by plant growth.

Non-CO_2 GHG emissions (represented by CH_4 and N_2O) cause an important part of emissions by fuelwood, agricultural waste and dung.

The use of a solar cooker can avoid the emission of several tons of CO_2 equivalent during its useful life, at costs largely covered by monetary fuel savings.

The global GHG emissions by the use of fuel for cooking are in the order of 5% of the estimated emissions by all human activities world-wide.

Keywords:
GHG emissions, CO_2 , cooking fuels, fuelwood, solar cookers, "meal portion" approach.

1. Introduction

Cooking is one of the foremost energy uses world-wide and causes important greenhouse gas (GHG) emissions. The quantification of these emissions is a central prerequisite for corrective action such as CDM project implementation and monitoring and emission trading in the sense of the Kyoto Protocol.

Different cooking energy carriers and their specific stoves cause different emissions, in CO_2 as well as in other GHG. Thus, the reduction potential for GHG emission by the use of solar cookers depends on the type of energy which is being replaced. The different cooking energy carriers discussed here are fuelwood, biogas, agricultural waste and dung, fossil fuels (kerosene, LPG), as well as electricity.

The present work has been conducted in the framework of the solar cooker pilot program which includes a comparative field test of solar cookers, jointly supported by the Governments of South Africa and Germany and carried out by DME (Department of Minerals and Energy) and GTZ (Gesellschaft für technische Zusammenarbeit).

2. Methodology

2.1 Fuel consumption and GHG emissions per meal portion

In general, the precision of figures on fuel consumption and GHG emissions by cooking is limited by the precision of available data on use rates and fuel consumption rates of different cooking appliances. This applies in particular for global consumption and emission figures which makes the quantitative comparison of different cooking technologies difficult.

An important gain in precision can be reached by using per-capita data and by dropping the reference to time where it is not needed. Thus, a “meal portion” method is applied, i.e. the analysis of fuel consumption per capita and per cooked meal (as an example, 2 meals for 4 persons count as 8 meal portions).

The logic of this “meal portion”- approach has been presented in DME/GTZ (2002) and used for payback calculations: it is based on the fact that solar cookers only save energy (and avoid GHG emissions) when they are used; and when they are used successfully, they save all of the fuel which would have been necessary to cook the same meal on another stove. Results of this approach are not expressed as a function of time, but of the number of meal portions (hence the name of the method). The advantage of the method is that it does not need any assumptions on use rates or fuel savings – notoriously unreliable and/or hard to obtain.

2.2 From fuel consumption to GHG emissions

Following Smith et al (2000), the analysis is based on the energy delivered to the pot per meal portion (coded *Edel* in eq.1 below), using the same value for all energy carriers. On the basis of experimental overall efficiency values (coded *Ef*), emission factors (*Efact*) and global warming potential (*GWP*) values, (Smith et al, 2000, Klingshirn, 2002, RWEDP, 2000), one obtains emission values (***Emv,*** in CO_2 equivalent) for each GHG and each energy carrier:

$$Emv = Edel * Efact * Ef * GWP \qquad (1)$$

Furthermore, the same number of meal portions per capita and year is used for all energy carriers.

2.3 GHG emissions: CO_2 and non-CO_2 contributions

For the analysis of the GHG emission of fuels, it is important to distinguish between:

- CO_2 emissions which can be partly or completely recycled by plant growth, and
- non-CO_2 GHG emissions, caused by incomplete combustion, which cannot be recycled by plant growth.

The GHG emissions other than CO_2 are represented here by the two most important contributors, CH_4 and N_2O. They are expressed in mass CO_2 equivalent.

2.4 The CO_2 balance of bio-fuels

The CO_2 impact of the burning of biomass is a complex issue (Herold, 1998; WBGU, 1998). It is a common misunderstanding that only fossil fuels contribute to the rising level of CO_2 in the atmosphere. In this sense, the use of biomass for fuel is frequently characterized as CO_2-neutral. In fact, biomass use for fuel ***can*** be CO_2-neutral, but it ***is*** not always. Any change in stored carbon (e.g. in trees and other plants, but also in stored dead wood such as furniture) results in changes in the atmospheric CO_2 level. Three types of situations can be distinguished:

1. A net **CO_2 increase** is caused e.g. by clearing of forest with subsequent burning of the cleared wood. If the forest is replaced by agricultural use, part of the CO_2 increase is reversed; the same applies if primary forest is replaced by secondary forest containing typically 30 to 60% of the original C stock (WBGU, 1998). The burning (and the rotting) of dead wood also causes a net GHG increase.

2. A sustainably exploited forest where felled trees are burned, but continuously re-grown (and where the stored C remains constant) is **CO_2-neutral**, just as the clearing of forest where felled trees are not burned but durably used as building materials, furniture, etc.

3. A **decrease** of CO_2 can be expected in the case of a sustainably exploited forest where felled trees are not burned but used as building materials, etc.

It is clear that most of the fuelwood production in developing countries belongs to a type 1 situation above, i.e. causes a net increase in atmospheric CO_2 levels. This is particularly true for commercially cut fuelwood, since sustainable forest management is radically more expensive than clearing (although firm regulations and incentives can – in principle - tilt the balance the other way). On the other hand, a type 2 situation can be ascribed to the burning of "indirect wood" , i.e. residues from wood cut for other purposes, and particularly residues which would have been burned in any case.

Under these assumptions, the global consumption of fuelwood for cooking (coded *FWC*) can be divided in a direct part (*FWCD*: wood felled or harvested for cooking – only this direct part is assumed to cause a net increase of CO_2), and an indirect part (*FWCI*: by-products from wood cut for other purposes but used for cooking – this part is assumed to be CO_2-neutral):

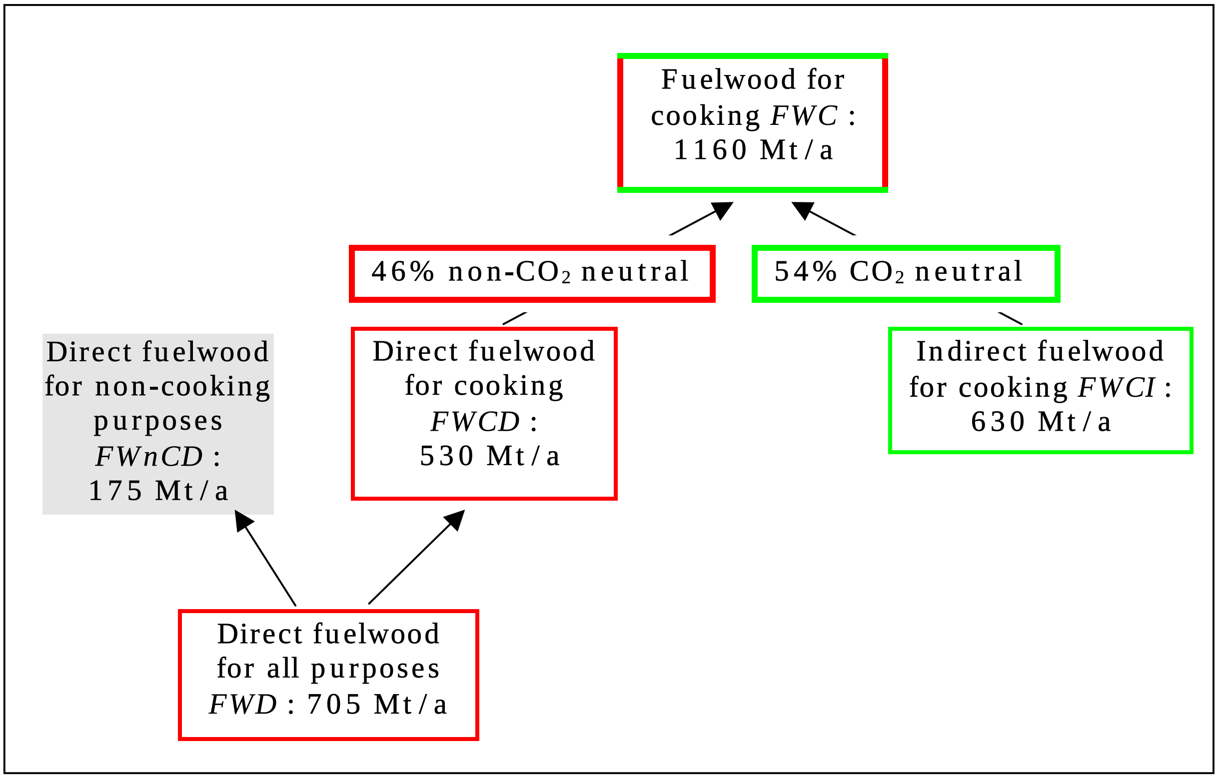
$$FWC = FWCD + FWCI \qquad (2)$$

This equation can be solved using available data (FAO, 1999): *FWC* is calculated by multiplying the number of fuelwood users with the per-capita consumption of fuelwood for cooking, whereas the direct production of fuelwood for cooking *FWCD* is obtained from the direct production of fuelwood *FWD* minus the direct fuelwood production for non-cooking purposes (such as process heat for craft and industry) *FWnCD*:

$$FWCD = FWD – FWnCD \qquad (3)$$

Figure 1 illustrates these categories. Under the given assumptions, close to 50% of the CO_2 emissions caused by fuelwood for cooking can be considered CO_2-neutral.

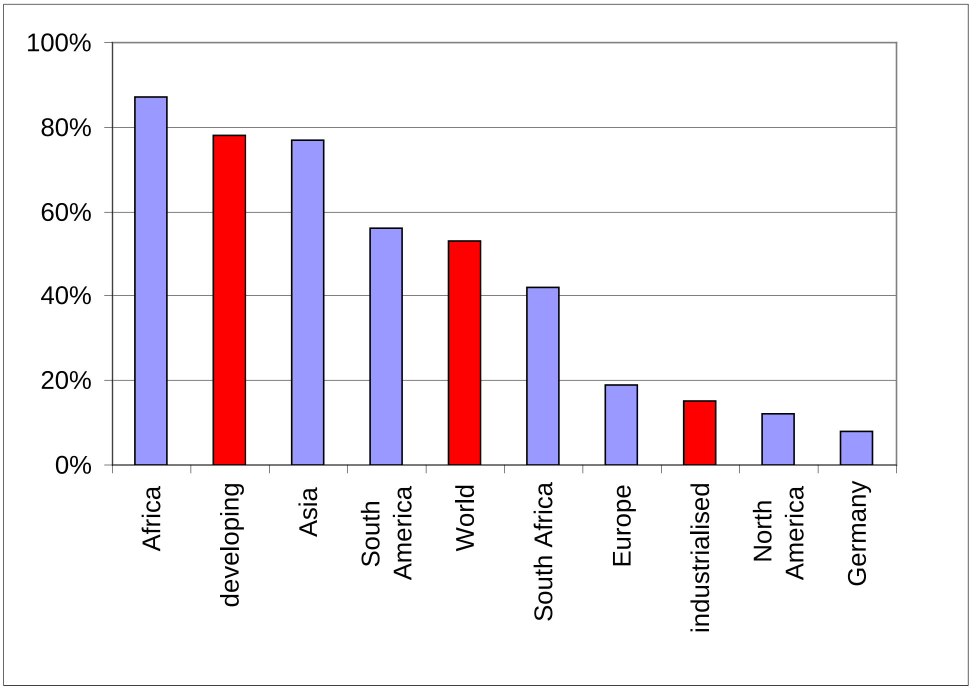
Fig.1: The different fuelwood categories in developing countries



Source: Synopsis (data by FAO, 1999)

As background information for this reasoning, Fig 2 gives an idea of the dominant position of direct fuelwood in the wood production in developing countries: almost 80% of all the wood produced is used as fuel; about 60% of all wood produced (75% of 80%) is used for cooking. Fuelwood, and in particular direct fuelwood for cooking, is by no means an obscure sub-product of some other, more important use mode. It is, in quantity and in value, the dominating use mode for wood in developing countries.

Figure 2: Percentage of direct fuelwood in the wood production of different countries / continents, and in developing and industrialized countries



Data source: FAO (1999)

2.5 The GHG emissions of non-wood biomass and fossil fuels

The GHG emissions of non-wood biomass are calculated for the burning of agricultural waste, dung, as well as for biogas, assuming complete recycling of CO_2. Non-CO_2 emissions are taken into account using the specific emission factors (Smith, 2000).

The emissions caused by the use of fossil fuels are calculated for LPG, kerosene, burned in the respective stoves (Smith, 2000). Electricity-caused emissions are represented by gas-fired power-plants (TSECO, 2002), taking into account the thermodynamic efficiency (the unavoidable losses of thermal power plants). In South Africa where most electricity is generated from coal, emissions will be significantly higher.

3. Results per meal portion

An overview of all results is shown in the Appendix. The details are discussed in the following section.

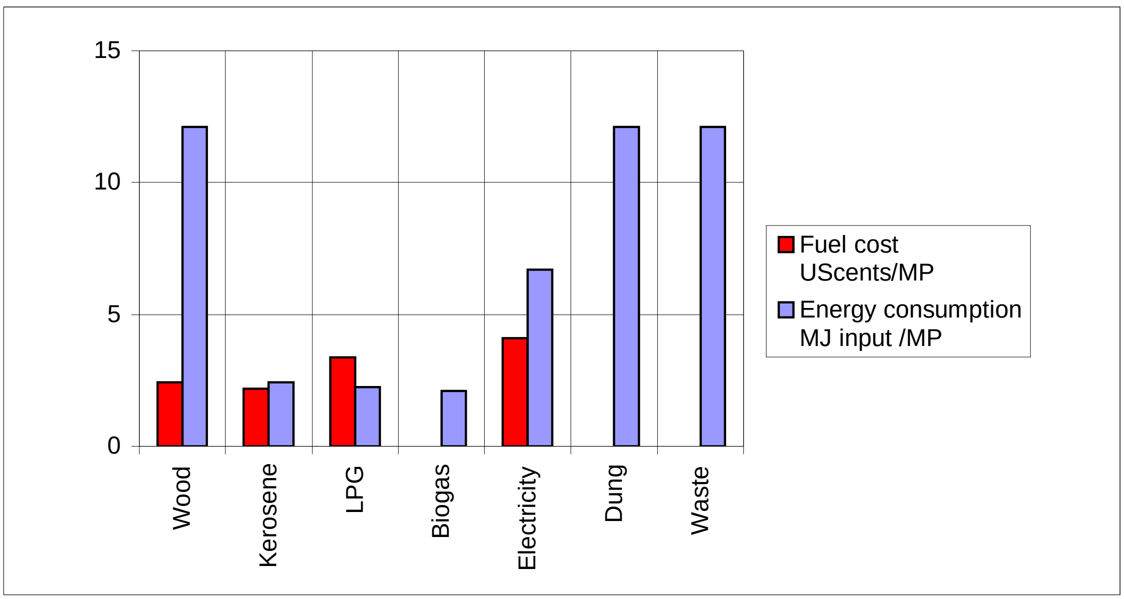
3.1 Cooking fuel consumption and cost

Figure 3 shows the fuel consumption and the fuel cost per meal portion.

Fuel consumption is highest for wood, waste, and dung, due to low thermal efficiency of the stoves in use.

Monetary fuel costs are highest for electricity, followed by LPG, (bought) wood, kerosene, and nil for collected fuels.

Figure 3

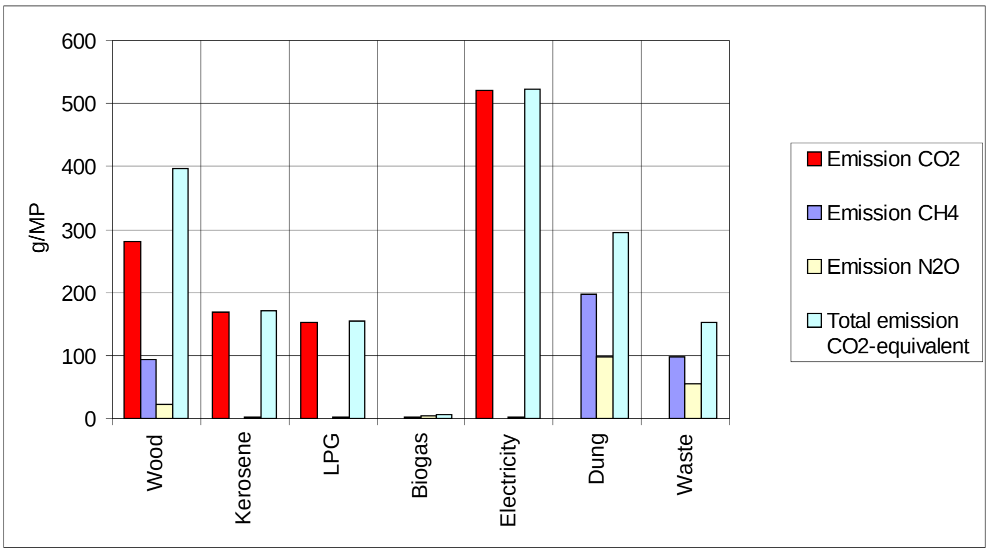


3.2 GHG emissions

Figure 4 shows the GHG emissions caused by the different fuels, for CO_2, non-CO_2 and total in g CO_2 equivalent per meal portion. CO_2 emissions are highest in electricity and wood (due to low energetic efficiency and a - partly or completely - non-sustainable CO_2 balance), non-CO_2 emissions are highest for incomplete combustion of dung, waste and wood.

Only biogas combines high energetic and combustion efficiency with a sustainable CO_2 balance which results in very low emission values. It can be added that a biogas leak of 0.1% (1 liter getting lost for each m^3 of gas) roughly doubles biogas GHG emissions.

Figure 4



4. The GHG-emission- and economic impact potential of solar cookers

The different impacts of solar cooker use depend on 2 types of issues:

- Cooker- and user-specific issues, such as its durability, use rate, capacity, and user household size

- The characteristics of the stove which would have been used instead of the solar cooker.

4.1 Meal-portion results

To avoid the uncertainty in determination of the use rate, the analysis follows again the meal-portion approach.

Table 3 shows that:

- the average avoided GHG emission per meal portion prepared by solar instead of wood is in the order of 400 g; e.g. a meal for 5 prepared on a solar cooker avoids the emission of 2 kg of CO_2 equivalent

- for the replacement of electricity, the emission impact is of similar magnitude, while the replacement of kerosene, LPG, dung and waste is less effective, and nil for the replacement of biogas

- The monetary fuel savings of a solar cooker per meal portion are in the order of 2 to 4 UScents for electricity, (bought) wood, coal, kerosene and LPG (and nil for the non-commercial fuels)

- The break-even (or pay-back) number of meal-portions (MP) per $ retail price is in the order of 25 MP for electricity and 30 to 45 MP for LPG, wood and kerosene: if the cooker (during its entire useful life, until it is discarded) is used for less than these 25 to 45 MP per $ of price, it causes a financial loss for the user (in this case, the GHG reduction actually has a financial cost); if it is used more, the user makes a profit and the GHG reduction comes for free.

Table 3

Solar stove avoided GHG emissions and avoided fuel costs by replacement of…	**Wood**	**Kerosene**	**LPG**	**Biogas**	**Electricity**	**Dung**	**Waste**
Avoided GHG emissions g CO2 eq. per MP	397	171	155	6	522	295	153
Avoided fuel cost UScents per MP	2,4	2,2	3,4	0	4,1	0	0
Break-even number of solar MP per $ retail price	41,7	45,5	29,4	-	24,4	-	-

It should be noted again that the meal portion results do not need any assumptions concerning solar cooker use rates and useful life. The statement is simply that a solar cooker whenever it is used to prepare a number x of meal portions, saves x times 0.4 kg of GHG emissions (and x times 2.4 UScents in fuel expenses) which would have occurred using woodfuel. This clearly implies that no savings occur if the solar cooker is not used.

4.2 Per solar cooker results: minimum requirements

Figure 5 shows the dependence of costs of fuel and avoided GHG emissions for a solar cooker with an assumed retail price of $35, in particular:

- The difference between cooker price and monetary fuel savings showing a linear decrease; the break-even point is reached at 1500 MP
- The asymptotically decreasing cost per ton of avoided GHG emission, for commercial fuelwood (break-even 1500 MP), for collected fuelwood with a "shadow cost" of 50% (break-even 3000 MP), and for wood collected rated at zero monetary value.

Figure 5

The more detailed emission and cost results for the same solar cooker are given in Table 4.

Table 4

	Wood	Kerosene	LPG	Biogas	Electricity	Dung	Waste	Comments
Break-even number of solar MP per $ retail pric	41	46	30	-	24	-	-	
Break-even MP at $35 retail price	1446	1607	1034	-	851	-	-	mass production retail price
Assumption for household size cap	8,7							FTSA average large families
Life cycle years	5							assumption
Number of solar cooked MP/a, cap	244							based on FTSA results
Average number of MP per solar cooker	10594							
Total emission t CO2-equivalent	4,2	1,8	1,6	0,062	5,5	3,1	1,6	
Cost per avoided t CO2 (except fuel cost) $	8,3	19	21	563	6	11	22	
Avoided fuel cost during solar cooker life cycle $	256	231	359	0	436	0	0	

Under the given assumptions, a solar cooker, during its life cycle of 5 years, replacing wood, avoids 4 t of GHG. The related cost, $8 per avoided t, is a small fraction of the savings in fuel.

In terms of GHG emission, the replacement of electricity is most effective, followed by wood and dung; the – very low – biogas emisions are very expensive to avoid. Concerning cost savings, the replacement of electricity by solar cooking takes first place, followed by LPG, wood and Kerosene.

It should be noted that these results depend on assumptions on household size, cooker price, use frequency and useful life, and are, therefore, less reliable than the MP data.

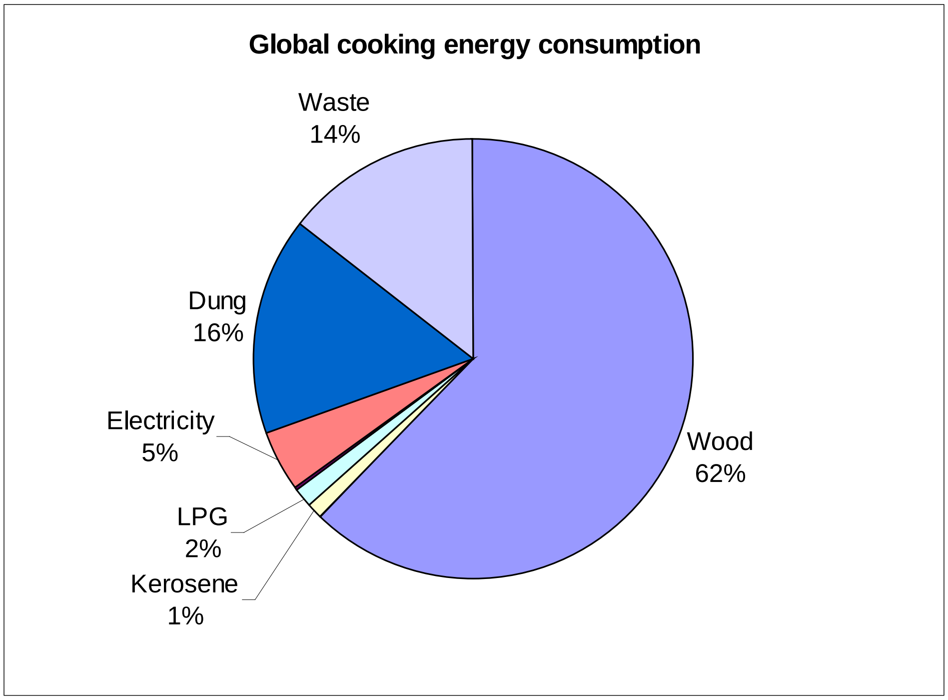
5. Estimations of global figures

The following global figures rest on the assumption that each fuel type is used by an estimated number of users (for details see Appendix). No multiple fuel use has been included. This, again, results in high error margins in the results.

5.1 Global cooking fuel consumption

As Fig 6 shows, over 90% of the cooking energy consumption world-wide comes from biomass, and 2/3 from wood.

Figure 6



In absolute terms, the daily fuelwood consumption for cooking is in the order of 7 million m^3 which corresponds to a container train of 1000 km length.

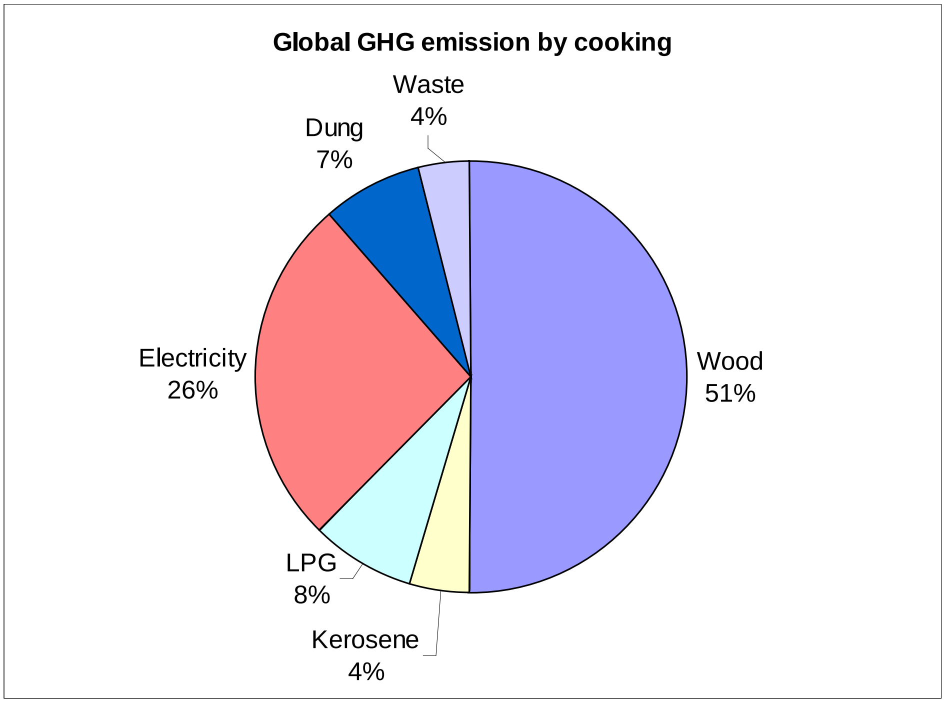
This preponderance of biomass is due to several factors:

- There are more biomass users than fossil fuel users
- The energy content of biomass is lower than the energy content of fossil fuels
- The energy efficiency of the traditional ways to cook with biomass is lower than the efficiency of fossil fuel stoves. In the case of electric cooking, the Carnot losses (waste heat at thermal power-plants) divide by 3 the overall efficiency of electric stoves.

5.2 Global GHG emissions by cooking

The global GHG emission by different cooking fuel types are shown in Fig 7.

Figure 7



Again, the major GHG contribution is caused by biomass, although to a lesser extent than in the case of fuel consumption (Fig 6), since all of the gas and electricity, but only part of the biomass use is non-sustainable.

The consumption and GHG emissions by fuel type are shown in Table 5.

Table 5

Global estimates		**Wood**	**Kerosene**	**LPG**	**Biogas**	**Electricity**	**Dung**	**Waste**
Number of users	millions	2500	500	1000	50	1000	500	500
Global consumption per fuel	million t/a	1190	17	29	4	88	305	266
Global emissions CO2 by fuel	million t/a CO2 equivalent	416	50	91	0	309	0	0
Global emissions non-CO2 by fuel	million t/a CO2 equivalent	174	0,5	1,3	0,2	1,3	88	45
Global emissions by fuel	million t/a CO2 equivalent	589	51	92	0,2	310	88	45
Global emissions all fuels	million t/a CO2 equivalent	**1175**						

The total GHG emissions by cooking represent roughly 5% of all GHG emissions caused by human activities and are in the order of the emissions of the US transport sector.

Overall, users of fuelwood for cooking accumulate the drawbacks in comparison to users of fossil fuels: wood is bulkier, less practical and – if it is bought – almost as expensive as gas. Moreover, it causes higher indoor air pollution and higher GHG emissions than all carriers except electricity.

Conclusions

Globally, close to 50% of the CO_2-emissions caused by the burning of wood for cooking are not recycled by plant growth and contribute to global warming.

Per capita greenhouse gas (GHG) emissions by the use of fuel for cooking are highest for electricity, followed by wood, kerosene and LPG. Thus, from a GHG point of view, low- or zero-emission stoves should replace in priority wood and electric stoves.

As for the GHG reduction potential of solar cookers, the “meal portion” approach, using a reduced set of assumptions based on experimental data, shows that solar cookers avoid the emission of up to 0.5 kg of CO_2-equivalent per meal portion.

In order to pay for themselves by fuel savings, solar cookers have to be used to prepare at least 25 to 40 meal portions per $ cooker retail price.

During the useful life of a solar cooker, up to 5 tons of avoided GHG emission can be expected.

The cost per avoided ton of GHG emission is estimated at $8, for the replacement of collected wood rated at zero monetary value; for commercial energy carriers, the costs are largely inferior to fuel savings.

Finally, global GHG emissions by cooking are in the order of 5% of the estimated emissions by all human-caused sources world-wide, or equivalent to the total GHG emissions by the US transport sector. The majority of these emissions is caused by the use of fuelwood.

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Acknowledgement

The authors are thankful for inputs from Hannelore Bergler, Eberhard Biermann, David Hancock, Agnes Klingshirn, Erica de Lange and Dieter Seifert.

APPENDIX: Compilation of input data and results

	Unit	Wood	Kerosene	LPG	Biogas	Electricity	Dung	Waste	References
Costs and emissions (MP values)									
Delivered energy per meal portion (Edel)	MJ delivered /MP	1,21							based on FTSA results
Emission factor (Efact) CO2	g/MJ del	502,8	140	126	142	430	885	777	Smith (2000), TSECO (2002)
Non-sustainable part of CO2 emission	%	46	100	100	0	100	0	0	this work
Sustainability corrected emission factor CO2	g/MJ del	231	140	126	0	430	0	0	
Emission factor CH4	g/MJ del	3,4	0,013	0,002	0,099	0,002	7,20	3,60	Smith (2000)
Emission factor N2O	g/MJ del	0,0652	0,0037	0,006	0,009	0,006	0,28	0,155	Smith (2000)
Global warming potential (gwp) CO2		1							Smith (2000)
gwp CH4		22,6							Smith (2000)
gwp N2O		290							Smith (2000)
Emission (Emv) CO2	g CO2/MP	280	169	152	0	520	0	0	
Emission CH4	g CO2 eq. / MP	94	0,4	0,1	2,7	0,1	197	98	
Emission N2O	g CO2 eq. / MP	23	1	2	3	2	98	54	
Total emission CO2-equivalent	g CO2 eq. / MP	397	171	155	6	522	295	153	
Number of cooked MP/a, cap	MP/a, cap	594							based on FTSA results
Fuel cost $/MJ input	$/MJ input	0,002	0,009	0,015	0	0,017	0	0	EDF (2002), GTZ-EM (2002)
Fuel cost $/MP	$/MP	0,024	0,022	0,034	0	0,041	0	0	
Overall efficiency (Ef)	%	10	50	53,6	57,4	18	10	10	Klingshirn (2002), REAP (2001), Smith (2000)
Combustion energy	MJ input /kg	15,1	43,12	45,5	17,7	45,5	11,8	13,03	REAP (2001), Smith (2000)
Energy consumption	MJ input /MP	12,1	2,4	2,26	2,1	6,7	12,1	12,1	
Solar cooker potential									
Break-even number of solar MP per $ retail price	MP/$	41,3	45,9	29,5	-	24,3	-	-	
Break-even MP at $35 retail price	MP	1446	1607	1034	-	851	-	-	mass production retail price assumption
Estimated household size		8,7							assumption (FTSA average large families)
Life cycle	a	5							assumption
Number of solar cooked MP/a, cap	MP/a, cap	244							based on FTSA results
Average number of MP per solar cooker	MP per solar cooker	10594							
Total emission CO2-equivalent	t	4,2	1,8	1,6	0,062	5,5	3,1	1,6	
Cost per avoided t CO2 (except fuel cost)	US$	8,3	19,3	21,4	563,3	6,3	11,2	21,6	
Avoided fuel cost during solar cooker life cycle	US$	256	231	359	0	436	0	0	
Global estimates									
Number of users (assumption)	millions	2500	500	1000	50	1000	500	500	assumption
Global consumption per fuel	million t/a	1190	17	29	4	88	305	276	
Global emissions CO2 by fuel	million t/a CO2 eq.	416	50	91	0	309	0	0	
Global emissions non-CO2 by fuel	million t/a CO2 eq.	174	0,5	1,3	0,17	1,3	88	45	
Global emissions by fuel	million t/a CO2 eq.	589	51	92	0,17	310	88	45	
Global emissions, all fuels	million t/a CO2 eq.	**1175**							

Note: assumptions are marked in yellow