Climate Change Mitigation and Adaptation Potential of Basic Energy Services

Discussion Paper:

Overview of potential in heating and cooking technologies and decentralised electricity generation

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Executive Summary

Projects related to decentralised renewable electricity generation and basic energy services for promoting the use of efficient cookstoves contribute to mitigating climate change. Such projects have generated financial revenues in the context of international market mechanisms such as the Clean Development Mechanism (CDM) and the voluntary market. Through the CDM, for example, over 200 projects have been registered, with expected greenhouse gas reductions totaling around 8.5 million tonnes of CO_2 equivalent annually. The price of emission credits long maintained a level of around 15 EUR per tonne; since 2012, however, this price has experienced a massive drop owing to a significant decrease in the demand for emission credits. Despite this development, cookstove projects continue to enjoy a privileged position and have managed to sell emission credits for 3-8 EUR per tonne, whereas the price of these credits reaches 0.50 EUR otherwise.

While decentralised electricity generation can play a role in achieving the adaptation needed to deal with the long-term effects of climate change, they do remain vulnerable to extreme meteorological conditions. Such vulnerabilities may, however, be reduced by effectively combining different energy sources such as hydropower and photovoltaics.

International climate financing mechanisms such as the Green Climate Fund (GCF) have the potential to mobilise new financial resources for projects related to basic energy services in the upcoming years. After the GCF approved USD 168 million for its first eight investment projects covering mitigation and adaptation in the end of 2015, the exact funding procedures associated with the GCF remain to be defined.

To date, the climate mitigation benefit achieved by these projects has been limited to greenhouse gas emissions; yet cookstove projects likewise reduce equally problematic soot emissions. Of note here, however, is that soot emissions are generally comprised of both black carbon and organic carbon. While black carbon increases global warming, organic carbon has a cooling effect. The Gold Standard certification initiative has put forth a baseline and monitoring method in this context. However, it has become evident that soot reductions amount to 10-20% of CO_2 reductions in cookstove projects and only 1% in the context of renewable energy projects. This is the case when a 100-year warming contribution (GWP_{100}) – as introduced through the Kyoto Protocol – is considered for comparing various climatically relevant substances. Were a 20-year global warming potential (GWP_{20}) applied instead of a 100-year potential (GWP_{100}), the effects would be 4 to 5 times higher, though such a change in approaches is politically very unlikely. Considering the marginal degree of additional benefits for climate change mitigation achieved by reducing soot, it remains doubtful whether investing in measurement systems for soot emissions would be worthwhile. As an alternative, standard emission factors could be considered. As long as the current level of uncertainty in estimating soot emissions persists, estimates have to significantly be reduced downwards. As such, including soot reductions for the sake of climate change mitigation cannot serve as a trump card for projects related to basic energy services. On the other hand, the benefits for human health are a strong argument for reducing soot emissions.

Table of Contents

Table of Abbreviations

AF	Adaptation Fund
AMS	Approved Small-scale Methodology
BC	Black carbon
CDM	Clean Development Mechanism
CERs	Certified Emission Reductions
CH_4	Methane
CIF	Climate Investment Funds
CO_2	Carbon dioxide
CO_2eq, CO_2e	CO_2 equivalent
COP/CMP	Conference of the Parties / Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol
CPA	Component Project Activity
GCF	Green Climate Fund
GEF	Global Environment Facility
GTP	Global Temperature Change Potential
GWP	Global Warming Potential
INDCs	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
LDC	Least-Developed Countries
N_2O	Nitrous oxide
NAMAs	Nationally Appropriate Mitigation Actions
OC	Organic carbon
PoA	Program of Activities
PV	Photovoltaic
REDD+	Reduced Emissions from Deforestation and Forest Degradation
RF	Radiative forcing
SGP	Small Grants Programme
SLCPs	Short-Lived Climate Pollutants
SLCFs	Short-Lived Climate Forcers
UNFCCC	United Nations Framework Convention on Climate Change

1. Introduction and background of the climate issue

The International Community has set a goal of limiting the progression of global climate change and the related rise in worldwide average temperatures to less than 2°C, in reference to pre-industrial levels. As an increase of 2° would itself significantly impact lives and economies around the globe, a further tightening of a “tolerable” rise in temperatures (to 1.5°C, for example) has also come under discussion and has been reinforced as an objective by the latest Climate Change Conference in Paris 2015. In order to meet the target of reducing greenhouse gas emissions and their broader impacts, measures that have already been initiated must seriously be intensified. Progress in the area of implementing global climate agreements has, however, been slow, but the Paris Conference has raised new hopes of an accelerated climate change mitigation, as all countries have agreed to implement mitigation measures and strengthen them every five years. As it currently stands, the globe is set to experience a rise in temperatures of 3°C by the year 2100 (Edenhofer et al. 2014). As such, there has been increasing importance placed on implementing the necessary adaptation in response to climate change to either hinder or mitigate the damaging impacts related to this developing situation.

This background paper investigates the possibilities that exist for reducing emissions and adapting in the area of poverty-oriented basic energy services, along with the financial and policy instruments that can be mobilised for this purpose. The central themes examined here are energy for cooking and decentralised electricity generation.

Chapter 1 presents an outline of the topic under investigation. Thereafter, the chapter examines the fundamentals on which an evaluation of the mitigation and adaptation potential of poverty-oriented basic energy services is based.

The second chapter focuses on evaluating specific technologies related to emission reductions and adaptations in the area of basic energy services. This not only encompasses “classic” greenhouse gases such as carbon dioxide (CO_2) but also includes substances such as soot and volatile chemical compounds that fall under the term “short-lived climate pollutants” (SLCPs[1]).

Chapter 3 presents an overview of both the existing financing possibilities and the development of mechanisms for financing the climate initiatives mentioned in the previous chapters.

The fourth and final chapter summarises the findings presented and goes on to examine the impacts of the Paris Agreement adopted by the UN Paris Climate Conference (COP21/CMP11) in December 2015.

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[1] The term SLCFs (short-lived climate forcers) is also used elsewhere, such as in the UNEP (2011).

1.1. Climate Change: mitigation and adaptation

The Earth’s climatic system is extraordinarily complex. It is not limited to processes that take place in the atmosphere but also encompasses diverse interactions between the atmosphere, biosphere, hydrosphere (oceans), cryosphere (snow and ice) and the geosphere (rock). This is not a stable system but one that changes over the course of geological periods. The scientific community agrees that the climatic changes, which can currently be observed and have unfolded in an extremely short span of time considering the Earth’s history, are the result of the anthropogenic emission of greenhouse gases and other climatically relevant substances (see IPCC 2013). This is primarily the consequence of burning fossil fuels such as coal, oil and gas. There are many diverse ways of minimizing greenhouse gas emissions stemming from energy generation. Along with utilising renewable energy sources (mainly solar energy, wind energy, hydropower and renewable biomass), decreasing energy consumption by way of efficient technologies and limiting or reducing consumption are also suitable methods for reducing emissions. Limiting and reducing consumption should primarily be considered in industrialised nations, and not in the context of poverty-oriented basic energy services. This raises the question of how to promote development that is both sustainable and has low-emission characteristics.

Reduction of emissions that alter the climate can be achieved through a variety of measures and policy instruments: direct governmental regulation is most suitable for increasing the energy efficiency of home appliances, vehicles and buildings. This approach is especially useful when consumers find it difficult to gather relevant information about the energy use of available technologies and when prevailing energy prices are relatively low. Fiscal measures such as subsidies or tax breaks can create financial incentives for procuring low-emission technologies or discourage the use of emission-intensive ones by way of emission taxes. Eliminating subsidies for fossil fuels could prove a very effective measure in many developing economies. Having continually gained ground over the past decade, market mechanisms such as offset schemes and emission trading systems create direct rewards for reducing emissions. In many instances, various instruments are combined, like in the case of feed-in tariffs for renewable energy.

Along with reducing greenhouse gas emissions, any comprehensive climate policy must also consider the consequences of existent and expected climate change, which often affect least-developed countries in particular. Adaptation to climate change, on the one hand, entails so-called “no-regret” measures, which sensibly should be pursued even if climate change is not as extreme as feared – including improvements to cultivation and irrigation techniques in agriculture. Such adaptations likewise include the establishment of monitoring systems of climatic parameters and water levels (see BMZ 2015) as well as early warning systems for extreme weather events such as cyclones, heavy precipitation and droughts.

At the international level, the 1992 United Nations Framework Convention on Climate Change (UNFCCC) establishes the basis for negotiating and implementing international measures for mitigating climate change. As its name implies, the UNFCCC sets the framework for defining goals aimed at minimising dangerous anthropogenic climate change. It specifies the principles for international climate policies such as the “common but differentiated responsibility” assumed by various countries and an obligation to compile national reports on their greenhouse gas emissions. It was the 1997 Kyoto Protocol that first defined binding emission targets for a group of 38 industrialised nations for the time period 2008-2012. Through its Clean Development Mechanism (CDM), the agreement made it possible for emission reductions achieved by projects in developing nations to count towards the emission reduction targets set within industrialised nations, which led a flourishing of emission credit trading. The progress of international climate policy has witnessed a slowdown in recent years; in 2009, the attempt in Copenhagen to create a successor to the Kyoto Protocol – where all countries contribute to mitigation – failed. Instead, the “Copenhagen Agreement” called on countries to submit non-binding commitments for their emission reductions to the UN. Additionally, industrialised nations stated that they would mobilise 100 billion USD in “international climate financing” for developing countries aimed at enacting measures to reduce emissions and adapt to climate change. As the Copenhagen Agreement failed to reach the consensus needed, a series of complex negotiations took place until 2012, and the agreement was finally subsumed under the UNFCCC. Furthermore, a renewed attempt to create a universal climate agreement by 2015 was decided. Within this context, participating nations were required to submit declarations of intent for their “Intended Nationally Determined Contributions” (INDCs) for implementing emission reductions and adaptation measures, set to take effect by 2020. The UN Climate Change Conference in Paris successfully adopted the Paris Agreement in December 2015, in which the Parties agreed to limit global average temperature increase to well below 2°C and to undertake efforts to limit it to 1.5°C. The Parties furthermore included a full article (Art. 6, UNFCCC 2015f) on market mechanisms, detailing both a centrally governed Sustainable Development Mechanism (SDM) and a framework for less formalised Cooperative Approaches (CA) under which Parties would be free to utilise so-called Internationally Transferable Mitigation Outcomes (ITMOs). The Paris Agreement is thus a cornerstone for markets in the post-2020 climate policy regime. This, however leaves open many possible developments on these two paths and the coming years will show how these two shells are filled with life. The decision to develop the detailed implementation rules for the Paris Agreement – in a nod to the CDM – explicitly calls for considering experience from past mechanisms, which indicates that the CDM likely serves as the blueprint for the SDM.

The Green Climate Fund (GCF) laid out in the Copenhagen Agreement was successfully endowed with 10 billion USD in 2014. The fund commenced work in 2015 and stated it would finance projects for emission reductions and adaptation in nearly equal proportion. In November 2015, just before the start of the Paris Conference, the GCF approved 168 million USD for its first eight investment projects and programmes covering mitigation and adaptation. This decision marks the end of the GCF’s launch phase and kick-starts the flow of climate finance to developing countries.

1.2. Basic Energy Services

The purpose of basic energy services is to cover the energy needs of households, municipal facilities (e.g. health centres, schools, municipal authorities) and small businesses (e.g. processing agricultural products). Table 1 depicts and breaks down the energy consumption of these users.

Table 1: Energy consumption for basic energy services by use

Use	Energy Source *(bold = essential)*
Cooking	**Biomass**, **fossil fuel**, **electricity**, solar energy, geothermal
Hot water	**Biomass**, **fossil fuels**, **electricity**, **solar thermal**, geothermal
Heating (living space)	**Biomass**, **fossil fuels**, **electricity**, solar thermal, geothermal
Cooling (food)	**Electricity**
Cooling (living space)	**Electricity**
Lighting	**Electricity**, **fossil fuels**, biomass
Communications	**Electricity**
Productive use	**fossil fuels**, **Electricity**
Mobility	**Fossil fuels**, biomass (methanol, ethanol, etc.), electricity

The present study primarily investigates efficient cookstoves (use: “cooking”) and decentralised electricity generation based on renewable energy sources. Decentralised electricity generation mainly covers the uses of cooling (foodstuff), lighting and communication, as depicted in Table 1. Uses such as cooking, hot water, heating and cooling (living space) tend to be energy intensive and generally supplied by centralised systems. Productive uses can very well be covered by decentralised electricity generation if they are carried out through small facilities (e.g. irrigation pumps).

Two aspects are central to the area of efficient cookstoves: first, the fuel that is used affects the burning process and the resulting emissions, and, second, the quality of the stove is decisive. This spans simple, three stone fires (with an assumed standard efficiency value of 10%, according to CDM), through conventional cookstoves without an improved combustion air supply (CDM standard value of 20%), up to improved cookstoves with optimised combustion, boasting a CDM standard value of over 20% (see CDM small-scale methodology AMS-II.G.).

Mitigation potential in terms of smoke emissions that are damaging to both the climate and human health increases in accordance with the quality of applied fuels and that of the stove used. In the context of poverty-oriented basic energy services, one limiting factor, however, is the cost of the stove used. When evaluating mitigation potentials, one must bear in mind that an “overvaluation of potentials can easily occur owing to the fact that emission-intensive cookstoves will continue to be used despite the availability of ‘clean’ fuels and efficient cookstoves” (“Fuel stacking” model, see Masera et al. 2000 or Yonemitsu et al. 2014). This clearly demonstrates that successfully disseminating efficient cookstoves is strongly contingent on existing local conditions and needs.

Decentralised electricity generation is vital in many developing countries due to a lack of country-wide electricity grids. In such cases, electricity is generally provided by diesel generators, a tried and tested source that offers a wide range of available capacities. For countries with coal deposits, small-scale coal power plants are often also operated, while hydropower is frequently used in areas with the corresponding resources. Even when formal grid connections are present, users still turn to decentralised electricity generation, especially when the grid experiences frequent blackouts.

The intensity of emissions from diesel generators depends both on their size and on how they have been maintained. Smaller generators are comparable to outdated coal power plants while larger ones have values approaching the average grid emission factors in many developing countries.

In terms of decentralised electricity generation, distinctions can primarily be made on the basis of size (installed capacity). Here, we may differentiate among stand-alone units for households (solar home systems) or individual units (e.g. pumping stations) and systems that power entire communities or towns (mini grids).

It proves difficult to set a uniform definition for maximum size or capacity (installed electrical output capacity in watts) of the relevant decentralised electricity generation systems as their characteristics are strongly contingent on the respective local conditions. Nevertheless, this study refers to an upper limit of 15 MW (small scale) as defined by the CDM Methodology AMS-I.A. “Electricity generation by the user” as well as an upper limit of 5 MW (microscale) in accordance with the CDM Methodological tool “Demonstrating additionality of microscale project activities”.

Technical design in regard to the continuity of the power supply comprises an additional differentiating factor. Possibilities here include systems with storage batteries (battery units), with backup diesel generators, with connections to larger regional or national electricity grids, or those without any form of backup or storage.

2. Evaluating mitigation and adaptation potential

This study utilises two approaches for evaluating mitigation and adaptation potential: one comprises a survey of the current relevant literature and the other is an analysis of the degree to which mitigation and adaptation measures in the areas of cooking technologies and electricity services can be observed under the existing climate policy mechanisms. In this context, the study particularly evaluates the current state of the CDM.

2.1. Mitigation

Two factors are of particular relevance when evaluating mitigation potentials. The first involves clarifying which greenhouse gases and other climatically relevant substances should be taken into consideration. In addition, applying a clear and consistent definition of terms[2] is also essential here. One must beware of using terms (e.g. white carbon) and cumulative parameters (a collection of several substances covered by a single term, e.g. SLCPs) that are prone to overlaps and may ultimately lead to misinterpretations.

In regard to climatically relevant substances, those emitted from electricity generation and those which subsequently develop in the atmosphere should be considered separately. In general, a distinction is drawn between greenhouse gases (e.g. carbon dioxide) and aerosols (particles in the atmosphere). For aerosols in particular, various substances can either have a warming or cooling effect on the climate: mineral dust, sulfur dioxide (sulfates) and organic carbon compounds (organic carbon) cool, while soot particles (black carbon, BC) contribute to warming (IPCC 2013, p.14 and 57).

In terms of the applied metrics, there are essentially three commonly used measurements in the area of climatically relevant substances. The first referenced here is radiative forcing (RF), which is given in watts per square metre (W/m^2) (see IPCC (2013) image SPM.5, p.14). A measurement of global warming potential (GWP) is used to estimate the radiative forcing value of various substances in relation to carbon dioxide taken over a certain time period – generally 100 years (IPCC 2013, p.58). The amount of time that a substance remains in the atmosphere along with its absolute quantity is important in this context. The emissions and emission reductions of the various climatically relevant substances can subsequently be converted into a unit (CO_2eq or CO_2e) that lends itself to comparison on the basis of the GWPs. Finally, in order to allow for a direct comparison with the 2° target, the global temperature change potential (GTP) is applied (IPCC 2013, p. 58).

2.1.1. Methodology and background for evaluating mitigation potential

The evaluations covered by this study comprise the following climatically relevant substances[3]:

- carbon dioxide (CO_2)

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[2] This study primarily makes reference to the classification underlying the 5th IPCC Assessment Report (IPCC 2013) and the terminology used by the US EPA for the topic area of black carbon (US EPA 2012, p.21), in connection with the detailed definition from Bond et al. (2013, p. 5394f). An overview of the applied classifications can be found in Annex A.

[3] This study does not analyze sulfur dioxide (SO_2) emissions in detail – the corresponding emissions are linked to the presence of sulfur in fuels. The amount of sulfur in firewood is relatively low. SO_2 emissions primarily arise from burning fossil fuels such as coal and oil, though this proportion greatly varies according to the extraction source. The emission of carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and nitrogen oxide (NOx), and the formation of tropospheric ozone as byproducts of these substances are only partly taken into account, as it is beyond the scope of the present study.

- methane (CH_4)
- nitrous oxide (N_2O)
- black carbon (BC)
- organic carbon (OC)

Several factors are relevant when considering cookstoves. Reducing the use of biomass, especially firewood, is always closely connected to the issue of deforestation. Granted that the biomass is renewable – meaning that the amount used is the same as the amount regrown – the UNFCCC deems it as climate neutral: the quantity of CO_2 released from burning is equivalent to the quantity that the plants previously captured from the atmosphere. As such, the CDM determines the portion of firewood and charcoal from non-renewable biomass sources for each country. Only this particular amount is then considered in relation to emission reductions. The standard value across countries lies between 65% (e.g. Jamaica) and 100% (e.g. Cameroon) (UNFCCC, n.d.).

Additionally, the UNFCCC also defines which sorts of biomass can be considered renewable (UNFCCC, 2006). Consequently, biomass emission reductions largely depend on whether a country effectively protects its forests, an issue covered by the UNFCCC keyword REDD+ (Reduced Emissions from Deforestation and Forest Degradation). Countries that effectively implement REDD+ activities are, as such, less of a priority in terms of biomass reductions than those which lag behind. Forest protection always requires the establishment of a regular system of forest management that produces wood for commercial uses in commercial rotation. The availability of this wood increases the portion of renewable biomass, concurrently decreasing the amount of carbon credits distributed for reducing biomass usage. The implementation of efficient cookstoves and the associated reduction in firewood (or charcoal) demand can make a significant contribution to forest protection in addition to directly reducing emissions.

One must bear in mind that the UNFCCC does not (completely) consider methane or soot particles released from burning biomass. The UNFCCC generally classifies methane as a greenhouse gas but methane is not accounted for under CDM methodology AMS-II.G.. Soot particles are even not considered at all. Should these substances be included in the future, biomass would no longer be climate neutral. The emission of methane and soot particles through cookstoves is not offset by the regrowth of plants, as is the case for carbon dioxide.

Whereas carbon dioxide invariably forms when fuels are burned, the release of methane, black carbon and organic carbon results from the incomplete combustion of substances containing carbon. As such, measures aimed at optimising the combustion process (e.g. design of combustion chambers, air supply, fuel preparation) can contribute to reducing emissions by way of minimising the by-products (methane, soot) of incomplete combustion. By decreasing the amount of fuel needed for operation, increases in stove efficiency alone can lead to a proportional reduction in the products that arise from incomplete combustion.

Several factors are relevant when considering decentralised electricity generation. When calculating the emission reductions of renewable energy projects for decentralised electricity generation, the use of diesel generators is generally assumed to serve as a point of reference (see Annex B). Development factors – such as the presence of suppressed electricity demand – are not taken into account by surveying the existence of diesel generators but rather by assuming that diesel generators would otherwise have been installed in the absence of renewable energy projects. Emissions of organic carbon, black carbon and methane from diesel generators are not considered at present.

A wide variety of methodologies can be applied when evaluating emission reductions in the area of cooking energy and decentralised electricity generation (refer to Annex B for a short description of each).

2.1.2. Evaluating mitigation potential

Evaluation based on radiative forcing. According to IPCC (2013, p.14), the anthropogenic rise in carbon dioxide concentrations since 1750 has resulted in a radiative forcing effect of around 1.7 W/m². In regard to evaluating black carbon and organic carbon emissions, one must consider that black carbon may contribute to warming through a variety of mechanisms: these include direct effects, interactions with clouds, and effects stemming from the accumulation on snow and ice (see US EPA 2013, p.19). Additionally, reductions in black carbon emissions generally also lead to reductions in organic carbon emissions. The net effect of climate warming (BC) and climate cooling (OC) must therefore as well be referenced when carrying out an evaluation (see US EPA 2013, p. 31). Evaluations must avoid "cherry picking" by only calculating the gross effect of an emission reduction. IPCC (2013, p.14) ascribes black carbon an effect of around 0.6 W/m², while organic carbon has a cooling effect of around -0.3 W/m³ in addition to a value of -0.5 W/m² that arises from interactions between all aerosols and clouds. These values are, however, to be understood as the sum of global emissions over the past 250 years and pertain to the difference in concentrations of climatically relevant substances between the year 1750 and today. As such, we must identify which portion of these can be ascribed to the technologies that are analysed in this study. It is also evident that any analysis which only considers black carbon for the area of aerosols will lead to incorrect interpretations – as it would ignore the cooling effects of organic carbon emissions as well as the associated indirect effects. In sum, it is important to note that, first, the net radiative forcing value of cumulative global soot emissions is actually relatively low, and, second, the inherent indirect effects also play an important role and should, as such, not be overlooked.

Evaluation based on the GWP. When determining the warming potential (GWP) of the SLCPs in comparison to carbon dioxide, a time span must first be selected. Carbon dioxide remains in the atmosphere for over 100 years (see Joos et al. 2013), compared to 12 years for methane (IPCC 2007, p. 212) and about one week for black carbon (Bond et al. 2013, p. 5389). As such, comparing substances with vastly differing atmospheric lifespans is problematic and only partially meaningful (see IPCC 2007, p. 211). The Gold Standard methodology for tackling black carbon (see description in Annex B) ascribes a GWP of 20 years, even though the international community set GWPs at 100 years through the Kyoto Protocol. Attempts to alter this have thus far proven unsuccessful: while criticism arises from those who support reducing the SLCPs, the 100-year time frame for GWP has been maintained for the sake of consistency. Table 2 clearly illustrates the decisive impact of the timeframe selected when taking the SLCPs into consideration.

Table 2: GWP of various climatically relevant substances per emitted tonne

Substance	GWP_{10}	GWP_{20}	GWP_{50}	GWP_{100}	GWP_{100} *
CO_2	1	1	1	1	**1**
CH_4	104.2	83.9	48.4	28.5	**25**
N_2O	246.6	263.7	275.6	264.8	**298**
BC	4349.2	2421.1	1139.3	**658.6**	-
OC	-438.5	-244.1	-114.9	**-66.4**	-

** According to AR4 (IPCC 2007, p. 212) as applicable to greenhouse gas inventories.*

Values in bold are further examined in this study.

Source: Myhre et al. (2013, p. 8SM-39) and IPCC (2007, p. 212)

Given the GWP indicates climatic impacts in relation to one tonne of a specific substance, evaluations are only possible in combination with the actual emission volume of a substance. Bond et al. (2004) estimate total emissions of black carbon to be 8 million tonnes and those of organic carbon to be 33.9 million tonnes for the year 1996. Of this, the use of biomass as a fuel amounts to 20 and 19%, respectively, equal to the emission of 1.6 million tonnes of black carbon and 6.4 million tonnes of organic carbon, or 1.1 billion and 0.4 billion tonnes of CO_2 equivalent. Therefore, the net effect equates to 0.7 billion tonnes of CO_2 equivalent. Experts estimate the annual energy-related use of biomass in the 1990s to have been 1.43 billion tonnes (Andreae, 1991). Recent estimates have yielded nearly identical results (Bailis et al. 2015). Burning this amount of biomass released 2.6 billion tonnes of CO_2. The ratio of classic CO_2 emissions to soot emissions for burning biomass fuel is 3.7:1, meaning that soot emissions amount to around 20% of total climatic impacts.

Emissions that arise from burning firewood in cookstoves may serve as the basis for evaluating the mitigation potential of single substances. Table 3 depicts a corresponding sample calculation. As the basis applied here is emissions per tonne of firewood, the emission total corresponds to the mitigation value, which can be achieved from saving one tonne of firewood.

Table 3: Climatically relevant substances emitted from the use of firewood in cookstoves (GWP_{100})

Substance	Emission of respective substance	Unit	Emission in CO_2e	Unit	Portion	Source:
CO_2	1.482 000* 2.059 200[#]	tCO_2/ t firewood	1.482 000 2.059 200	tCO_2e/ t firewood	82.6% 79.9%	1)
CH_4	0.004 680* 0.014 040[#]	tCH_4/ t firewood	0.117 000 0.351 000	tCO_2e/ t firewood	6.5% 13.6%	1)
N_2O	0.000 062* 0.000 234[#]	tN_2O/ t firewood	0.018 595 0.069 732	tCO_2e/ t firewood	1.0% 2.7%	1)
BC	0.000 600* 0.000 700[#]	t BC/ t firewood	0.395 160 0.461 020	tCO_2e/ t firewood	22.0% 17.9%	2)
OC	0.003 300* 0.005 500[#]	t OC/ t firewood	-0.219 120 -0.365 200	tCO_2e/ t firewood	-12.2% -14.2%	2)
BC and OC	-	-	0.176 040 0.095 820	tCO_2e/ t firewood	9.8% 3.7%	2)

The calculation was done once for the lower limit (*) and once for the upper limit ([#]) of emissions.[4]
Source: authors' own calculation with GWP_{100} from Table 2 in accordance with 1)= IPCC (2006, Table 1.2, p. 1.19 and Table 2.5, p. 2.23) and 2) Johnson et al. (2011, Table 1)[5]*.*

The ratio between black carbon and organic carbon arising from combustion in cookstoves, varies considerably depending on the source or calculation applied. The ratio for the selected cookstoves, as presented in Table 3, differs from the values attained by Bailis et al (2015)[6] as well as from the general overview of biomass combustion by Bond et al (2004), rendering a generally applicable ratio unattainable.

When considering charcoal instead of firewood, the CDM assumes that the production of one tonne of charcoal requires six tonnes of firewood (see AMS-II.G and AMS-III.BG). However, the specific energy content of charcoal is only 1.9 greater than that of firewood (IPCC 2006, Table 1.2, p. 1.19). Moreover, the coking that is required in charcoal production emits methane. The CDM sets a standard value of 0.030 t CH_4 per tonne of charcoal, or 0.75 tonnes of CO_2 equivalents (UNFCCC

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[4] If similarly calculated based on GWP_{20}, the resultant portion of BC/OC is between 10 and 25% of the entire climate impact.

[5] The following cookstoves are part of the study by Johnson et al. (2011): Uganda traditional, Uganda StoveTec, Nepal traditional, Nepal Improved Biomass, India traditional, India Oorja.

[6] See Annex C.

2014a, p. 8). According to Bailis et al. (2015, Table 12, p. 41) neither BC nor OC are released in the production of charcoal. During combustion in charcoal stoves, 0.2 g of BC and 1.5 g of OC are emitted per kg of charcoal. As such, a net value of 0.032 tonnes of CO_2 equivalent is released from soot per tonne of charcoal, an insignificant amount compared to the 2.9 – 3.6 tonnes of CO_2 equivalent arising from charcoal combustion (just 1%).

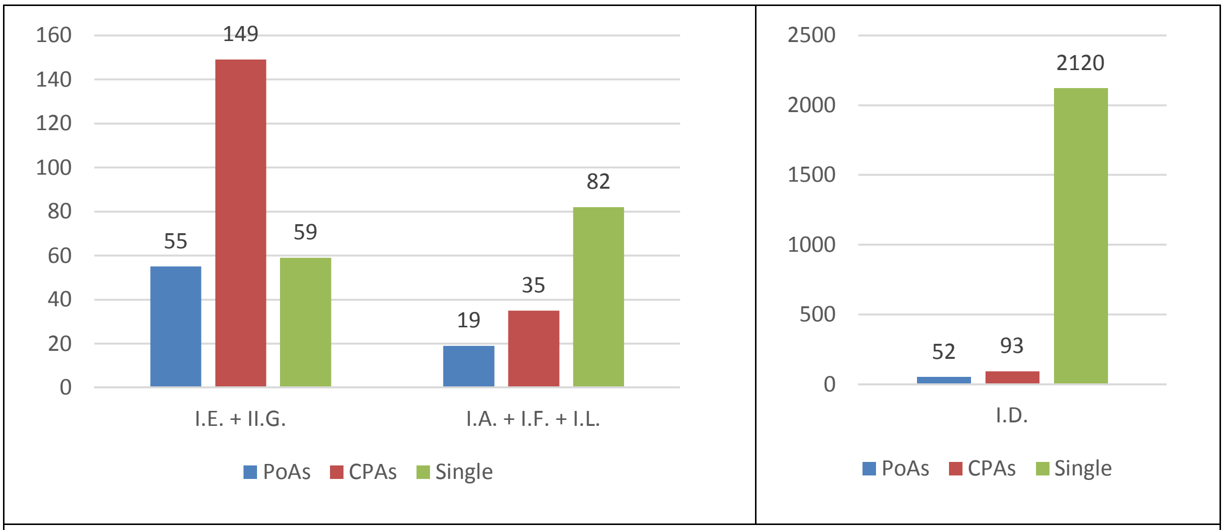
The percentage of BC/OC emissions for firewood therefore amounts to around 10% (up to 20%) for the overall climatically relevant emissions considered here – though the level of uncertainly remains large. The total for charcoal is only about 1%, which the CDM methodology does not take into consideration. In order to take account of BC/OC within emission reductions, a corresponding system for monitoring must be implemented, which, in all likelihood, would prove costly. Any agreement on standard values would likewise entail a high margin of uncertainly. Annex C presents additional emission values from existing literature. The introduction of efficient cookstoves and a transition from firewood/charcoal to gaseous fuels would, nevertheless, lead to a reduction in BC/OC emissions and have an associated positive impact on climate change. This is reflected through countless studies that tout the corresponding mitigation measures as highly suitable for reducing black carbon emissions in the area of cookstoves (e.g. UNEP 2011, Shindell et al. 2012 or World Bank and International Cryosphere Climate Initiative 2013).

Besides their impact on the global climate, black carbon emissions likewise influence local weatherUNEP (2011, p. 19) lists effects on evaporation, cloud formation, precipitation and influences on wind patterns.

For the area of decentralised electricity generation, CH_4, N_2O, black carbon and organic carbon emissions assume low single-digit percentages compared to CO_2 emissions. A simplified sample calculation for GWP_{100} based on IPCC (2006) and CIMAC (2012) finds that CO_2 emissions comprise over 99% of the climatic impact; exact emissions data is, however, still scarce (see World Bank and International Cryosphere Climate Initiative 2013, p. 27).

Evaluation based on implemented CDM projects. The typical CDM methodologies AMS-I.E. and AMS-II.G. for cookstoves and AMS-I.A., AMS-I.F and AMS-I.L. methodologies for decentralised electricity generation are in wide usage (see Image 1 and Image 2). In regard to decentralised electricity generation, however, a significantly greater number of projects has been implemented in the area of grid-connected renewable electricity generation under CDM (the AMS-I.D. methodology here), resulting in markedly higher emission reductions.

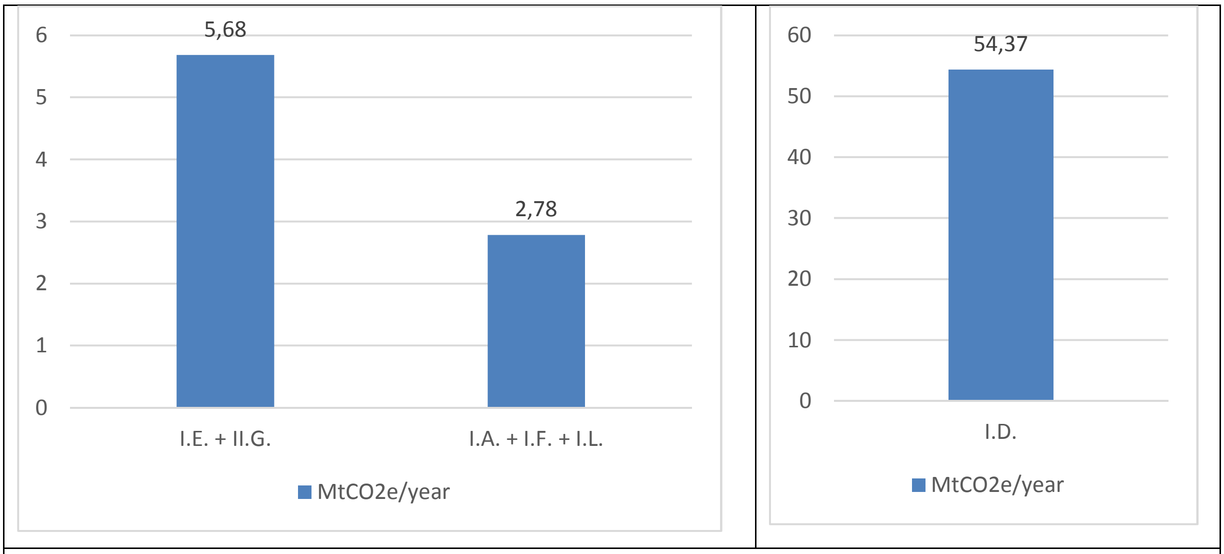
Image 1: Number of CDM projects and the distribution of emission credits



The graphs illustrate the number of registered PoAs (including related CPA registrations) as well as single CDM projects that apply at least one of the depicted CDM methodologies.

Source: evaluation according to IGES (2015a and 2015b)

Image 2: Emission reductions from CDM projects



The graphs depict the expected annual emission reductions from registered PoAs (including the related CPA registrations) according to project documentation as well as those from single CDM projects that apply at least one of the associated CDM methodologies.

Source: evaluation based on IGES (2015a and 2015b)

Evaluation based on co-benefits. Apart from the discussion on climate, the positive effects achieved from efficient cookstoves and decentralised electricity generation are likewise significant for the social and economic spheres. Projects related to cooking energy can lead to substantial livelihood improvements in the poorest regions on the globe by mitigating health hazards, illnesses and deaths (see UNEP 2011). One prime example includes the cool storage opportunities for foodstuff and medications provided by decentralised electricity generation.

In terms of climate change mitigation, such positive impacts are considered to be co-benefits along with emission reductions. The following section delves into these effects in relation to adaptation.

2.2. Adaptation

2.2.1. Methodology and background for evaluating adaptation potential

To date, there is still a lack of agreement on a consistent or even standardised metric for evaluating adaptation measures at the international level. The approach for evaluating the monetary and health-related utility of adaptation projects put forward by Köhler and Michaelowa (2013) remains in the trial phase. In order to carry out at least one qualitative assessment, the following evaluation of adaptation potentials present in technologies related to basic energy services will proceed as follows:

1. Differentiation among energy outputs: heating and cooking technologies will be considered separately from technologies for electricity generation.
2. Both technology areas will be considered in terms of their vulnerability to climate change effects as well as their potential contributions to adaptation and heightened resilience. Typical adaptation activities such as water services, food processing, coastal protection and early warning systems will be taken into account.

A survey of existing literature on this issue area serves as the basis for evaluation using these criteria.

2.2.2. Evaluation of adaptation potential

Heating and cooking technology:

Considering that users in developing countries often rely on biomass derived from unsustainable sources, increasing efficiency and changing fuel types directly lead to increased resilience against the effects of climate change. Forests are vital for storing ground water, protecting coastlines, serving as barriers against erosion and desertification, and supplying nutrients and construction materials. As a hydrothermal ecosystem, they may also have direct influence on local microclimates. When forests are destroyed through overutilisation as a source of fuel, vulnerabilities to the effects of climate change can increase significantly (see Locatelli und Pramova, 2015).

1. <u>Technological resilience against the effects of climate change:</u>
   As many traditional heating and cooking technologies run on biomass combustion, fuel shortfalls and price increases put serious limitations on their usage. In the context of climate

change impacts, this issue is intertwined with the existence of forests. In the Southern Hemisphere, where most developing countries are found, the IPCC identifies high probability for climate change negatively impacting forests (see Locatelli and Pramova, 2015). As such, a transition from traditional cookstoves to energy-saving fossil or charcoal-based technologies would result in heightened resilience to the effects of climate change by significantly reducing or even entirely eliminating the demand for firewood and charcoal.

2. <u>Technologies and their contributions to increasing society's overall resilience:</u>
   Higher efficiency in burning firewood, implementing sustainable forestry practices and transitioning to other fuels can each make an important contribution to curbing deforestation. Such measures directly support adaptation as forests are the providers of vital ecological services, especially in the context of a rapidly changing climate: mangroves play a role in protecting coastlines while inland forests provide groundwater storage, serve as protection against desertification and erosion, and deliver nutrients and building materials. Furthermore, as hydrothermal ecosystems, forests also directly influence local microclimates (see Locatelli and Pramova 2015). Minimising indoor air pollution with efficient cookstoves improves the general health of the population, especially women, making them stronger and less susceptible to the effects of extreme weather.

Decentralised electricity services:

1. <u>The resilience of technologies against the effects of climate change:</u>
   Decentralised renewable energy generation generally enjoys far greater resilience to the effects of climate change compared to large, centralised power plants – despite any higher individual vulnerability. Thermal electricity generation from coal or nuclear power plants demands a relatively large amount of water for cooling. Considering that surface water and air temperatures are rising across the globe, this can increase the likelihood of outages. In contrast, photovoltaic (PV) and wind turbines hardly require any water for its operation (see Macknick et al. 2009). Fluctuations in precipitation greatly impact electricity production from hydropower, especially for smaller plants with limited catchment areas. Extreme precipitation can even destroy hydropower plants, especially smaller ones. PV facilities can be affected by heightened cloud cover. In an ideal system, negative impacts on the parameters of one form of generation would be compensated for by positive effects on another form of generation. A combination of PV and hydropower[7] could, for example, dampen variability due to cloud cover and precipitation: PV would produce more electricity during periods of low cloud cover and precipitation, while hydropower would experience the opposite effect. As the availability of biomass directly depends on the amount of precipitation, biomass and hydropower plants are similar in terms of their vulnerabilities. Karekezi et al. (2009) call for the greater use and diversity of decentralised renewables in order to minimise the one-sided dependence on and

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[7] Granted that geographic conditions allow for such a combination.

vulnerabilities of large-scale hydropower experienced by East African economies. As the result of droughts in this region between 2004 and 2006, electricity generation from hydropower plants dropped by 25% and the GDP of affected countries fell by several percentage points, partially owing to the need to import fossil fuels to compensate for the loss in energy production. In the worst case, increased demand for imports could also place pressures on local currency values.

Severe storms are equally dangerous for wind and PV facilities. Decentralised renewables exhibit a higher degree of resilience on account of their relatively low level of technical complexity, often allowing them to resume operations faster than large-scale plants following extreme weather. Additionally, there are no extended transmission grids that require repair in cases where local distribution infrastructure is affected (see Wood, 2012). Despite these benefits, the total loss of a decentralised renewable energy system still remains a possibility.

Owing to their flexibility, decentralised electricity generation systems allow for synergies with other adaptation measures, such as in population resettlement, which allows for electricity generation systems to be taken along.

2. The contribution of technologies to increasing overall social resilience:
   In countries suffering from development and adaptation deficits, large portions of the population do not have access to electricity owing to a lack of relevant infrastructure. When electricity is available, a population’s resilience against extreme weather conditions such as heat waves (through cooling) and droughts (through irrigation) is improved. Equipment that runs on electricity – such as desalinisation plants, water pumps and cooling or drying systems – are particularly vital for securing basic life conditions through water services and agricultural production and processing. Medical equipment, air conditioning, meteorological measurement systems, communication and early warning systems, and climate data processing can also contribute to decentrally heightening resilience but depend on a stable supply of electricity (see Noble et al. 2014, p. 845ff). Services like these could, of course, be enabled through a centralised electricity supply as well. Especially in the least development countries, however, such supply systems are not always available throughout the entire country and they are also susceptible to the vulnerabilities listed above.

3. Overview of financing options for basic energy services

The costs related to acquiring highly efficient cookstoves or installing decentralised electricity generation (e.g. small-scale solar facilities) are very high for many local populations, while operating costs are relatively low (World Bank, 2011, p. 21). While simple efficient cookstoves cost between 3 and 10 USD, mid-range models cost between 15 and 30 USD and improved stoves – such as models with biomass carburettors – can cost as much as 50 to 120 USD (Putti et al., 2015, p. 5)[8]. The prices for small-scale solar facilities have drastically fallen in recent years, currently costing less than 5 USD per watt (IEA 2014, p. 56). One proven financing model for small-scale solar involves international funds that operate alongside NGOs or microfinancing institutions. The options that exist in this context are listed in the following.

3.1. Clean Development Mechanism

Conditions. The Clean Development Mechanism (CDM) sets out a comprehensive set of conditions. Besides applying recognised methodologies (see Annex B), assessments of “additionality” play a decisive role in the CDM. All projects are required to go through an official registration process. Projects are ultimately financed through the sale of corresponding emission credits (Certified Emission Reductions, CERs). One of the central buyers of CERs used to be the European Union’s Emissions Trading System. However, this scheme has limited the cumulative use of CERs to the level of 1.6 billion tonnes of CO_2 up until 2021, which has already by and large been reached. Moreover, CERs for projects registered after 31st of December 2012 may only stem from projects in least developed countries (LDCs), which has brought the current price for CERs to the very low level of 0.25 to 0.50 €/CER.

Various programmes which purchase (existing) CDM credits exist, four of which are particularly relevant here: projects for decentralised basic electricity services in low-income countries – building on the CDM infrastructure – are supported through the *Carbon Initiative for Development* (*Ci-Dev*). These projects must generate both CERs and additional benefits for sustainable development (Ci-Dev, 2013). The *Norwegian Carbon Procurement Facility (NorCaP)* and the *NEFCO Carbon Funds (NeCF)* allow for certificates to be purchased from existing projects that have become untenable due to the low CER price as well as for new CDM projects to be established (NEFCO, 2014, Annex I and Annex II). The latter only allows for projects in LDCs (NEFCO, 2014, Annex II). NorCaP projects outside of LDCs require a minimum CER volume of 300,000, whereas an upper limit is in place for both sorts of project (NorCaP: 3 million CER, NeCF: 1 million CER). Nevertheless, projects that exceed these limits may still be established (NEFCO, 2014, Annex I and Annex II). In 2014, the Swedish Energy Agency (SEA) purchased 4 million CERs from eight cookstove projects in Ethiopia, Ivory Coast, Ghana, Cameroon, Malawi, Nigeria, Zambia, Togo and Uganda (SEA 2014), and in 2013, the agency already acquired 1 million CERs from stove programmes in Ghana and Uganda (Point Carbon 2013).

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[8] Costs range from 500 to 1,500 USD for efficient biomass stoves requiring biogas facilities (Putti et al., 2015, p.5).

The price for CER transactions from cookstove projects[9] averaged 6.3 USD in 2013 from a total volume of 2.3 million CERs. The price even reached 12.1 USD for Gold Standard projects in 2013 (Hamrick 2014).

Suitability for measures. The methodologies put forth by the CDM for efficient cookstoves as well as for off-grid electrification were often taken as being complex. Despite this, the number of registered projects indicates that this hurdle can be overcome. As of today, many CDM projects[10] and programmes (Program of Activities, PoAs) for efficient cookstoves have been implemented in places like Haiti, Nepal and Mozambique (UNFCCC, 2015c), and there have even been a large number of projects in the area of decentralised electricity services[11]. Projects related to decentralised electricity generation and efficient stoves, in particular, have proven to generally be well suited for CDM financing. Both types of project have also proven well suited for financing through Ci-Dev, especially since direct benefits can be expected for poor and vulnerable households in both cases, leading to their prioritisation within the Ci-Dev programme (Ci-Dev, 2013)[12]. As the exclusion criteria set out by NorCaP and NeCF do not apply to either type of project, these financing programmes are deemed suitable[13].

Outlook of possible developments. The UNFCCC has recently opened up the possibility of “cancelling” CERs, which would allow for CDM projects to be transformed into projects on the voluntary market. It is difficult to predict whether the purchase schemes named above will remain in place or whether new mechanisms will be integrated. After the phase of disillusionment stemming from the price fallout on the CER market has passed, it remains to be seen whether the willingness to purchase credits under the CDM will rise in light of the Paris Agreement. While the CDM is referred to as the basis of the new mechanism, this leaves its specific future role and relevance uncertain. Several proposed improvements, such as the financing of CDM activities through climate finance institutions, the development of a stand-alone CDM PoA guidance, the digitisation of documents to reduce transaction costs, and the expanded scope of work for Regional Collaboration Centers might pave the way for a successful transition of the CDM, Cookstove projects continue to be attractive and may mobilise above-average prices.

3.2. Voluntary carbon market

Conditions. The voluntary market is highly fragmented with various certification systems in fierce competition for project initiators and buyers. The conditions laid out by these certification systems are

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[9] Comparable information for decentralised electricity generation is currently not available.

[10] There have been 30 CDM projects for efficient cookstoves since 2012 in India alone (Warnecke et al., 2015, p.18).

[11] Since 2012, for example, there have been 48 household lighting projects in China and India (Warnecke et al., 2015, p.18).

[12] The authors were unable to find more exact information on projects already supported.

[13] 16% of the total volume for the first round of NorCaP financing went to projects related to household energy efficiency, 10% to biomass energy, and 4% to the area of solar energy (NEFCO, n.d.). The authors were unable to find more detailed project information, which may have included projects related to decentralised electricity generation and efficient cookstoves.

generally in line with those of the CDM, requiring certain methodologies to be applied in calculating emission reductions.

Suitability for measures. The Gold Standard database contains over 100 cookstove projects (markit, 2015) [14], reflecting the suitability of these projects in accordance with the Gold Standard. In terms of transaction volumes, cookstove projects accounted for 4.2% while biomass energy, biogas and PV projects accounted for 1.7% of those on the voluntary carbon market for 2014. The average price for credits from cookstove projects in 2014 was 5.8 USD, compared to 9.2 USD in 2013 (Hamrick et al., 2015, p.12). Hence, this price was significantly higher than the overall average price for credits, which was 3.8 USD in 2014 and 4.9 USD in 2013[15]. (Hamrick et al., 2015, p.3).

Outlook of possible developments. Assuming that demand does not rise by any great degree and that supplies rise on account of more projects and the issuance of credits, the price fallout that has recently been observed will, unfortunately, persist. Moreover, it likewise remains to be seen whether the black carbon methodology set out by the Gold Standard will be adopted and whether buyers can be found for the corresponding credits.

3.3. NAMAs

Conditions. Nationally Appropriate Mitigation Actions (NAMAs) are national measures for climate change mitigation in developing countries, which are not bound to any regulations under the UNFCCC. As such, they can be executed both at the national level or based on projects and programmes by sector (UNFCCC, 2014b). In principle, these can be financed either bilaterally or through international funds, such as the Global Environmental Facility (GEF) or potentially even the Green Climate Fund (GCF) in the future. Whereas any NAMA could yet make use of the multilateral funding approach, the NAMA facility created by Germany and Great Britain has already been operational for three years. The NAMA facility calls for refined financing applications for implementing NAMAs. The three application rounds that have thus far been carried out saw such high demand that only 10% of applications were ultimately financed (NAMA Facility, 2014).

Suitability for measures. There is currently a broad range of NAMAs that address the topic of basic energy services. While a portion of these have already been implemented, others still seek financing. NAMAs involving efficient cookstoves have, for example, been planned for Mexico (UNFCCC, 2015a) and the Gambia (Ecofys, 2015a). Within the latter project, four people will receive training in the production of efficient cookstoves as well as subsidies for manufacturing, which is meant to facilitate the production and use of 200,000 efficient cookstoves (Ecofys, 2015a). Furthermore, various

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[14] The database only contains projects that were explicitly released for publication. There may well be additional cookstove projects not listed on the website. The volume has markedly increased in recent years, with 2011 only registering a total of 30 stove projects (World Bank, 2011, p. 26).

[15] This average price weighted according to volume does not take account of credits from the REDD-Early Movers agreement (Hamrick et al., 2015, p.3).

measures are envisioned to increase awareness of efficient cookstoves among the population (Ecofys, 2015a). Another NAMA related to biomass is planned for Burkina Faso, supported through the NAMA Facility (NAMA facility, 2015). NAMAs are likewise planned for rural electrification (Gambia (UNFCCC, 2015b). In the latter, private public partnerships will enable electrification in rural areas by way of providing either rechargeable batteries or individual grid connections for households (UNFCCC, 2015b), supplying electricity to some 800 households. In the second phase, additional private public partnerships are planned that will either replace thermal energy through renewables within existing grids or become producers of renewable energy themselves (UNFCCC, 2015b).

Outlook for potential developments. Financial support is currently being sought for preparing and implementing many NAMAs, leading to strong competition for the scarce available resources. Should the GCF eventually also come to finance NAMAs, this would unlock additional financing opportunities.

3.4. Green Climate Fund

Conditions. The Green Climate Fund (GCF) finances projects and programmes that promote paradigm shifts for low-emission and climate-resilient development paths in the context of sustainable development (Art. 2 Governing instrument, GI). Projects/programmes should therefore target such paradigm shifts and not be too detailed. The “initial investment framework“ lays out the follow criteria for projects: impact potential, potential for a paradigm shift, sustainable development potential, needs of the recipient country, ownership by the recipient (country ownership), efficiency and effectiveness – though the latter relate to economic aspects (GCF/B.09/23, Annex III). Possibilities for scaling-up and diffusion along with the existence of co-benefits receive particular importance (GCF/B.09/23, Annex III).

Suitability for measures. The GCF classifies projects according to their scale: the larger the project, the stricter the evaluation. It would prove difficult for projects that only focus on basic energy services for small regions to receive financing due to a lack of potential for bringing about a paradigm shift. If such applications to the GCF include approaches for expanding their scope to other regions, it would, in principle, be feasible for them to receive financial support. For projects applying to the GCF, it is also of benefit if they offer high potential for additional sustainable social benefits (e.g. health). As the GCF has a particular gender policy and places great value on the consideration of gender issues, it is beneficial for projects related to cookstoves to entail positive effects for women. Moreover, the GI of the GCF states that integrated approaches which take both mitigation and adaption into account should explicitly be supported (GI, par. 37).

Outlook for potential developments. The GCF commenced its funding activities in fall 2015 through the approved financing of eight projects and programmes covering mitigation and adaptation measures. Due to this short time frame, it is still too early to make reference to project experiences from the GCF. Furthermore, the future arrangement of the GCF will directly affect the finance capabilities of the projects involved. Financial intermediaries have to be identified in accordance with the fund's final arrangement. These intermediaries could, for example, provide microloans for the purchase cookstoves or offer financial contributions for investments in decentralised electricity generation. In addition, it remains to be seen whether CDM activities might directly be financed through the Green Climate Fund (GCF) in the near future. A respective financing link is being evaluated at the moment (e.g. during an in-session workshop at SB44 in May 2016).

3.5. Adaptation Fund

Conditions. The Adaptation Fund (AF) finances concrete adaptation projects and programmes in countries that are signatories of the Kyoto Protocol (AF 2011). Some of the project selection criteria include: support from the government of the partner country, social and environmental benefits – with a focus on the most vulnerable groups and gender issues, cost effectiveness, accordance with national development plans, information management aspects, and accordance with the AF's "Results Framework" (AF, n.d.).

Suitability for measures. The AF defines outcomes that should be achieved by the supported projects. One of the outcomes that might be relevant for basic energy services is "diversified and strengthened livelihoods and sources of income for vulnerable people in targeted areas". This outcome could be measured using the indicator "percentage of households and communities having more secure (increased) access to livelihood assets", which is named in AF's Results Framework (AF, 2011). Many AF projects related to agriculture include the improvement of water services, some of which are enabled by wind-driven pumps. Increasing the use of renewable energy sources would also be possible in this context.

Outlook for potential developments. Originally, the AF was meant to primarily secure financing by way of a 2% fee on CDM and JI emission credits. Owing to the low price of CDM /JI credits, AF has received direct subsidies from donor countries for several years. This low price also casts uncertainty on how the AF's financial situation and, in turn, the support options offered by the AF will develop – also in relation to operationalising the GCF. Some countries wish to eliminate the AF as soon as the GCF becomes operational.

3.6. Global Environmental Facility

Conditions. For its 6th period (2014-2018), the Global Environment Facility (GEF) has named efficient cookstove financing as a potential measure within the framework of the programme "Promote the timely development, demonstration, and financing of low-carbon technologies and mitigation options" in the focal area related to mitigating climate change (GEF, 2014, p. 59f.)[16]. The transformational potential of the applied technologies is also central here (GEF, 2014, p. 59). Since

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[16] GEF set the goal of 230 million USD for this programme. This is the largest financial target within the climate change mitigation focal area (GEF, 2014, p. 72).

GEF‘s Small Grants Programme (SGP) finances many projects related to basic energy services (especially cookstoves, solar facilities and off-grid electricity generation) (SGP, 2015a), the programme’s regulations are presented in the following (SGP, 2015c):

- programmes must outline how they contribute to the GEF focal areas (in this case the mitigation of climate change),
- they must specify how they contribute to the national SGP strategies of the respective country (see SGP, 2015b),
- they must be established by community-based organisations or by non-governmental organisations, and
- they are eligible to apply for financing of up to 50,000 USD.

Suitability for measures. The SGP is well suited for supporting projects related to basic energy services. This is illustrated by the fact that the SGP has already supported many projects, especially those related to efficient cookstoves (with around 70 projects) but also those in the area of off-grid energy generation such as small-scale solar facilities (with around 25 projects).

Outlook for potential developments. The GEF will receive new financial resources through replenishment meetings. These meetings are linked to the GEF periods of activity, such as GEF-6, which each set their own focal area. As such, future financing for projects related to basic energy services through the GEF will remain contingent on both the financial resources available and the focal area set by the GEF periods. The current GEF-6 period received 4.43 billion USD in financing and runs until the end of 2018.

3.7. Climate Investment Funds

Conditions. The Climate Investment Funds (CIF) consists of the Clean Technology Fund and the Strategic Climate Fund. The latter entails three programmes[17], of which one, the Scaling Up Renewable Energy Program (SREP), presently finances projects related to basic energy services. SREP countries have to be entitled to receiving ODA[18] support and host an active, multilateral development programme (CIF, 2009, par. 14). The criteria for programme selection are: transformative effects; economic, social and environmental benefits; economic feasibility; leverage of additional funding; capacity building for project implementation; and a sufficient critical mass of investment (CIF, 2009, par. 23). Improvements for health are listed as additional target benefits with specific reference to efficient cookstoves (CIF, 2012, p.6, p.12).

Suitability for measures. The SREP is suited for projects related to basic energy services. The programme currently finances projects such as the diffusion of business models for clean cookstoves

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[17] The Forest Investment Program, the Pilot Program for Climate Resilience and the Scaling Up Renewable Energy Program.

[18] Official Development Aid.

(in Honduras) and rural electrification through clean energies (in Ethiopia and Mali) (CIF, 2015). A country in which this programme is executed must have the status of a pilot country within SREP[19]. It remains to be seen whether SREP will name additional pilot countries in the future. Projects related to basic energy services are well suited for addressing the following indicative outcomes and outputs for SREP: mini power grids, municipal energy services and market expansion for modern sources of energy (CIF, 2012, p. 6).

Outlook for potential developments. The SREP has an endowment of 796 million USD, of which 501 million USD have already been allocated. It has selected 27 pilot countries and continues to process project applications. It remains to be seen whether an additional CIF replenishment meeting will be held: a so-called “Sunset Clause” exists for the CIF which states that it must cease operations and not issue any further commitments once a new global financing mechanism has taken effect (CIF, 2008, art. 57)[20]. This only applies as long as the UNFCCC does not make an opposing ruling (CIF, 2008, art. 58).

4. Conclusion and prospects

Over the past 10 years, the international climate regime has developed numerous methodologies – of greater or lesser complexity – for calculating emission reductions of efficient cookstoves and decentralised electricity generation on the basis of renewable energy. These methodologies have been applied to dozens of projects within the CDM framework. In the future, these could be simplified in part. The main obstacle to mobilising such project types in the context of international climate policies, however, is the lack of a stable financing mechanism. Firstly, the demand for CDM emission credits is currently so low that the overall price for credits of 0.5 €/tonne of CO_2 equivalent on the secondary market is not high enough to mobilise new projects. There are, however, presently a number of niche clients for stove projects offering prices of 3-8 €, allowing for a dozen additional projects to be mobilised. The situation is better on the voluntary market, although prices have been falling in this market as well.

For the area of decentralised electricity generation, a significantly higher number of projects related to grid-connected electricity generation from renewable energy sources have been implemented, resulting in far greater emission reductions. Despite this, there have also been a considerable number of projects for the area of decentralised electricity generation through the CDM.

In regard to evaluating black carbon and organic carbon, the Gold Standard methodology presented in this study serves as a first step for implementing projects. The extent to which this methodology will find practical application in the future is yet to be determined. Additionally, one point of criticism is that this methodology uses the GWP_{20} rather than the GWP_{100}. Even if the calculable benefit for

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[19] See CIF, 2014 for the selection criteria for the second round of pilot countries in 2014.

[20] Once the Green Climate Fund begins financing projects, one could argue that that a new architecture for climate financing has become effective.

climate change mitigation increases – particularly by way of cookstove projects – through the inclusion of black carbon and organic carbon reductions, this still does not overcome the issue of deficient demand and low prices. The calculations found in this study point to a 10 to 20% portion of BC/OC emissions within the total cookstove emissions under consideration. In terms of decentralised electricity generation, the added potential from including SLCPs is negligible. Bold statements currently in circulation such as

- global warming can be reduced by up to half a degree through SLCP reductions (see World Bank 2013 and CCAC 2014), or
- "BLACK CARBON - A Climate Factor Responsible for 20% of Global Warming" (Gold Standard n.d.)

can only be confirmed in part and such generalising statements deserve critical reflection. Even if the warming effect of black carbon appears to have been scientifically validated, while mitigation measures have exhibited quick effects owing to the substance's short duration, this should not lead actors to less intensively combat the long-term effects of carbon dioxide emissions through the corresponding emission reductions (see Allen 2015). This is all the more relevant since financial resources for climate change measures are currently limited. When considering black carbon emissions, the organic carbon emissions that arise in parallel need to be taken into account as well. This broader context is, unfortunately, not taken into account or clearly indicated in all the studies analysed.

The relevance of climate financing mechanisms, such as the GCF, for projects related to basic energy services has been relatively low so far – with the exception of the SGP and GEF. An opportunity does, however, still exist in relation to the GCF for realising projects related to basic energy services in the category of small-scale projects. This is highly dependent on the regulatory framework as well as on the question of whether the GCF sees itself as more of a development bank or as an instrument for battling climate change. The former option would strengthen the role of basic energy service projects, for which many years of experience within development cooperation exist. After its first financing activities were approved in the fall of 2015, it is still too early to make reference to project experiences from the GCF at this stage. In addition, it remains to be seen whether CDM activities might be eligible to receive financing through climate finance institutions including the GCF in the future.

The recently adopted Paris Agreement stands to exhibit significant influence on the financing situation of projects related to basic energy services. However, its relevance as a catalyst for global involvement in climate mitigation, spurring the demand for emission credits and the availability of public climate funding resources, critically depends on its upcoming implementation by the Parties. In particular the introduction and design of the new market mechanisms, the centrally governed Sustainable Development Mechanism (SDM) and a framework for less formalised Cooperative Approaches (CA), will critically shape the future of climate finance and emission trading.

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Annex A: Overview of classification for climatically relevant substances

Greenhouse gases under the Kyoto Protocol

Carbon dioxide (CO_2)

Methane (CH_4)

Nitrous oxide (N_2O)

Hydrofluorocarbons (HFCs)

Perfluorocarbons (PFCs)

Sulfur hexafluoride (SF_6)

Source: United Nations 1998, Annex A

IPCC Classification

	Emitted compound	**Resulting atmospheric drivers**
Well-mixed greenhouse gases	CO_2	CO_2
	CH_4	CO_2, H_2O^{str}, O_3, CH_4
	Halocarbons[21]	O_3, CFCs, HCFCs
	N_2O	N_2O
	HFCs[22], PFCs, SF_6	diverse
Short-lived gases and aerosols	CO	CO_2, CH_4, O_3
	NMVOC	CO_2, CH_4, O_3
	NOx	Nitrate, CH_4, O_3
	Aerosols and precursors (mineral dust, SO_2, NH_3, organic carbon and black carbon)	Mineral dust, sulphate, nitrate, organic carbon, black carbon
		Cloud adjustments due to aerosols

Source: IPCC 2013, p. 14 and 57

Substance abbreviations:	
CO_2	carbon dioxide
CH_4	methane
H_2O^{str}	water (water vapour), in the stratosphere
O_3	ozone
CFCs	chlorofluorocarbons
HCFCs	hydrochlorofluorocarbons
N_2O	nitrous oxide
HFCs	fluorinated hydrocarbons
PFCs	Perfluorinated compounds
SF_6	sulfur hexafluoride
CO	carbon monoxide
NMVOC	non-methane volatile organic compound
NOx	nitrogen oxide
SO_2	sulfur dioxide
NH_3	ammonia

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[21] A few compounds in this group are short-lived. (IPCC 2013, p. 1397)

[22] A few compounds in this group are short-lived. (IPCC 2013, p. 1397)

US EPA Classification / Terminology

Substance:	**Abbreviation:**	**Description:**
Black carbon	BC	BC is a solid form of mostly pure carbon that absorbs solar radiation (light) at all wavelengths. BC is the most effective form of PM, by mass, at absorbing solar energy, and is produced by incomplete combustion.
Organic carbon	OC	OC generally refers to the mix of compounds containing carbon bound with other elements like hydrogen or oxygen. OC may be a product of incomplete combustion, or formed through the oxidation of VOCs in the atmosphere. Both primary and secondary OC possess radiative properties that fall along a continuum from light-absorbing to light-scattering.
Brown carbon	BrC	BrC refers to a class of OC compounds that absorb ultraviolet (UV) and visible solar radiation. Like BC, BrC is a product of incomplete combustion.
Carbonaceous PM		Carbonaceous PM includes BC and OC. Primary combustion particles are largely composed of these materials.
Light absorbing carbon	LAC	Light absorbing carbon consists of BC plus BrC.
Soot		Soot, a complex mixture of mostly BC and OC, is the primary light-absorbing pollutant emitted by the incomplete combustion of fossil fuels, biofuels, and biomass.
Source: US EPA 2012, p. 21		

CCAC/UNEP SLCP Classification

Substance:	**Abbreviation:**	**Description:**
Black Carbon	BC	Black carbon is a major component of soot and is produced by incomplete combustion of fossil fuel and biomass. It is emitted from various sources including diesel cars and trucks, residential stoves, forest fires, agricultural open burning and some industrial facilities. It has a warming impact on climate 460-1500 times stronger than CO_2. Its lifetime varies from a few days to a few weeks. When deposited on ice and snow, black carbon causes both atmospheric warming and an increase of melting rate. It also influences cloud formation and impacts regional circulation and rainfall patterns. In addition, black carbon impacts human health. It is a primary component of particulate matter in air pollution that is the major environmental cause of premature death globally.
Methane	CH_4	Methane (CH_4) is a greenhouse gas that is over 20 times more potent than CO_2, and has an atmospheric lifetime of about 12 years. It is produced through natural processes (i.e. the decomposition of plant and animal waste), but is also emitted from many man-made sources, including coal mines, natural gas and oil systems, and landfills. Methane directly influences the climate system and also has indirect impacts on human health and ecosystems, in particular

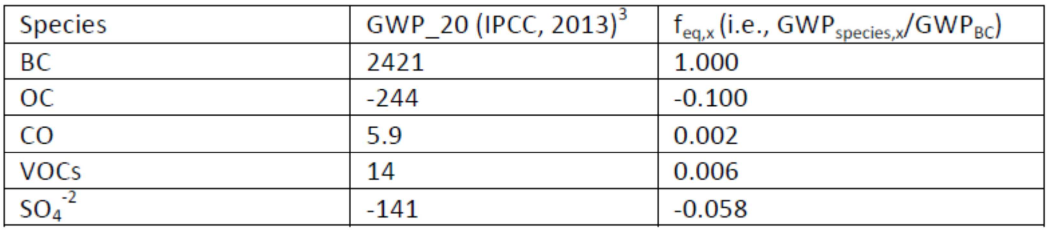
		through its role as a precursor of tropospheric ozone.
Tropospheric ozone	O_3	Tropospheric or ground level ozone (O_3) is the ozone present in the lowest portion of the atmosphere (up to 10-15 km above the ground). It is responsible for a large part of the human enhancement of the global greenhouse effect and has a lifetime of a few days to a few weeks. It is not directly emitted but formed by sunlight-driven oxidation of other agents, called ozone precursors, in particular methane (CH_4) but also carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs) and nitrogen oxides (NO_X). Tropospheric ozone is a harmful pollutant that has detrimental impacts on human health and plants and is responsible for important reductions in crop yields
Hydrofluorocarbons	HFCs	HFCs are man-made greenhouse gases used in air conditioning, refrigeration, solvents, foam blowing agents, and aerosols. Many HFCs remain in the atmosphere for less than 15 years. Though they represent a small fraction of the current total greenhouse gases (less than one percent), their warming impact is particularly strong and, if left unchecked, HFCs could account for nearly 20 percent of climate pollution by 2050.
Source: Climate & Clean Air Coalition to reduce short-lived climate pollutants. *Website: http://www.unep.org/ccac/Short-LivedClimatePollutants/Definitions/tabid/130285*		

Annex B: Overview of available quantification methodologies

This annex contains an overview of commonly applied methodologies for the area of cooking energy (❶) as well as decentralised electricity generation (❷). This section considers both CDM and GS methodologies. This overview is by no means exhaustive. CDM methodologies can be viewed on the website https://cdm.unfccc.int/methodologies/SSCmethodologies/approved, the GS methodologies at http://www.goldstandard.org/resources/energy-requirements.

Entries in column 1: *Mechanism (CDM or GS)* *Application (❶=cooking energy, ❷=decentralised electricity generation, ❸=other areas)* *⓿=primary focus, ⓪=secondary focus* *Climatically relevant substances considered by the methodology*	
CDM ❶❷ CO_2	Even if the CDM small-scale methodology **AMS-I.C. "Thermal energy production with or without electricity"** (Version 20.0) does not primarily target the area of cooking energy, there are a number of cooking energy projects that apply this methodology. The methodology finds particular use in combination with biogas projects for households. Additionally, numerous projects for solar water heating apply this methodology. This primarily involves the use of renewable energy sources such as solar energy biomass/biogas. As cogeneration of power and heat is also permitted, electricity can likewise be produced. In calculations for the **emission reduction** in smaller scale systems (capacity), thermal energy output is divided by the efficiency of the baseline system and then multiplied by a (CO_2) emission factor for the fossil fuel used in the baseline situation. Along with determining the electricity generated, **monitoring** also encompasses numerous parameters that are relevant according to the type and scope of the projects.
CDM ❶ CO_2	The CDM small-scale methodology **AMS-I.E. "Switch from non-renewable biomass for thermal applications by the user"** (Version 6.0) is one of the central methodologies within cooking energy. It addresses the replacement of non-renewable biomass through renewable energy sources. The area of application includes drinking water systems as well as cookstoves. The renewable energy sources are typically solar energy or renewable biomass and biogas. This methodology relates to the portion of non-renewable biomass of the firewood used in a country and makes reference to the option of country-specific standard values published through the CDM (https://cdm.unfccc.int/DNA/fNRB/index.html). The **emission reduction** is calculated on the basis of the emission factor of 81.6 t CO_2/TJ, which represents an estimated theoretical mix for fossil fuels. This is solely based on the possible emission of carbon dioxide arising from burning. The fuel usage on which this is based can be determined based on historic data or sampling. **Monitoring** encompasses an assessment of the functionality of the distributed cookstoves. On account of the large number of cookstoves

	covered through this methodology, sampling is permissible.
CDM ❶ CO_2	The CDM small-scale methodology **AMS-I.I. “Biogas/biomass thermal applications for households/small users”** (Version 4.0) specifically targets the implementation of many (small) cookstoves along with applications for which biogas or biomass is used. In principle, however, it shares a similar structure with the AMS-I.C.
CDM ❶ CO_2	The CDM small-scale methodology **AMS-I.K. “Solar cookers for households”** (Version 1.0) is, similar to the AMS-I.I. methodology, also a variant of the AMS-I.C. methodology.
CDM ❶ CO_2	The CDM small-scale methodology **AMS-II.G. “Energy efficiency measures in thermal applications of non-renewable biomass”** (Version 7.0) is the second CDM methodology that is specifically intended for the topic of cookstoves. In contrast to the “fuel transition” inherent in the AMS-I.E., this methodology addresses the issue of efficiency increases for cookstoves and other applications. Reductions in the use of non-renewable biomass are targeted here. The **emission reduction**, realised through fuel savings, is then calculated similarly to the AMS-I.E. methodology with the emission factor of 81.6 t CO_2/TJ, which represents an estimated fossil fuel mix. Compared to the AMS-I.E., **monitoring** is here essentially extended to determining the efficiency of cookstoves.
CDM ❶❸ CH_4	The CDM large-scale methodology **ACM0021 “Reduction of emissions from charcoal production by improved kiln design and/or abatement of methane”** (Version 1.0.0) can be applied to methane reductions in charcoal production. The project emissions under consideration here include unavoided methane emissions from the production processes along with CO_2 emissions from additional electricity and fuel usage.
CDM ❶❸ CH_4	The CDM small-scale methodology **AMS-III.K. “Avoidance of methane release from charcoal production”** (Version 5.0) defines the basis for methane reductions for small-scale projects, similar to ACM0021. The project emissions under consideration here include unavoided methane emissions from production processes along with CO_2 emissions from additional electricity and fuel use.
CDM ❶❸ CO_2 CH_4	The CDM small-scale methodology **AMS-III.BG. “Emission reduction through sustainable charcoal production and consumption”** (Version 3.0) combines emission reductions stemming from the substitution of non-renewable through renewable biomass as well as the reduction of methane emissions in charcoal production. The standard value of 0.03 t methane/t charcoal is defined as the baseline for charcoal production. The project emissions under consideration here include unavoided methane emissions from the production process along with CO_2 emissions from additional electricity and fuel use.
GS ❶ CO_2	The Gold Standard methodology **“Simplified Methodology for Efficient Cookstoves”** essentially has the same scope as the CDM AMS-II.G methodology. It does, however, use a different approach for calculating the **emission reduction**. Rather than applying an emission factor based on a mix of thermal fossil fuels, a standard value of 1.747

<table>
<tr>
<td>CH_4
N_2O</td>
<td>tCO_2/t firewood is taken for the CO_2 emissions along with a value of 0.455 tCO_2/t firewood for non-CO_2 emissions, in accordance with IPCC (2006). As a result, higher emission reduction values are achieved here compared to the CDM.</td>
</tr>
<tr>
<td>GS
❶
CO_2
CH_4
N_2O</td>
<td>The Gold Standard methodology “Technologies and Practices to Displace Decentralised Thermal Energy Consumption” is likewise applicable for cookstoves and follows the same approach in relation to the emissions factors. It differentiates between a CO_2 emission factor and a non-CO_2 emissions factor in calculating the emissions reduction. The corresponding values should be assessed for specific fuels. This methodology is of particular significance being that it is linked to the Gold Standard methodology on the topic of black carbon.</td>
</tr>
<tr>
<td>GS
❶
BC
OC
CO
NO_x
NMVOC
SO_4</td>
<td>
<p>The Gold Standard methodology “Quantification of climate related emission reductions of Black Carbon and Co-emitted Species due to the replacement of less efficient cookstoves with improved efficiency cookstoves” goes beyond identifying the typical set of greenhouse gases (CO_2, CH_4 and N_2O). The following substances are considered: BC, OC, CO, NO_x, NMVOCs and SO_2. These are summarised as “black carbon and co-emitted species” and given in units of kg BCe. The calculation for the emission reduction is based on the difference in emissions between the projects and baseline. The respective total emissions result from an emission factor (g of each substance emitted per kg of fuel used), which has to be identified by the monitoring process, the total fuel consumption, and a factor through which the various substances are transferred to the sum parameters. These factors are, in turn, based on the GWP_{20} according to IPCC (2013); the following values have been set:</p>

<table>
<tr><th>Species</th><th>GWP_20 (IPCC, 2013)[3]</th><th>$f_{eq,x}$ (i.e., $GWP_{species,x}/GWP_{BC}$)</th></tr>
<tr><td>BC</td><td>2421</td><td>1.000</td></tr>
<tr><td>OC</td><td>-244</td><td>-0.100</td></tr>
<tr><td>CO</td><td>5.9</td><td>0.002</td></tr>
<tr><td>VOCs</td><td>14</td><td>0.006</td></tr>
<tr><td>SO_4^{-2}</td><td>-141</td><td>-0.058</td></tr>
</table>
<p><i>Source Gold Standard (2013, p.7)</i></p>
<p>Compared to “conventional” cookstove methodologies, this likely entails a larger monitoring effort due to the necessary laboratory analyses and field tests.</p>
<p>“Black Carbon Equivalent (BCe) Emission Reduction” are calculated rather than “Verified Emission Reductions (VERs) within this methodological framework. It therefore does not envision or allow for any direct comparisons or a conversion into VERs.</p>
</td>
</tr>
<tr>
<td>CDM
❷
CO_2</td>
<td>The CDM small-scale methodology AMS-I.A. “Electricity generation by the user” (Version 16) for the area of decentralised electricity generation targets energy services for households that have lacked grid connections. Technologies that can be applied here include solar, hydro wind and biomass. It allows for the establishment of new facilities (Greenfield) as well as the replacement of existing systems that use fossil</td>
</tr>
</table>

	fuels. In order to compensate for transmission and distribution losses arising from diesel generator-based “mini grids”, an emission factor of 0.8 kg CO_2e/kWh is taken as a standard value for calculating the **emission reduction**, which is either based on the electricity consumption of the connected consumers or on the amount of electricity generated. Alternatively, the CDM AMS-I.F. methodology values from outlined in Table 2 can be applied provided there is a justification. As a CDM methodology, black carbon / organic carbon emissions are not taken into account here. This methodology only makes use of CO_2 emissions as a basis for calculation, derived from the combustion of diesel. Along with an assessment of the functionality of all components, **monitoring** must also identifies the amount of electricity and the total fuel consumption, for cases in which biomass is used.
CDM ❷ CO_2	The CDM small-scale methodology **AMS-I.F. “Renewable electricity generation for captive use and mini-grid”** (Version 3.0) is similar in form to the AMS-I.A. methodology, though it also takes account of situations in which consumers are supplied with electricity from a national or regional power grid. The **emission reduction** is calculated on the basis of electricity production and the corresponding emissions factors. The respective values for this methodology can be found in Table 2, which may also be used for AMS-I.A.. The standard value is 0.8 kg CO_2e/kWh; depending on the situation, a value of up to 2.4 kg CO_2e/kWh may also be applied. As with the AMS-I.A. methodology, only CO_2 is taken into account. **Monitoring** identifies the electricity production as well as the respective fuel consumption. Additionally, this methodology also presents an overview in Table 3 that is applicable for the CDM methodologies AMS-I.A., AMS-I.D. and AMS-I.F.
CDM ❷❸ CO_2	The **CDM** small-scale methodology **AMS-I.B. “Mechanical energy for the user with or without electrical energy”** (Version 12.0) addresses the availability of mechanical energy for households and other users, but it also allows for the generation of electricity. The installation of water pumps or machines run by solar or wind energy would represent a typical project. This methodology assumes that mechanical energy is otherwise derived from diesel motors. The **emission reduction** is determined by way of CO_2 emissions from burning diesel, as in the AMS-I.A. and AMS-I.F. methodologies. Emissions arising from the electricity or fossil fuels used within the project are taken to be project emissions. Moreover, emissions from the cultivation of biomass (CO_2, CH_4 and N_2O), if present, are taken into account and the corresponding parameters identified through **monitoring**.
CDM ❷ CO_2	The **CDM** small-scale methodology **AMS-I.L. “Electrification of rural communities using renewable energy”** (Version 3.0) addresses electricity generation from renewable energy sources and the development of “mini grids”, solely fed by renewables, in municipalities not connected to a national grid or regional grid. Households must comprise 75% of the users. Fossil systems are taken as a baseline (diesel generators or candles and kerosene lamps). The amount of electricity generated

	by the project is multiplied by emissions factors in order to calculate the **emission reduction**. The following standard values are to be applied: 6.8 kg CO_2/kWh up to the first 55kWh per year and consumer; 1.3 kg CO_2/kWh for consumption beyond that, up to 250 kWh; and 1.0 kg CO_2/kWh for consumption above 250 kWh. Factors that have to be identified for **monitoring** include electricity consumption according to consumer type (household or non-household).

Annex C: Selection of quantitative data for effects on the climate

Emissions of well-mixed GHGs and SLCFs from woodfuels are 1.0–1.2 Gt CO_2e / year.

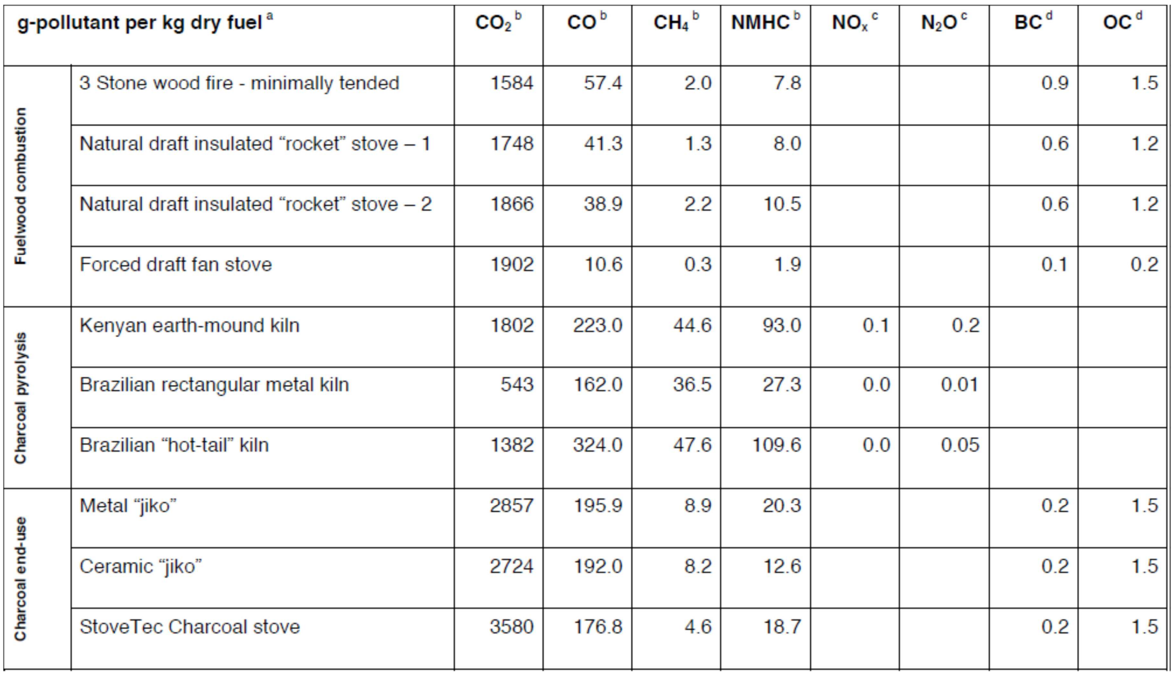
100 million improved stoves could reduce this by 11–17%.

Source: Bailis et al. 2015, p. 269 and 266

Traditional solid fuel stoves and open cooking fires account for over 1.5 Mt of black carbon, which represents 20% of global black carbon emissions.

Source: World Bank 2015, p. 24

Emission factors of GHGs and SLCFs from woodfuel combustion and charcoal pyrolysis:



g-pollutant per kg dry fuel [a]		**CO_2** [b]	**CO** [b]	**CH_4** [b]	**NMHC** [b]	**NO_x** [c]	**N_2O** [c]	**BC** [d]	**OC** [d]
Fuelwood combustion	3 Stone wood fire - minimally tended	1584	57.4	2.0	7.8			0.9	1.5
	Natural draft insulated “rocket” stove – 1	1748	41.3	1.3	8.0			0.6	1.2
	Natural draft insulated “rocket” stove – 2	1866	38.9	2.2	10.5			0.6	1.2
	Forced draft fan stove	1902	10.6	0.3	1.9			0.1	0.2
Charcoal pyrolysis	Kenyan earth-mound kiln	1802	223.0	44.6	93.0	0.1	0.2		
	Brazilian rectangular metal kiln	543	162.0	36.5	27.3	0.0	0.01		
	Brazilian “hot-tail” kiln	1382	324.0	47.6	109.6	0.0	0.05		
Charcoal end-use	Metal “jiko”	2857	195.9	8.9	20.3			0.2	1.5
	Ceramic “jiko”	2724	192.0	8.2	12.6			0.2	1.5
	StoveTec Charcoal stove	3580	176.8	4.6	18.7			0.2	1.5

Bailis et al. 2015, Supplementary information, Table 12, p. 41

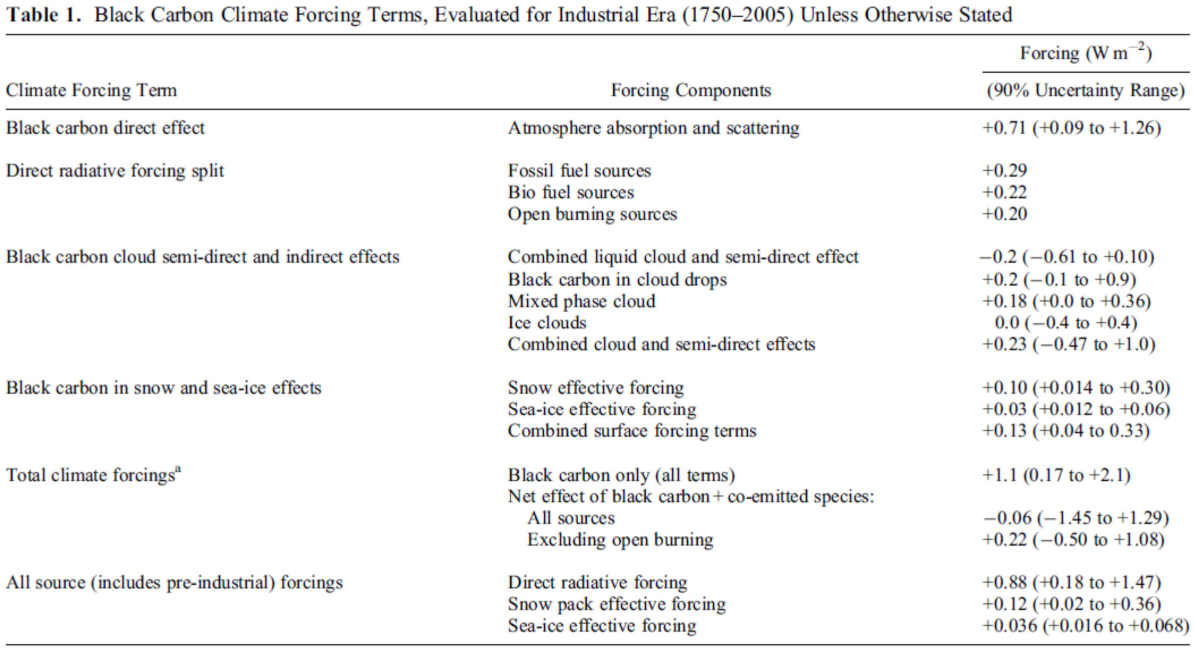


Table 1. Black Carbon Climate Forcing Terms, Evaluated for Industrial Era (1750–2005) Unless Otherwise Stated

Climate Forcing Term	Forcing Components	Forcing (W m^{-2}) (90% Uncertainty Range)
Black carbon direct effect	Atmosphere absorption and scattering	+0.71 (+0.09 to +1.26)
Direct radiative forcing split	Fossil fuel sources	+0.29
	Bio fuel sources	+0.22
	Open burning sources	+0.20
Black carbon cloud semi-direct and indirect effects	Combined liquid cloud and semi-direct effect	−0.2 (−0.61 to +0.10)
	Black carbon in cloud drops	+0.2 (−0.1 to +0.9)
	Mixed phase cloud	+0.18 (+0.0 to +0.36)
	Ice clouds	0.0 (−0.4 to +0.4)
	Combined cloud and semi-direct effects	+0.23 (−0.47 to +1.0)
Black carbon in snow and sea-ice effects	Snow effective forcing	+0.10 (+0.014 to +0.30)
	Sea-ice effective forcing	+0.03 (+0.012 to +0.06)
	Combined surface forcing terms	+0.13 (+0.04 to 0.33)
Total climate forcings[a]	Black carbon only (all terms)	+1.1 (0.17 to +2.1)
	Net effect of black carbon + co-emitted species:	
	All sources	−0.06 (−1.45 to +1.29)
	Excluding open burning	+0.22 (−0.50 to +1.08)
All source (includes pre-industrial) forcings	Direct radiative forcing	+0.88 (+0.18 to +1.47)
	Snow pack effective forcing	+0.12 (+0.02 to +0.36)
	Sea-ice effective forcing	+0.036 (+0.016 to +0.068)

Source: Bond et al. 2013, Table 1, p. 5386

(Regional) Decrease in radiative forcing from black carbon reduction measures:

Himalayas: –7.3 W/m^2 (–3.0 to –11.6)

Artic:–1.4 W/m^2 (–0.6 to –2.2)

East African Highlands: –1.2 W/m^2 (+0.7 to –3.1)

Andes and Patagonia: –0.3 W/m^2 (+0.1 to –0.7)

Antarctica: –1.1 W/m^2 (–0.5 to –1.7)

Source: World Bank and International Cryosphere Climate Initiative 2013, p. 35, 37, 39,