Emission reductions and possible CO_2-bonuses obtainable by the use of solar cookers in Chadian families.

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The aim of this paper is to calculate the approximate amount of greenhouse (GHG) gases, that can be avoided by a Chadian family (family size is 5,3 persons on average) if it switches from wood or charcoal to solar cooking in 50 % of cooking procedures[1]. From a previous study [Krämer 2003], the consumption of wood – used either directly as fuel or indirectly as charcoal – was known to be about 1.04 kg/person/day, and 2011.9 kg per year for an average sized family. Many Chadian families consume both wood and charcoal, the relative share of each however varies between the extremes of nearly exclusive wood consumption and nearly exclusive charcoal consumption. The use of charcoal is increasing rapidly at the expense of wood. To facilitate calculations, I assume that the change from wood to charcoal does not affect the amount of final wood fuel energy consumed – 30112.5 MJ annually on average. This energy amount is equivalent to the above mentioned 2011.9 kg of fuel wood, and to 967,25 kg of charcoal (2,65 kg per day), if we take the conversion factors reported from Chad [The World Bank, HEP/SAR 1998] into account.

There is a lack of quantitative data from Chad on GHG emissions resulting from fuel wood and – more important – charcoal making and use. But such data are available from other countries, where charcoal plays an important role, for instance from Kenya. In both countries similar earth mound kilns are used. According to Kirk. R. Smith and co-workers [2001] their measurement results can be applied to other countries where similar conditions prevail, as long as there are no reliable country specific data.

Uncertainties about the efficiency of charcoaling in Chad

The emission data presented by Pennise et al. refer to the making of 1 kg charcoal. The stated that the amount of wood consumed in the process was 3,64 kg of dry wood, which corresponds to an efficiency (yield) of 27.47 % on a weight basis (in fact the yield of their 5 earth mound kilns varied from 0.216 to 0.342). The efficiency in Chad reported in the document HEP/SAR (World Bank 1998) is only 13 %. It is not easy to explain the difference. Probably several factors are at work. Humidity of wood may be an important factor. In Chad, itinerant gangs of wood cuuters and charcoalers felling trees do not wait until the wood becomes air-dry; they use "wet" wood, lowering the efficiency of the process. The work done by Pennise et. al. on the other hand was done under controlled conditions.

[1] A 50 % use frequency is reported by J.-P. Viala , Berlin, 1999. In Burkina Faso 55 % of fuel expenses were economised by using the Papillon cooker (personal communication by Dr. Bernd Hafner).

The size and construction of kilns, operating conditions and attendance also have to be taken into account. There is a need for studies on the emissions of charcoaling in Chad, but it is highly improbable that these studies will lead to lower emission figures than those obtained in Kenya by Pennise et al. [2001] and Smith et al. [1999].

Figures:

1 kg wood corresponds to	15 MJ*
1 kg charcoal corresponds to	30,8 MJ*
Efficiency of charcoaling in Chad (on a weight basis)[2]:	13 % (HEP/SAP, WB 1998).
Wood consumption (primary energy),	1,04 kg/Person/Tag
Carbon content of wood	44 %*
Carbon content of charcoal	75 %*
Mean family size in Chad[3]:	5,3 persons

Data with * are taken from: David M. Pennise, Kirk R. Smith: Emissions of greenhouse gases and other airborne pollutants from charcoal making in Kenya and Brazil", Journal of Geophysical Research – Atmosphere, 2001, 24143-24155, source: http://www.ehs.sph.berkeley.edu/krsmith/publications/01_pennise_1.pdf

Definition of Global Warming Commitment (GWC)

We might believe, that all carbon contained in the wood used for charcoal making goes either into charcoal or emissions. This is true, in a sense. But in emission calculations based on the Kyoto Protocol, particulate and liquid carbon emissions are excluded. The same is true of some gases, the Global Warming Potential of which is not well established. On the other hand, some intermediary products of combustion (Products if Incomplete Combustion, abbr. PIC)[4], though finally ending up as carbon dioxide after the end of their lifespan in the atmosphere, have a greater GWP than CO_2. To take account for these differences, the notion of Global Warming Commitment (GWC) has been coined.

The most important GHG is carbon dioxide (CO_2). It is therefore used as a standard. The greenhouse effect of other GHG can be related either to the whole molecule of CO_2, or to the carbon content of CO_2 (atomic weight of carbon divided by the molecular weight of carbon dioxide).

The GWC (Global Warming Commitment) is the contribution of a particular GHG to overall warming. Different GHGs are characterized on a molar basis by

[2] HEP/SAP, World Bank, 1998

[3] République du Tchad, Ministère du Plan et de l'Aménagement du Territoire : « Etat de la Population du Tchad en 1998 : Situation de la Femme », N'Djamena 1999

[4] In the case of modern biomasse use – as for instance in wood pellet appliances – these Products of Incomplete Combustion are collected and burnt. Therefore we have to distinguish strictly between traditional and modern biomass combustion.

their carbon content. If we multiply this carbon content with the specific Global Warming Potential, we obtain the Global Warming Commitment (GWC) of the gas in question. A shorthand notation for the GWC of a gas is C, followed by a hyphen and the chemical formula of the gas (for instance $C\text{-}CO_2$ for carbon dioxide and $C\text{-}CH_4$ for methane). For ease of understanding, a different notation is used here in parallel: $GWC_{carbondioxide}$ and $GWC_{methane}$.

To calculate the climate effect of a particular process involving different greenhouse gases, GWCs are summed up, leading to the Primary GWC and the Total GWC. The Primary GWC comprises the specific GWC of CO_2, CH_4 and N_2O. But $GWC_{dinitrogenoxide}$ (from N_2O) is not included here in accordance with Bailis et al. [2003], who argues: "Despite a large GWP on a molecular basis for N_2O, the nitrogen content of typical wood fuels is quite small and only trace amounts of nitrogenous species are released from the fuel itself. Further, the combustion temperatures of household biomass stoves are generally too low to react with atmospheric nitrogen in any appreciable way. Hence the contribution of N_2O to the GHG emissions and net global warming commitment (GWC) of household-scale wood fuel combustion is negligible … and its exclusion from this study does not affect our conclusions". We are left with:

Primary GWC = $GWC_{carbondioxide} + GWC_{methane} + GWC_{dinitrogenoxide}$

Total GWC includes Primary GWC and the GWC of other products of incomplete combustion (PICs, like TNMHC, that is Total Non-Methane Hydrocarbon Compounds), the GWP of which is less certain.

Sustainable and non-sustainable wood production.

With regard to renewability of wood resources, Pennise und Smith <u>consider two possible cases</u>, a) und b).

a) the resulting CO_2 is again bound up in vegetation (recycled, sustainable consumption);

b) the resulting CO_2 is not bound up in vegetation (unsustainable consumption).

If we assume that all the CO_2 set free during combustion of wood and in the charcoal cycle is bound up by new growth of vegetation, CO_2 can be omitted from the calculations. The GWC of Methane (and N_2O) has, however, a damaging effect on the climate even if the wood used is entirely replaced by new growth. This is due to the high GWP of Methane (56) and its relatively long lifetime of over 12 years. In this case the primary GWC would be 0,82 kg $C\text{-}CO_{2eq}$ (carbon of carbon dioxide equivalents) according to Pennise &. Smith [2001].

If CO_2 is not recycled (case b), the higher values of GWC – i.e. 1,35 for primary GWC and 2,58 for total GWC – are to be applied.

As one of the motives of solar cooker promotion is the aim to cut exploitation of forests down to sustainable levels, we are justified to use case b) for our calculation.

Sustainability or renewability of wood resources has to be defined in a geographical context, related to a nation or even a sub-national region. We have to be aware of the fact, that fuel wood is normally not traded across frontiers. Clearly, surplus wood in areas out of reach to the consumer is of no avail to him.

Case 1: only wood is consumed in the family.

Only emissions from open fireplaces are considered here, as only 4 % of the Chadian population use fuel-saving cook stoves [FAO 2004] and the emissions of an open three-stone fireplace are not very different from those of a fuel saving woodstove. Bailis et al., [2003], give the following emission factors per kg of fuel:

	Emission factors in g pollutant per kg fuel, according to Bailis et. al. [2003]			
	3-stone-fire	corresponding carbon content (C)	GWP (time horizon 20 years)	GWC
CO_2	1390 (± 19)	0,379 kg	1	0,379
CH_4	3,2 (± 1,5)	0,0024 kg	56[5]	0,1344
Primary GWC				0,5134

Tab. 1: Emission factors for CO_2 and methane, in kg of pollutant per kg of fuel, standard deviations in brackets, [extracted from Bailis et al., 2003, Tab 8]. The last three columns are my addition. The carbon content of CO_2 emissions is obtained by multiplying the emission factor with the weight share of carbon in the CO_2 molecule (0.2727). The carbon content of CH_4 emissions is obtained likewise by multiplication of the emission factor of CH_4 with the weight share of carbon in CH_4.

The GWC of methane in the last column is obtained by multiplication of the amount emitted with the GWP of methane (56).

Case a) Sustainable wood production: In this case $GWC_{carbondioxide}$ may be left out, and $GWC_{methane}$ is the culprit. The value of 0.1344 kg has to be multiplied with the amount of fuel wood consumed annually by our family, namely 2011,88 kg. **The Primary GWC is 270,4 kg, corresponding to 991,28 CO_{2eq}.**

Case b) Unsustainable wood production: The Primary GWC for 1 kg of fuel wood is $GWC_{carbondioxide}$ + $GWC_{methane}$ = 0,5134 kg. If we multiply this value

5 See „Greenhouse Gas inventory Data / Global Warming Potentials, source http://ghg.unfccc.int/gwp.html .

with the annual fuel wood consumption of 2011,88 we obtain a **Primary GWC of 1032,9 kg** corresponding to 3786,6 kg CO_{2eq}.

The energy obtained is 30 112,5 MJ. If 50 % of this amount of energy were obtained by using the solar cooker, the emissions would be halved:

In case a) Primary GWC of 135,2 kg corresponding to 495,64 kg CO_{2eq}

In case b) Primary GWC of 515.33 kg corresponding to 1889,2 kg CO_{2eq} would be avoided.

Case 2: only charcoal is consumed in the family.

If we assume that shifting from wood to charcoal does not affect the amount of energy consumed, the consumption is equally 30 112,5 MJ. This corresponds to 977,68 kg of charcoal.

Unlike fuel wood, charcoal use implies two phases, during which emissions occur, production and consumption.

Gas emissions in GWC during the making of 1 kg of charcoal [Pennise et al., 2001]:
0,49 kg CO_2-C (i.e. $GWC_{carbondioxide}$)
0,099 kg CO-C ($GWC_{carbonmonoxide}$)
0,036 kg CH_4-C ($GWC_{methane}$)
0,066 kg TNMOC-C (GWC of Total Non-Methane Organic Compounds)
0,00015 kg N_20 ($GWC_{dinitrogenoxide}$)

Apart from these compounds, there are other organic carbon containing gases, particles and liquids (condensates) produced during the manufacture of charcoal, which enter into the category of total GWC.

Primary GWC:	0,82 kg if CO_2 is recycled by trees (case a)
Total GWC:	1,89 kg if CO_2 is recycled by trees (case a)
Primary GWC:	1,35 kg if there is no recycling of CO_2 by trees (case b)
Total GWC:	2,58 kg if there is no recycling of CO_2 by trees (case b)

In tables 2 und 3 these results are applied to the charcoal consumption of a family consisting of 5,3 persons, assuming exclusive use of charcoal for fuel. The effect of the use of a solar cooker in 50 % of cooking procedures is also calculated.

	Global Warming Capacity (GWC)	GWC in kg emitted per kg of charcoal produced, [Pennise et al., 2001],	GWC in kg emitted annually by using of 2.65 kg charcoal daily (CO_2-values in parenthesis)	Reduction of GWC when using the solar in 50 % of cooking procedures (CO_2-values in parenthesis)
Charcoal-making	Primary GWC	0,82 kg,	793,15 kg (2907,69 kg)	396,57 kg (1453,83 kg)
	Total GWC	1,89 kg	1828,10 kg (6701,81 kg)	914 kg (3351 kg)

Table 2: case a). The amount of CO_2 set free during production of charcoal is again bound up by trees (sustainable wood consumption). Annual emissions are calculated for an average Chadian family of 5,3 persons. Corresponding CO_2 values in brackets.

	Global Warming Capacity (GWC)	GWC in kg emitted per kg of charcoal produced, [Pennise et al., 2001],	GWC in kg emitted per year by a household of 5,3 persons, (CO_2-values in parenthesis)	Reduction of emissions when using the solar in 50 % of cooking procedures, (CO_2-values in parenthesis)
Charcoal-making	Primary GWC	1,35 kg,	1305,7 kg, (4786,7 kg)	652,85 kg (2393,35 kg)
	Total GWC	2,58 kg	2495,5 kg, (9148,5 kg)	1247,75 kg, (4574,25 kg)

Table 3: case b). The amount of CO_2 set free during production is not bound up by new growth (unsustainable wood consumption). Annual emissions are calculated for an average Chadian family of 5,3 persons. Corresponding CO_2 values in brackets.

Emissions during charcoal use:

Bailis et. al. [2003, p.15] estimate that 0,8 kg Primary GWC are emitted during combustion of 1 kg of charcoal. Our average Chadian family causes thus annual emissions of 0,8 x 967,25 kg = 773,8 kg carbon equivalents by the daily use of 2,65 kg of charcoal. This quantity corresponds 2836,75 kg CO_2.

Emissions of the entire charcoal cycle:

To calculate the GWC of the entire charcoal cycle for our average family, we have to sum up the GWC of charcoal production and charcoal use:

Primary $GWC_{sustainable}$: 793,15 kg + 773,8 kg = 1566.95 kg,

corresponding to 5744,44 kg of CO_2

Primary $GWC_{unsustainable}$: 1305,7 + 725,4 = 2031,1 kg

corresponding to 7446,01 CO_2.

Total $GWC_{sustainable}$: 1828,10 kg + 773.8 =2601.9 kg,

corresponding to 9538,57 kg CO_2

Total $GWC_{unsustainable}$: 2495,5 +773.8 = 3269,3 kg

corresponding to 11985,25 CO_{2}.

As explained earlier, the solar cookers are intended to replace the unsustainable part of wood consumption. This means that we are dealing with case b).

Case 3: A solar cooker is used :

Because of weather constraints, the solar cooker cannot be used every day. Here we assume that it is used in 1 out of 2 cooking procedures. Therefore a second energy source is necessary. This will normally be wood fuel (wood or charcoal). On the other hand, within the limits of the power output limit (in the case of the Papillon this is 1 kW) there are no limitations to energy consumption, leaving energy available for small scale commercial activities. Many Chadian household use both wood and charcoal.

The quantity of emissions avoided by the use of the solar cooker depend on the relative shares of wood and charcoal before substitution and on the frequency of use of the cooker.

If 50 % of the emissions which occurred in the charcoal cycle prior to the use of the solar cooker can be avoided by switching to solar cooking, the emissions could be diminished by:

Primary $GWC_{sustainable}$: 783.48 kg,

corresponding to 2872 kg of CO_2

Primary $GWC_{unsustainable}$: 1015,55 kg

corresponding to 3723 kg CO_2.

Total $GWC_{sustainable}$: 1300,9 kg,

corresponding to 4769.3 kg CO_2

Total $GWC_{unsustainable}$: 1634,7kg

corresponding to 5992.6 CO_{2}.

Conclusions:

The range of avoided emissions is as follows:

Primary $GWC_{unsustainable}$ of 515.33 kg corresponding to 1889,2 kg CO_{2eq} (wood fuel consumption) to

Primary $GWC_{unsustainable}$: of 1015,55 kg corresponding to 3723 kg CO_2 (charcoal consumption).

We should be aware of the fact that substitution of wood fuels by solar cookers not only avoids emissions, but also preserves forest stands as a natural carbon sink.

Synopsis of CO_2-reductions:

	Emission of CO_2-equivalents depending on the form of fuel, in tons/year	CO_2 reduction obtainable through the use of a Papillon cooker in 1 cooking procedure out of 2, in tons/year
Fuel wood from sustainable production	1,39	0,7
Fuel wood from unsustainable	1,88	0,94
Charcoal from sustainable wood production	5,74	2,87
Charcoal from unsustainable wood	7,45	3,73

Tab. 4: Synoptic table of possible CO_{2eq} reductions through the use of a Papillon cooker, depending on the form of the energy substituted, taking an average Chadian family (5,3 persons) with a cooking energy consumption of 30112.5 MJ/year as an example. Amounts calculated on the basis of emission data (primary GWC) by Pennise et al. [2001] in Kenya.

Financial support via greenhouse gas compensation offsets:

A Papillon cooker costs approximately 150 Euro in Burkina Faso. In Chad the price will be about the same; it should be diminished to about 50 Euro to make solar cookers available to larger segments of the population. For a project geared at marketing 1000 Papillon cookers, 100 000 Euro of climate protection funds are necessary, without transaction costs.
The calculations show, that a solar cooker can avoid 1015,55 kg Primary GWC corresponding to 3,723 tons of CO_2 per year, if only charcoal was used before substitution, much more than if fuel wood only was burnt (1889,2 kg CO_{2eq}). This has policy implications. Promotion efforts should concentrate on

households using primarily charcoal, at least if climate protection funds are made available.
If we accept that wood consumption exceeds new growth, solar cookers can be assumed to replace the unsustainable part of consumption, as long as they are not yet very numerous; and the corresponding figure has to be taken into account. In the medium run however, when solar cookers are growing in numbers, the percentage of unsustainable wood consumption has to be estimated.

But, as stated above, households using charcoal and fuel wood as well are probably more frequent. The precise share of either fuel is not known now. It seems reasonable to count with an average emission avoidance of 3 tons GWC per year and 15 tons in five years, if a solar cooker is used. The current market price of CO2 at the beginning of this year (2005) is 8.5 Euro according to the German newspaper TAZ; so the price of the cookers could be brought down considerably, making cookers available to larger segments of the population and even cover the cost of evaluation. Because of the high transaction costs of CDM projects, however, a CO2-compensation scheme on a voluntary basis seems easier to realize.

Important side effects would be job creation, technical innovation, transfer of skills, a significant contribution to the fight against poverty, more gender equity, progress in the fight against soil erosion and against loss of bio-diversity, and others.

The data presented show that investing in the promotion of the Papillon solar cooker is an attractive use for climate compensation funds.

Some quotations referring to biomass combustion and charcoal combustion:

„Unfortunately, through deforestation and other non-renewable practices, much burned biomass is not replaced. Even with recycling of the carbon, a biomass fuel cycle can produce a net increase in global warming commitment (GWC) because of the emitted PIC, which have, on average, a higher global warming potential (GWP) per kilogram carbon than CO_2." [Kirk R. Smith et al., 1998].

„...we estimate that 0.77-1.63 kg C-CO_2 (carbon as carbon dioxide equivalents) is emitted per kilogramme of charcoal produced“ [David M. Pennise et al., 2001].

"This implies that charcoal fuel cycles are among the most greenhouse-gas-intensive in the world", [David M. Pennise et al., 2001].

"Charcoal production has increased in recent years, at a rate of approximately 3 % per year over the period 1991-1995" [FAO 1997, quoted in: David M Pennise et al., [2001].

“When the emissions from charcoal production, measured in a previous study, were included in the assessment, the disparity between the GHG[6] emissions from charcoal and firewood increased significantly, with non-CO2 emission factors (g-C per kg of fuel burned) for charcoal production and consumption 6 to 13 times higher than emissions from woodstoves”. [Bailis et al.2003].

“Current estimates are that biomass burning accounts not only for 25-45 % of the annual global emissions of CO_2, But also for 15-50 % of CO, 3-10% of CH4, and 24 % of TNMOC” [Levine, 1990, Crutzen and Andreae, 1990, Andreae, 1991, quoted in Pennise et al.,[2001].

“These emission factors can be applied to other areas of the world where similar charcoal-making methods are used. This will allow for somewhat better global estimates of the inventory of greenhouse gas and air pollutant emissions from the production of charcoal” [Smith & Pennise, 1999].

“Given the emission of large amounts of products of incomplete combustion, during the charcoal-making process, we might expect the use of charcoal to have a greater impact on global warming commitment than its share of fuel demand” [David M. Pennise et al., 2001].

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