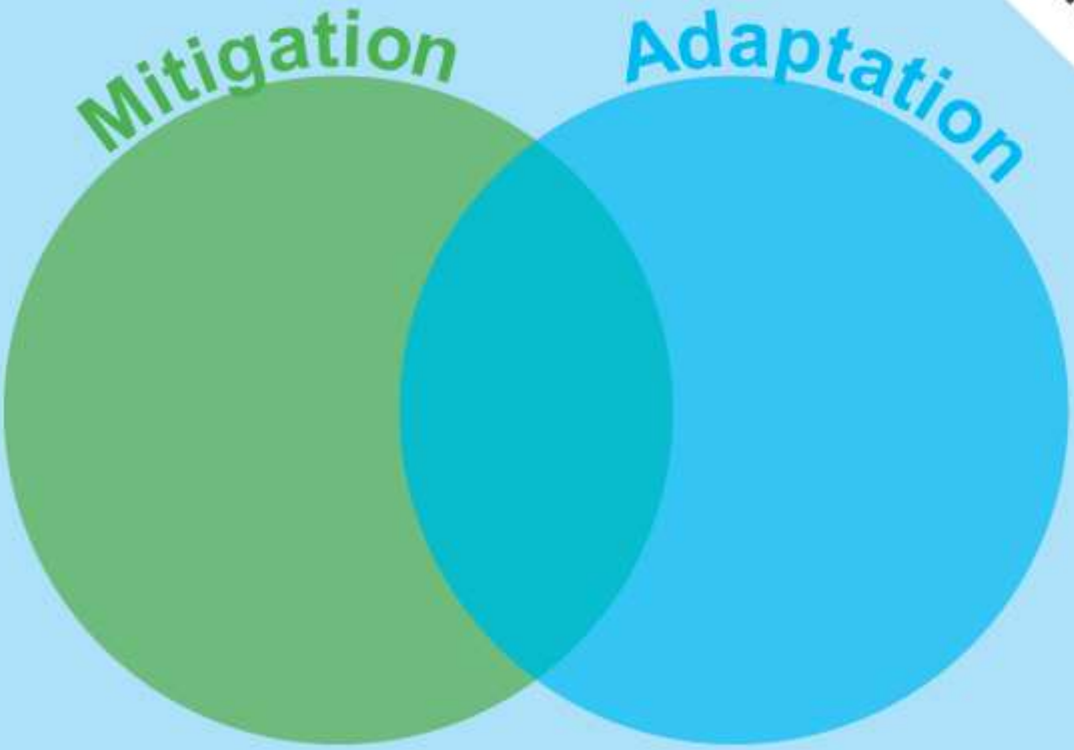
White Paper



WHITE PAPER
Climate Mitigation and Adaptation with Eco-Village Development (EVD) Solutions in South Asia

2nd Edition, October 2018

IDEA Grameen Shakti inseda wafd INFORSE-South ASIA International Network for Sustainable Energy CANSA South Asia

White Paper on Climate Mitigation and Adaption with Eco-Village Development (EVD) Solutions in South Asia

2nd Edition, October 2018

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Read more on the project and download this and other publications from
http://www.inforse.org/asia/EVD.htm and http://www.ecovillagedevelopment.net/

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List of Contents

1. Summary for Policy Makers page 2
2. Introduction page 4
3. Improved Cookstoves page 7
4. Household Biogas Plants page 18
5. Household Scale Power (solar home systems, solar lamps) page 25
6. Village Scale Power (mini and micro grids) page 27
7. Solar Drying page 30
8. Organic Farming and Composting page 32
9. Climate Mitigation Effects on Village Level page 34

References page 39
Appendix 1 page 42

1. Summary for Policy Makers

This White Paper *"Climate Mitigation and Adaptation with Eco-Village Development (EVD) Solutions in South Asia"* analyses and presents climate-effects of EVD solutions, using existing cases from villages in South Asia. EVD combines village-level developmental planning with local sustainable solutions to give villagers climate-resilient supplies of energy, water, agricultural products, and other necessities and livelihood improvements, depending upon the choices of the villagers.

The authors select six high-impact EVD solutions and describe the importance of each in mitigation of climate change and adaptation to climate change. Improved cookstoves, household biogas plants, solar home systems, renewable energy mini- and micro-grids, solar drying, and organic farming (including composting) have been found to reduce greenhouse-gas (GHG) and particle emissions considerably while improving quality of life.

The analysis covers all substantial greenhouse emissions that the authors could identify and quantify, gases as well as particles of black carbon. Adaptation benefits are identified as well, but not quantified. The selected high-impact EVD solutions are analysed in the chapters 3-8. Chapter 9 presents examples of total village-level GHG-emission reductions.

The following table briefly summarizes the six key technologies and their major climate impacts.

EVD Solution	Mitigation Impact	Adaptation Impact
Improved Cookstove (ICS) Technologies	In households: GHG and black-carbon emissions from cooking are reduced by 1-3 tons CO_2 - equivalents (CO_2e) per family per year.	Not assessed (n.a.)
	In village and household industries, GHG and black carbon emissions are reduced significantly.	n.a.
Household Biogas Plants	GHG and black carbon emissions from cooking and agriculture are reduced by 1 - 4 tons CO_2e per family per year.	Soil improvement
Solar Lighting	Use in homes reduces CO_2 emissions from kerosene and other non-solar light sources by roughly 0.34 tons per family per year.	Provides light during cyclones
Solar or hydro micro- and mini-grids	Typical reduces CO_2 emissions from uses of electricity and/or of diesel engines by 0.7 tons per family per year.	n.a.
Solar Dryers	Typically reduces CO_2 emissions by 1.4-3 tons per year when solar drying replaces electric or fossil-fuelled dryers.	Preservation of food in changing weather
Organic Farming & Gardening, Including Composting	Organic practices replace GHG producing N-fertiliser, increase soil carbon, which reduces CO_2 emissions from agriculture. It is difficult to quantify emission reductions.	Improve soil for moisture retention. Crop rotation gives more stable yield in changing climate

From the selected case studies, the authors find the following village-level climate mitigation effects:

- For every 100 households adopting the selected EVD solutions, emissions can be reduced by nearly 500 tons of CO_2 - equivalent (CO_2e)/year compared with a baseline of traditional provision of cooking and light, such as electricity from kerosene, diesel, or the Indian central power grid.
- In two examples based on actual villages with 50 and 70 families, EVD solutions reduce GHG emissions by respectively, 546 and 114 tons of CO_2e/year, while helping the villagers with better energy and livelihoods.
- For a cluster of several villages, emission reductions with EVD solutions are estimated to be around 1800 tons CO_2e/year by the end of the implementation, which provides improved cooking technologies and solar dryers to 250 households.

Analysis of the range of EVD solutions reveals that the greatest mitigation benefits and co-benefits come from improvements of cooking technologies. Of the cooking practices analysed, use of biogas delivers the highest GHG reductions. The next-highest potential for mitigation comes with changing to renewable energy use for electricity. In some villages, other energy uses, such as brick-making, give high emissions.

Some of the emission reductions discussed here are recognised internationally today and are eligible for support from the Clean Development Mechanism (CDM), Gold Standard, and other emission-reduction projects. This is particularly true of CO_2 emission reductions from introduction of improved cooking technologies and of solar home systems. The GHG reductions that the authors identify in two of the three village case studies encompass and surpass these recognised benefits because they include all GHGs, such as black-carbon. Emissions of these previously overlooked greenhouse-effecting particles are considerably reduced with improved cooking solutions.

A smaller but significant GHG reduction comes with the inclusion of solutions, which are normally not covered by CDM projects. In this analysis this is the case of the solar dryers.

Importantly, this White Paper points out significant, verifiable, cumulative climate benefits from combined solutions with emphasis on climate mitigation as well as on climate adaptation benefits.

2. Introduction

In South Asia, more than half the population lives in villages and the development of the subcontinent is linked to the development of the villages. One concept for a sustainable development for villages in South Asia is the Eco-Village Development (EVD) concept. EVD is an integrated low-carbon development approach in pre-existing villages. The aims of EVD include village-based developments and livelihood improvements as well as climate change adaptation and mitigation.

The EVD involves the implementation of inexpensive renewable energy solutions, food security interventions, and livelihood enhancing solutions. The bundle of practices includes technologies like household size biogas plants, improved cookstoves, solar energy (that are development solutions that contribute to mitigation and eventually climate adaptation), roof-water harvesting, solar greenhouse technology and others (that are development solutions that in some situations contribute to climate adaptation).

In EVD, the solutions are pro-poor, replicable, cost-effective, income generating, climate resilient, and low emission of greenhouse drivers (gases and particles) as well as of local pollutants. The concept includes adapting solutions to local needs and circumstances while including a bottom-up, multi-stakeholder approach, gender mainstreaming, and technology transfers where appropriate.

In the table 2.1 are the main EVD solutions listed with their effects on greenhouse emissions, indicating those analysed in this report as well as the main ones that are omitted in the following.

This report analyses several local Clean Development Mechanism (CDM) projects on EVD solutions (improved cookstoves, household biogas, solar home systems). Because of the nature of CDM, which allows industrialised countries and specific emitters (as airline passengers) to buy certified emission reductions (CER) credits generated by emission reductions in developing projects, these emission reductions are well-documented according to established methodologies.

By looking at the EVD project interventions, and its effects on unsustainable fuel use, emissions and related issues, a comparison can be made between the more traditional development route or lack of development, and the gains of implementing EVD solutions. The report takes project examples from Bangladesh, India, Nepal, and Sri Lanka, and also the literature used is predominantly specific to this area.

It is important to note that these technologies have measurable as well as intangible co-benefits to the households and local communities as well. These co-benefits have been shown to have further cascading, indirect effects on greenhouse emissions due to behavioural changes in the project communities. However, despite the wealth of anecdotal data in this regard[1], given the current challenges with collecting reliable, verifiable and easily quantifiable data on these co-benefits, we have left this aspect out of the analyses presented in this paper.

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[1]See *Eco Village Development as Climate Solution. Proposals from South Asia, August 2016,* INFORSE-South Asia: http://www.inforse.org/asia/EVD.htm . See also, Eco Village Development Case Studies, 2017, WAFD: http://www.climateandgender.org/wp-content/uploads/2017/08/Case-studies2.pdf .

Table 2.1: Main EVD solutions, their mitigation effects, and if they are included in the analysis in this report.

Solution	Mitigation type	Mitigation importance*	Adaptation type	Analysed in this report
Improved Cookstove (ICS)	Reduces emissions of cooking, CO_2 and other emissions	High	Not assessed (n.a.)	Mitigation
Large ICS for Rural Household Industries	Reduces emissions of household industries, CO_2 and other emissions	Medium on village level (high on individual level)	n.a.	Mitigation mentioned under ICS
Improved brickmaking	Reduces emissions on household industries, CO_2 and others	Medium on village level (high on individual level)	n.a.	No
Household biogas	Reduces emission of cooking and in agriculture	High	Soil improvement	Mitigation
Solar light in homes	Reduces emissions of CO_2 from kerosene and others	High	Gives light and communication during cyclones	Mitigation Adaptation
Solar and hydro micro and mini grids	Reduces emissions of $CO_2$from electricity and diesel engines	High	n.a.	Mitigation
Improved water mills	Reduces emissions of $CO_2$from electricity and diesel engines	High where streams available	n.a.	Mitigation
Hydraulic Ram pumps	Replaces diesel and electric pumps, reducing CO_2emissions	High where streams available	Improve water supply	No
Rainwater harvesting	Replaces piped and collected water which reduce electricity for water pumping thereby reducing emissions of CO_2	Small	Irrigation and alternative water source	No
Micro irrigation	Saves irrigation water	Small	Better crop yield in changing rain	No
Solar dryer	Replaces electric and fossil fuel drying, reducing emissions of CO_2	Medium	Preservation of food in changing weather	Mitigation Adaptation

Organic farming & gardening Composting	Replace N-fertiliser that has greenhouse emission in production	Medium – Small	Improve soil for moisture retention- crop rotation for more stable yield	Mitigation Adaptation
Greenhouses	Effects not evaluated	Not evaluated	Better farming in changing weather	No

* Mitigation importance is the estimate by the authors of the effects on a South Asian scale. Solutions with small-medium importance on the regional scale can have high importance on local/village scale, such as hydraulic ram pumps and large improved stoves for village industries.

The EVD Concept and practices are described in the publication "**Eco Village Development as Climate Solution. Proposals from South Asia",** published in August 2016 / 4th edition 2017. The Publication and other information on EVD is available from INFORSE-South Asia:
http://www.inforse.org/asia/EVD.htm
http://www.inforse.org/asia/Pub_EcoVillageDev_SouthAsia.htm

3. Improved Cookstoves

Photos: Anagi improved cookstove (Sri Lanka, left), improved cookstove with chimney (India), Heera improved cookstove with chimney and water tank (India). Photos by IDEA, AIWC (India), and INSEDA.

3.0 Introduction and Summary

The cooking solutions proposed as part of the eco-village developments are to replace traditional cooking over simple fire-places and stoves with improved cookstove solutions with higher efficiency and less pollution, indoor as well as outdoor. The global technical potential for greenhouse emission reductions with improved cookstove projects has been estimated to 1 gigaton of carbon dioxide equivalents (1 Gt CO_2e) per year, based on 1 to 3 tons of CO_2e per stove (Müller et al. 2011). Our analysis finds an average reduction of global warming equivalent to 2 tons of CO_2e per stove of CO_2 only and around 3 tons CO_2e if other greenhouse gases and particles are included. If the (wood) fuel is grown sustainably, it is only the non-CO_2 gases + particles that contribute to global warming, but if it is unsustainable felling, also the CO_2-emissions contribute. Often the biomass is partly sustainable. With the use of residues and dung as fuel, part of the CO_2 released would also be released with normal decomposing such as combustion, but by far not all.

As it is estimated that as much as two third of India's households still rely on traditional biomass for cooking (IEA 2015), an average of 2 ton of CO_2e reduction per cookstove will represent a national reduction of 340 million tons of CO_{2e} emissions-or about ⅓ of the global estimate mentioned above. Apart from the above reduction of global warming, improved cookstoves will typically reduce the solid biomass used for cooking and heating with around 50%.

In addition to global warming, the change to improved cookstoves will lead to considerable health benefits and money/time saved on gathering or purchasing fuel. The health problems of indoor air pollution, in particular with small particles (pm 2.5), is a major problem in many developing countries, in particular for women and children. Improved cookstoves reduce this because of less fuel use and more complete combustion, and for improved cookstoves with chimneys also by avoiding the emission of the flue gases in the kitchen.
Another benefit for development and poverty reduction is that the reduced time spent in collecting fuel wood can be invested in other work such as education children. Cookstoves with additional features, such as water heating, can further reduce drudgery of women. Improved cookstoves can also be the basis for kitchen improvements, to give better working conditions in the kitchen in a number of ways.

In addition to cooking of own food, some villages have commercial cooking for village productions, hotels, schools, and others. Often this cooking is done with traditional stoves or three stone fires. Given the large consumption at these facilities, they have a bigger risk of driving unsustainable fuel use than normal households.
With commercial improved cookstoves, the reductions in fuel use and emissions can be large. In a case from Sri Lanka, reported reductions in fuel wood use was a factor 5, and the user reports that she with this reduction could grow the fuel wood herself. Therefore, the risk of using unsustainable use becomes very small. (IDEA 2018)

To compare cookstove performances, The Global Alliance for Clean Cookstoves has cooperated with the International Standardization Organization (ISO) to develop a standard for this. The result is the IWA (International Workshop Agreement) 11: 2012: "*Guidelines for evaluating cookstove performance*" [IWA 11:2012]. This standard rates cookstoves on four (4) indicators (efficiency, indoor emissions, total emissions, safety), for each indicator dividing the stoves in 5 Tiers (0: lowest performing to 4: highest performing). The tier boundaries are defined by quantitative limit values determined by laboratory testing. See the limit values in Table 3.7.
This is expected to encourage a consumer based "selection of the fittest" development of the improved cook stove (ICS) production. Unfortunately, at the time of printing of this publication (October 2018), most of the stoves, used in the EVD project, have not been rated according to the IWA scheme.

Figure 3.1: Improved Cookstoves ratings according to IWA11:2012.

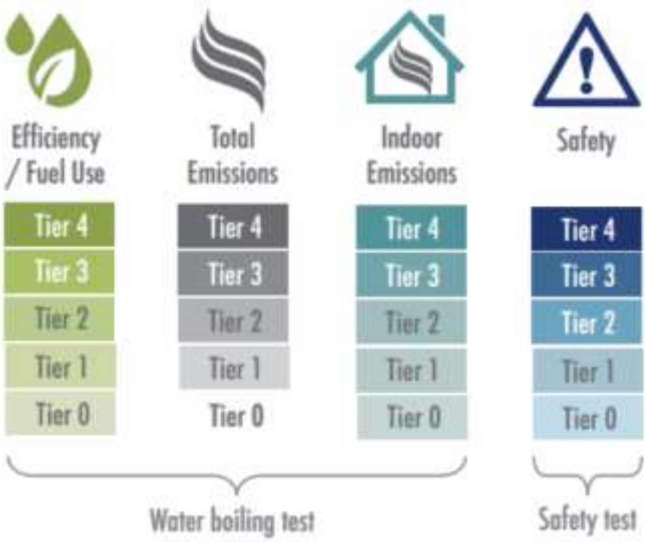

Table 3.1: Comparison of wood-burning cookstoves net greenhouse gas (GHG) emissions per year

Stove and fuel type	Net GHG emissions per year	GHG Savings over traditional stove, unsustainable wood	GHG Savings over traditional stove, sustainable wood*
Traditional cookstove, unsustainable wood	4.4 ton CO_2e	0	n.a
Traditional cookstoves, sustainable wood	1.6 ton CO_2e	2.8 ton CO_2e*	0
Improved cookstove, tier 1	2 / 0.4 ton CO_2e	2.4 tonCO_2e	1.2 ton CO_2e
Improved cookstoves, tier 3	1.1 / 0.2 ton CO_2e	3.3 ton CO_2e	1.4 tonCO_2e
LPG stove	0.4 ton CO_2e	4 ton CO_2e	1.2 ton CO_2e

** With change from unsustainable to fully sustainable wood.*

The data includes CO_2, particles such as black carbon and organic gases. For improved cookstoves, the figures illustrate use of sustainable and unsustainable wood respectively, but they do not include indirect land-use effects. Average figures are used and hence they contain some uncertainty, as explained in the following pages. For charcoal stoves, greenhouse emissions and savings potentials are larger due to the inefficient production of charcoal.

The comparison illustrates the obvious priority of shifting from use of unsustainable biomass to any of the alternative means of cooking and fuel type.

The indirect land-use effects are very context-specific, so it is not possible to give an indication for all cases. In a best-case situation there is no effect, if for instance the trees used for firewood are also grown for other purposes, such as shading, and the wood is not used for other purposes, but is discarded with burning. In the worst-case situation, where a fuel-forest is planted that replaces other agriculture that is then shifted to land that is cleared in a deforestation process, the effect is substantial, and similar to the unsustainable biomass use.

3.1 GHG Cookstoves Baseline

The effect of cookstoves on greenhouse emissions on the household level can hardly be overstated. In India, the primary fuels used in rural areas in 2011 were firewood (62,5 %), crop residues (12,3%), LPG (11,4%) and dung cakes (10,9%) (Singh et al., 2014: 1036).[12] In some rural districts, firewood use can even be close to 100% (97.9% in the Indian Kolar District, Karnataka State, for instance) (SACRED, 2012: 17). Developments in the last decade have been that the use of dung is decreasing, and the use of firewood is increasing (TERI, 2010: 17). LPG consumption is projected to increase, which reflects the increasing wealth of rural households, and in some areas also subsidies. For the target groups of many of the projects analysed, the cost barrier for LPG is nevertheless too high and traditional fuels prevail as the main sources of energy (SACRED, 2012: 16).

In some cases, the greenhouse gases emitted from biomass used for cooking in for instance can be several times more than from cooking with fossil fuel use in the form of LPG (Bhattacharya and Salam, 2002: 306, Kool et al., 2012: 13). For all of these reasons the baseline of this chapter focuses on firewood. Data for LPG use is included for comparison.

The traditional stoves have efficiencies usually lying between only 5% and 15% according to a number of field surveys (Bond and Templeton, 2011: 349). In laboratory conditions efficiencies have reached up to above 25% (RTKC, 2017), but this is not representative of practical use.

2 *Figures are from the 2011 National census.*

The following table outlines the prevalent traditional stoves in the South Asia, and their efficiency rates. These cookstoves are roughly divided into stoves using wood/agri-residues and charcoal burning stoves (Bhattacharya et al., 2005: 162).

Table 3.2: Efficiency of traditional South Asian cookstoves

Country	Type of Stove	Efficiency (%)	Fuel type
India	Simple mud chulha Traditional Indian chulha Sheet metal un-insulated chulha Mud coated bucket chulha	12.0 12.5 18.0 21.0	Fuelwood, dung Fuelwood, crop residues, dung Charcoal Charcoal
Nepal	Agenu (open fire stove) Chulo/mud stove	8.9 12.0	Fuelwood, residues, dung Fuelwood, residues
Sri Lanka	Single and two pot mud stove Three-stone stove	13.0 8.0	Fuelwood-agri-residues Fuelwood-agri-residues
Bangladesh	Mud stove	5.0-15.0	Biomass (various)

Data in table adapted from: (Perera and Sugathapala, 2002: 92, Bhattacharya and Salam, 2002: 308, Bond and Templeton, 2011: 349).[3]

The low efficiencies of traditional stoves translate directly into high fuel consumptions, high emissions, and high life cycle costs.

When cooking is done with wood from areas with deforestation, or with coal, the full amount of CO_2, that is emitted with combustion, is contributing to build-up of CO_2 in the atmosphere. When cooking is done with materials that otherwise would be returned to the soil, such as cow-dung, the emissions from combustion is replacing partly biological degradation of the materials, the CO_2 build-up in the atmosphere is only a part of the emissions from the combustion. This fraction will typically vary from a minimum of 50% for woody materials to around 90% for manure, over a 20-year horizon. If the biomass is derived from sustainable farming and forestry practices, there are no net effect on CO_2 in the atmosphere. There may still be indirect effects in the form of indirect land-use changes, where the wood/biomass production replaces food crops, which subsequently have to be produced on other areas.

CO_2 emissions from combustion of coal and unsustainable biomass is around 0,39 kg CO_2/kWh of fuel[4].
When cooking is done with biomass that otherwise would be returned to the soil, we can assume an average of 1/3 of this level of emissions, around 0,13 kg CO_2/kWh in a 20-year perspective or less. This is based on the assumption that 2/3 or more of the hydrocarbons in the biomass will be converted to CO_2 and water within 20 years by normal processes, such as composting.
Combustion of LPG gives CO_2 emissions of 0.26 kg/kWh of gas[5]. In addition to the lower specific emission of gas compared with unsustainable biomass, LPG stoves are more efficient than biomass stoves.

Stoves emit a number of different gases and particles. While CO_2 is the best-known greenhouse gas, also a number of products of incomplete combustion (PIC) contribute to global warming. These emissions include methane (CH_4), non-methane hydro-carbon gases (NM-HC), laughing gas (N_2O), and particles of black carbon (soot). A few PIC contributes to global cooling, such as organic carbon (OC, brown carbon).

3 *Efficiencies get determined per standard water boiling tests (as determined in the CBM methodologies).*
4 https://www.volker-quaschning.de/datserv/CO2-spez/index_e.php accessed 10.07.2017
5 http://www.oryxenergies.com/en/products-services/businesses/businesses-lpg/environment accessed 10.07.2017

The largest PIC in volume is carbon monoxide (CO). It is in itself not a direct GHG, but indirectly affects the burden of CH_4 (IPCC, 2007b). It has been proposed that CO emissions should have a global warming potential (GWP), but this is not (yet) the case. Thus, we do not include a GWP for CO in this study.

Black carbon and some other PIC have strong global warming effects, but only stay in the atmosphere for a shorter time. They are short-lived climate pollutants. There is a large potential for reducing global warming on a short term by reducing the short-lived climate pollutants. Swift action to reduce these emissions might reduce global warming up to 0.6'C by mid-century (UNEP GAP 2017 - 2). While this can ease global warming on a short term, it cannot replace phase-out of long-lived climate gases as CO_2, that has increasing long-term effects with the accumulation in the atmosphere.

A recent study concludes that using GWP to compare short-lived climate pollutants as black carbon with CO_2 introduces some errors and that a new method for comparison should be introduced (Myles 2018). If this is done, the relative effect of black carbon will be larger for actions to reduce global warming on a shorter term (until 2030 – 2050), but smaller for actions to reduce long-term warming.

Of the hydrocarbon gases from stoves, methane has the largest GWP, 34 times CO_2 (IPCC, WG1, 2013, 100-year horizon). Methane emissions for traditional wood stoves is estimated to be 520 mg/MJ wood fuel [BHATTACHARYA, S. C. & SALAM, P. A. 2002], equal to 1.87 g/kWh fuel. We will use thus value in this report.

Other organic gases from stoves is a mix of gases called non-methane hydro carbons (NM-HC). As an average GWP for NM-HC has been proposed a GWP of 12 (Edwards & Smith 2002). Emissions for traditional wood stoves are estimated to be 1.4 g for the boiling of one ltr of water and keep it warm for 30 min [Maccarty et al., 2009], equal to about 1 g/kWh of fuel wood. We will use this figure on this report.

N_2O is a very potent and long-lived greenhouse gas with a GWP of 298 (IPCC WG1, 2013, 100-year horizon). It is formed in small quantities in all cookstoves, but less in efficient stoves simply because the fuel use is less. Emissions for a traditional stove is estimated to 4 mg/MJ fuel [BHATTACHARYA, S. C. & SALAM, P. A. 2002], equal to 0.014 g/kWh fuel.

Fine particulate matter, especially particles smaller than 2.5 micro meters (PM2.5), is both causing global warming and is the main culprit causing respiratory health problems. Most freshly emitted soot particles fall in this category (Preble et al., 2014: 6486). Black carbon (BC) is the portion of these small particles that are forms of carbon that are strongly light absorbing (soot). Black carbon is transported in the atmosphere where it absorbs solar radiation and contributes to regional and global climate change. It has warming effects, including its detrimental effects on snow cover, which is both relevant on a global scale as it affects the snow cover on the poles, and regionally in the Himalayas. Even very low concentrations of black carbon on snow trigger melting (Ramanathan and Balakrishnan, 2007: 4).

The GWP of black carbon has considerable uncertainty and is still debated. According to IPCC 2013 table 8.A.6, the GWP ranges from 100 to 1700[6], which also reflects different time-horizons.

Some studies find a difference between different world regions because of distance to snow and ice cover that can be melted. One study finds that the effect of emissions from South Asia are almost 20% lower than other world regions (Collins et.al. 2013) and indicates a value for South Asia of 170 - 500

[6] *The high values are for 20-year time horizons while the low values are for 500-year time horizons, we will use GWP for 100-year time horizons*

with a median of 340[7]. Other studies find much higher GWP values for South Asia, ranging from 640 to 910 as median values (Fuglestedtvedt 2010, table A2). In conclusion, we will use a GWP = 630 (average of global median values of 4 studies cited in IPCC 2013, table 8.A.6, 100-year time horizon).

Around 30% of global human induced black carbon emissions are caused by household biomass combustion (Preble et al., 2014: 6484), and 25% is from small cookstoves (Rehman et al. 2011), while the share is considerably higher in South Asia.
As mentioned above, a new study (Myles 2018) suggests a new way of comparing short-lived climate pollutants as black carbon with the longer-lived pollutant, but there is yet no new values based on this revised concept.

For the emissions of black carbon (BC) from cookstoves, a series of field tests found median value of 0.09 g/MJ wood fuel equal to 0,32 g/kWh fuel for Indian Chulhas and that the ratio between BC and total small particles (PM2.5) had a median value of 17% . [Garland et.al 2017]. For improved stoves the total emissions were lower, while for most of them, the ratio between BC and PM2.5 were the same, but there were exceptions. Another series of tests of wood and other traditional fuels on a traditional Indian chulha stove found a median value of elemental carbon emissions of 0.9 g/kg wood, equal to around 0,23 g/kWh fuel [Apporva Panday et al. 2017], but higher total (PM2.5) emissions. Both test shows considerable variations between individual measurements and 95% confidence intervals in the range of -30% to + 50%. These two studies are so far the most comprehensive field tests that we have been able to identify. We will for black carbon emissions use the average of the median values of the two studies: 0.28 g/kWh fuel. For the ratio between black carbon and totL PM2.5 we will use the value of 17% for all wood fuelled stoves from [Garland et.al 2017].

A part of particles consists of organic carbon (OC) that is found to have a cooling effect. The cooling effect has been estimated to 50 times the warming effect of CO_2 (GWP = -50 for OC), with some uncertainty. (Maccarty et al., 2009). Because the ratio between BC and OC from fire including improved cookstoves are usually in the order of 1: 1-5, the warming effect of BC is generally well above the cooling effect of OC. One study, [Garland et.al 2017], simply assumed that of the total PM2.5, the fraction that was not BC was simply OC. Another study, [Apporva Panday et al. 2017], measured the amount of OC separately and found a median value of 4.9 g/kg fuel wood, about half of total PM2.5 of 10.5 g/kg. Based in this, we will in this report a ratio between OC and total PM2.5 of 50% for all wood fuelled stoves.

Adding up all these non-CO_2 greenhouse gases from traditional wood stoves gives 0.21 g CO_2e/kWh fuel, in a 100-year perspective. If this is added to unsustainable biomass use, it increases greenhouse emissions of unsustainable biomass from 0.39 to 0.60 g CO_2e/kWh fuel in a 100-year time perspective. It also means that traditional cookstoves contribute considerable to climate change, even if the fuel is fully sustainable.

The table 3.3 (below) lists typical emissions from stoves and their global warming potential (GWP) relative to CO_2.

The combustion products of traditional cookstoves also give pollution-related health problems. Indoor air pollution caused by the inefficient use of solid fuels is responsible for 4.3 million deaths a year (World Health Organization, 2016). Indoor air pollution, for a significant portion caused by

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[7] *The study finds that GWP of black carbon is 340 in median value for four regions of the world + 20% for effects on snow and ice, in total 410, while the value is South Asia is 18% lower or 340 as median value. Uncertainty is given to +/-50%*

traditional cooking stoves, is worldwide thought to be responsible for 2.7% of the total global burden of disease (Bond and Templeton, 2011: 349)[8].

3.2 GHG Emissions with Improved Cookstoves

Research carried out by Aprovecho Research Centre (Maccarty et al., 2009), illustrates that all cooking-related emissions are significantly reduced by utilising improved cookstoves (ICS) technology. As illustrated in the tables below, typically improved cookstoves double the cooking efficiency. In addition, ICS reduce the use of fuel for cooking, reduce smoke, and at times allow the use of less costly fuels (straw and other agricultural residues instead of wood).

Below is given typical emissions for different greenhouse gases other than CO_2 per kWh of fuel used.

Table 3.3: Typical non-CO_2 greenhouse emissions from different cooking options

Emissions:	Black carbon	CH_4	NM-HC	N_2O	Total non-CO_2 greenhouse emissions*
Units	g/kWh fuel	g/kWh fuel	g/kWh fuel	g/kWh fuel	Kg CO_2e/kWh fuel
Traditional stoves (wood)	0.27	1.9	1.0	0.014	0.21
Improved stoves (wood)	0.04 - 0.08	1.4	0.5	0.014	0.08 - 0.1
Biogas stoves**	0	0.2	Not available	0.02	0.01
LPG stoves	0	0.08	Not available	0.007	0.005

*Adapted from: (Bhattacharya and Salam, 2002: 313) and MacCarty et.al. 2008. For GWP is used values cited in above text. * Including cooling from organic carbon (OC)*

*** Only emissions from stoves, see chapter 4 regarding total emissions from biogas plants*

Indian surveys put the rural households that use improved cookstoves somewhere between 5% and 7% (M/s G K Energy Marketers Pvt Ltd and Vitol S.A., 2012a: 2) and the number is increasing. There is a wide variety of improved cookstoves on the market in the South Asian countries, and in each location, some are more suitable than others. Variations in designs include whether the stove provide for one or two pots, fuel types used, inclusion of chimney, and efficiency. The following table provides an overview of popular improved stoves in South Asia, the fuel type used, and their efficiency.

Table 3.4: Improved cookstove efficiency and fuel type, selected cookstoves

Improved cookstove design	Efficiency %	Fuel
Anagi stove - 1 & 2 pot	21.0	Fuelwood
Ceylon charcoal stove	30.0	Charcoal
Sarvodaya two-pot stove	22.0	Fuelwood
CISIR single-pot stove	24.0	Fuelwood
IDB stove	20.0	Fuelwood
NERD stove	27.0	Fuelwood

Adapted from: (Perera and Sugathapala, 2002: 92), (INFORSE Asia 2007).

8 *Diseases reported as following from exposure to products of incomplete combustion include acute respiratory infections; asthma; blindness; cancer; chronic obstructive pulmonary disease; eye discomfort, headache, back pain; reduced birth weight; stillbirth; and tuberculosis (Panwar et al., 2009: 576).*

There are many other designs, also newer designs with higher efficiency than for the stoves in table 3.4. In general, the efficiency of improved stoves ranges between around 20% and 50%. Read more on stoves and their efficiencies in Appendix 1. Household biogas digesters (as discussed at length in the following chapter) also require specific stoves. The efficiencies of biogas stoves are comparable to those of LPG stoves, varying between 40% and 65% (Bhattacharya and Salam, 2002: 310). Bhattacharya employs an efficiency rate of 55% for LPG and biogas stoves. This information compiled and compared with the traditional stoves gives the CO_2 emissions given in table 3.5.

Table 3.5: CO_2 emissions from cooking

	Fuel Emissions, CO_2	Efficiency	Emissions from cooking, CO_2
	per kWh fuel	%	per kWh useful energy
Traditional fire, unsustainable biomass	0.39	15	2,6
Traditional fire, biomass by-product	0.13	15	0.9
Improved stove, unsustainable biomass	0.39	30	1.3
Improved stove, biomass by-products	0.13	30	0.4
All biomass stoves & fires, sustainable biomass	0	n.a.	0
LPG stove	0.26	50	0.5

Adapted from: (Ravindranath and Balachandra, 2009). CO_2 emission reductions are calculated using data from appendix 1.

For selected projects with improved stoves in South Asia, the avoided CO_2 emissions has been estimated to be from 0.9 to 3.37ton CO_2/year per households with an average of 2 ton, see table 3.6.

Table 3.6: Avoided emissions per household of participating communities in six South Asian Clean Development Mechanism (CDM) projects, only CO_2.

	Number of households participating	Avoided emissions
		ton CO_2/year/household
JSMBT (India)	21500	1.98
Maharashtra (India)	14400	0.90
Bagepallimicrostoves (India)	4500	3.37
Egluro (Nepal	22920	1.45
SAMUHA (India)	21500	2.17
Seva Mandir (India)	18500	2.37
Total/average	103320	2.04

Adapted from: (Egluro UK and Centre for Rural Technology Nepal, 2011: 43, JanaraSamuha Mutual Benefit Trust, 2011: 3, SAMUHA, 2011: 3, Shome et al., 2011: 10, Bagepalli Coolie Sangha, 2012: 3, M/s G K Energy Marketers Pvt Ltd and Vitol S.A., 2012b: 31, Seva Mandir, 2013: 4)[9].

As the improved stoves increase efficiency, there are also less emissions such as CO, NM-HC, and fine particulate matter (Seva Mandir, 2013: 9) that are both harmful and causes global warming. There are less measurements of these other emissions, but with introduction of the standard ISO-IWA 11:2012 by The Global Alliance for Clean Cookstoves and others, there are now guidelines for evaluating

9 *The Maharashtra project is actually being implemented on a considerably larger scale than is apparent in this table. It is implement across the state in different time frames, in 30 planned phases. Since the households are similar the project design analysis is the same for all these locations. The PDD as considered here is for one of the 30 phases (M/s G K Energy Marketers Pvt Ltd and Vitol S.A., 2016b: 45).*

cookstove performance. With this standard, cookstoves are rated on four (4) indicators (efficiency, indoor emissions, total emissions, safety). For each indicator, stoves are divided in 5 Tiers (0: lowest performing to 4: highest performing). Efficiency and emissions of BC 2.5 pm are important for the greenhouse effect of stove use. The limits for the IWA tiers relevant for greenhouse effects are given in the table below.

Table 3.7 Energy efficiency and emissions of particles (including black and organic carbon) for the 5 IWA tiers for cookstoves

Efficiency/fuel use Sub-tiers	High-power thermal efficiency (%)	Low power specific consumption (MJ/min/L)
Tier 0	< 15	> 0.050
Tier 1	>= 15	<= 0.050
Tier 2	>= 25	<= 0.039
Tier 3	>=35	<= 0.028
Tier 4	>=40	<= 0.017
Emission PM2.5 Sub-tiers	High-power PM2.5 (mg/MJ-delivered) *	Low power PM2.5 (mg/min/L)
Tier 0	➢ 979	➢ 8
Tier 1	<= 979	<= 8
Tier 2	<= 386	<= 4
Tier 3	<= 168	<= 2
Tier 4	<= 41	<= 1

* Milligrams per megajoule delivered to the pot(s)
From http://cleancookstoves.org/technology-and-fuels/standards/iwa-tiers-of-performance.html

There are also financial gains to be considered. Because of the efficiency of the stoves and therefore smaller need for firewood, often the costs to households are smaller than with traditional stoves. The following table sets out the monetary differences:

Table 3.8: Annualised levelized cost (ALC) of energy for household cooking solutions per GJ of heat output, in Indian Rupees (Rs), 1 Rs = 0.0136 EUR = 0.0155 USD

Cooking technologies	ALC, Rs/GJ (US$/GJ)
Traditional fuelwood stove	271 (6.63)
Efficient cookstoves	164 (4.01)
Biogas plant and stoves, dung-based	394 (9.63)
Kerosene stove for cooking	460 (11.25)

Adapted from: (Ravindranath and Balachandra, 2009)[10].

Even for households that are gathering firewood and where the monetary benefits might not be directly obvious, improved stoves reduce drudgery, especially for women. With improved stoves, there is a decline in time needed for these cooking activities as there is need for less wood. This especially affects women, who often face the burden of cooking and fuel collection (Panwar et al., 2009: 577).

[10] *1 euro equals around 70 Indian Rupees.40*

3.4. Summary of Mitigation Effects

While there are some uncertainties of the emissions, the change from traditional to improved cookstoves substantially reduces the greenhouse emissions from cookstoves by reduction of fuel use, as well as by reductions of emissions of non-CO_2 climate emissions, for instance black carbon.

Using an example of a family using 5 kg wood/day (1825 kg /year) for cooking on a traditional fire, the alternatives gives the emissions and energy uses shown in table 3.9.

Table 3.9: Biomass stoves, comparison

GHG Emissions Compared	Traditional stoves, un-sustainable biomass	Traditional stoves, sustainable biomass	Improved stove, Tier 1	Improved stove, Tier 3	LPG stoves
Efficiency	11%	11%	20%	35%	55%
Emissions of CO_2/kWh fuel	0.39	0	0.39	0.39	0.26
Annual fuel use (kWh)	7300	7300	4015	2294	1460
Emissions of particles BC, OC, pm2.5, kg CO_2e/kWh	0.13	0.13	0.04	0.02	n.a.
Emissions CH4 kg CO_2e/kWh fuel	0.06	0.06	0.05	0.05	0.003
Emissions NM-HC kg CO_2e/kWh fuel	0.012	0.012	0.006	0.006	n.a.
Emissions of N2O kg CO_2e/kWh fuel	0.004	0.004	0.004	0.004	0.002
Total emissions, unsustainable biomass, kg CO_2e/kWh fuel	0.60	n.a.	0.49	0.47	0.26
Total emissions, sustainable Bio, kg CO_2e/kWh fuel	n.a.	0.21	0.10	0.08	0.26
Emissions in kg CO_2e/year, unsustainable biomass	4400	n.a.	2000	1100	390
Emissions in kg CO_2e/year, sustainable biomass		1600	400	180	390
Emission. reductions in kg CO_2e/year, unsustainable biom.	n.a	2800	2400	3300	4000
Emission reductions in kg CO_2e/year, sustainable biomass	n.a.	n.a.	1200	1400	1200

Adapted from chapter 3.1 and 3.2:
Efficiency and CO_2: This report, Annual fuel consumption: estimate of fuel consumption of 5 kg wood/day/family with traditional stoves and relatively less for improved stoves. Black C: Emissions from IWA Tiers of performance, see http://cleancookstoves.org/technology-and-fuels/standards/iwa-tiers-of-performance.html (Accessed 15.07.2017)
CH_4 and N_20: Adapted from: Bhattacharya and Salam, 2002: 313.
MN-HC: A laboratory comparison of the global warming impact of five major types of biomass cooking stoves Nordica MacCarty, Damon Ogle, and Dean Still and others, Aprovecho Research Centre, OR, USA, et.al.

Some studies have found considerable higher wood consumptions of traditional cooking than 5 kg/day per family, up to more than double of these figures. See table. 4.2 and the cases for cold climates in chapter 9.

3.5. Other Effects of Improved Cookstoves

Improved cookstoves has a number of local development benefits that improves the lives of the users. They reduce the solid biomass used for cooking and heating with around 50%. This has the direct benefit that less time is spent on collecting fuel wood can be invested in other work such as education children. In areas without direct access to forests or suitable vegetation, they save money to buy fuel wood. Cookstoves with additional features, such as water heating, can further reduce drudgery in women. The lower fuel demand will also reduce the pressure on forests resources and other vegetation. If it is combined with forest regulation, it can also reduce deforestation that is a continued problem in many developing countries.

The change to improved cookstoves also leads to considerable health benefits because of reduced indoor air pollution. The health problems of indoor air pollution, in particular with small particles (pm 2.5), is a major problem in many developing countries, in particular for women and children. Improved cookstoves reduce this because of less fuel use and more complete combustion, and for improved cookstoves with chimneys also by avoiding the emission of the flue gases in the kitchen.
As mentioned above. indoor air pollution caused by the inefficient use of solid fuels is currently responsible for 4.3 million deaths a year (World Health Organization, 2016) of which at least 1/3 in South Asia. This can obviously be substantially reduced with improved cookstoves.

4. Household Biogas Plants

Photo: Household biogas plant (India) with inlet to the right, digester in centre, and outlet to left. Photo by INSEDA.

4.0 Introduction and Summary

This chapter considers household biogas plants (HBP). By means of anaerobic digestion, the HPBs transform cattle manure and other soft biomass to biogas to be used for cooking needs through a process which also generates digestate or bio slurry that can be used as an agricultural fertiliser. This dual use adds to the emission reductions created by HBPs. Some sources say that by converting manure into methane biogas instead of letting it decompose, GHG emissions could be reduced by 99 million metric tons worldwide (Cuéllar and Webber, 2008: 13, TERI, 2010). Each biogas stove typically has lower total greenhouse emissions than all other options (traditional and improved cookstoves, LPG), but methane leakages above a few percent, can make biogas less advantageous from the climate perspective.

Biogas programs for household levels have been implemented in South Asia for the last several decades, providing measurable data regarding impacts on greenhouse gas emissions. The Biogas Support Program (BSP) Nepal has been operational since 1992 in various forms, and it was lauded internationally for its activities. In 2005, it was honoured with an award for having built 137000 household biogas plants, in 66 of Nepal's 75 districts. These activities have saved 400.000 tonnes of firewood, 800.000 litres of kerosene, and has prevented 600.000 tonnes of GHG emissions (Dixit, 2005).

The plants under consideration are small-scale and household level. Typically, at least three or four cows are needed to fuel a biogas plant that provides cooking gas for a five-member family that cook two meals a day. 1.5 to 2.4 m^3 gas needs to be produced, which corresponds to the production from a 2 m^3 capacity plant, which is typically the smallest type available (Bond and Templeton, 2011: 350). As part of the EVD program, smaller plants, with a capacity of 1 m^3, that only need 25 kg of manure a day (which corresponds to the daily production of two cows) have been designed by INSEDA and is now in use in small farms in mountainous regions in India (INFORSE, 2016: 18). HBPs provide significant emission reductions for rural households in South Asia. The positive effects are expected to increase given the improvements in biogas plant design and innovation in materials used.

Table 4.1: Biogas guideline data

Biogas energy	6 kWh/m^3 = 0.61 L diesel fuel
Biogas generation	0.3 – 0.5 m^3 gas/m^3 digester volume per day
Digestate generation	58 kg per m^3 biogas
Cow yields	0.4 m^3/kg dung per animal per day
Gas requirement for cooking	0.3 to 0.9 m^3/person per day

Adapted from: (Bond and Templeton, 2011: 350, Mezzullo et al., 2013: 659, EAWAG (Swiss Federal Institute of Aquatic Science and Technology) and DorotheeSpuhler (Seecon International gmbh), 2014).

To create a complete picture of the effects on GHG of the plants, the emissions generated by the HBPs in operation are considered. This includes the direct emissions such as leakages and other gas losses and those of the energy provision, but also the emissions resulting from the handling and use of the manure and digestate (Møller et al.: 5, Bruun et al., 2014: 736). Lastly the emissions of potential direct and indirect land use change can be considered (Cherubini et al., 2009: 437). Emission mitigation following from carbon binding in the soil of HBP digestate is also evaluated.

The result is that the main effects from HBP is the reduction of emissions from the cookstoves they replace. If a HBP replaces a traditional fireplace (as an Indian chulha), it will in average reduce greenhouse emissions with a bit above 4 tons CO_{2e}/year, if the wood use is from unsustainable sources (as deforestation) and around 1.4 tons CO_{2e}/year if it replaces fuelwood that is grown in fully sustainable ways.

4.1 Establishing a Baseline

For the village level in South Asia (as well as in many developing countries in other parts of the world) the biggest use of biomass for energy is firewood, and its use is primarily for cooking, as discussed in chapter 3.

Biogas in rural South Asia is mostly used as a cooking fuel, where it replaces primarily wood fuel, but also dung, crop residues, and to a lesser extent LPG. Typical emissions greenhouse gases and particles from use of wood fuel and LPG for cooking are given in table 3.1.

Biogas use has in itself greenhouse gas emissions, and the introduction of biogas has a number of effects related to greenhouse gas emissions. The main greenhouse gas effects of biogas plants are:

Net CO_2 emissions from combustion of the biogas

With biogas about half of the organic material in manure and other feedstock is converted to methane and CO_2. If the manure was applied directly to the soil, this material is also added to the soil, adding more carbon to the soil. This extra carbon is on forms that are easily degradable, also in a soil environment (as in biogas digester). A Danish estimate is that of the organic materials removed with biogas plants, 97% will be converted to CO_2 in the soil within 20 years. For South Asia where soil temperatures are typically higher, the conversion will be higher, i.e. above 97%. Thus, the net emissions are negligible in a 20-year perspective and are not included (Jørgensen et.al, 2013).

Reduced or increased methane emissions from manure handling
Manure has natural emission of methane, which depends very much on how the manure is treated. If it is dried, as with the practice of dried cow-dung cakes, the emissions are small, but if the manure is kept in wet pits the emissions can be very high. If manure is kept in wet pits before it is fed into biogas plants, these emissions can also be noticeable, but if they are fed fresh (same day it is produced) into the plant, the pre-treatment emissions will be negligible.

Gas leakage from plant and piping
There can be methane emissions from the biogas plant itself, and from the piping. These are small if the plants are well made and maintained, but for a less well made and maintained some percent methane loss is possible, with a maximum around 10%.

Emissions from digested materials
Digested materials have emissions of methane, but if the materials are aerated and/or dried, the emissions will stop soon after the material has left the biogas plant.

Emission effects of soil by applying digested materials
When applying digested materials from biogas instead of undigested manure or chemical fertiliser, it gives an effect on emissions of methane and N_2O from the soil.

The methodologies and data of six HBP projects throughout South Asia have been used to quantify above emissions and compare with baselines with no introduction of biogas plants. The projects are:
-The Biogas Support Program - Nepal (BSP-Nepal),
-The CDM Biogas Project of Mahasakthi Women Cooperative Federation,
-The YEPL Biogas project in Maharastha,
-The Bagepalli Coolie project,
-The INSEDA project in Kerala,
-The SACRED project in Karnataka.

The CDM projects have in common that they target rural communities, and implement HBPs following the UNFCCC CDM methodologies, mainly replacing woody biomass use. The emission calculations that these CDM projects are based on are calculated by quantifying the replacement of firewood with biogas. See chapter 3 regarding greenhouse emissions from traditional fireplaces using wood.

4.2 Effects on GHG Emissions with HBPs

The major GHG emission reduction with biogas use is coming from the avoidance of other, more polluting, fuel-sources. Looking at the consumption of firewood (both unsustainably harvested, where forests and land are degraded and sustainably harvested, where trees and plants are growing to fully replace the used biomass) and the effect of a HBP on the consumption as given by CDM projects, emission reductions can be calculated.
The data in table 4.2 was provided by CDM projects-partners compiled on the UNFCCC website. The CDM project values are based on the CO_2 emissions avoided by unsustainable fuel-use, and most disregard other positive effects on emission reduction such as fertiliser use and reduction of particle emissions (black carbon), which this report does consider[11].

[11] *The considerably higher value for the Maharashtra project is due to the replacement of fossil fuels, not biomass.*

Table 4.2: Estimated GHG emission reductions per project, using CDM methodology

	Average annual consumption of woody biomass avoided by using HBPs	Calculated annual emission reduction per household	Biogas units installed in project activity	Estimated annual emission reduction
	tonne/household/year	tCO_{2e}/year	amount	tCO_{2e}/year
BSP-Nepal	2,84	2,78	9692	26926
Mahasakthi Women Cooperative Federation	2,83	3,29	6000	19740
INSEDA SDA Kerala Project (India)		5,63	2690	15151
Biogas project in Maharashtra (India)	5,32	7,99	6000	47907
SACRED (India)	3,71	3,71	5000	18550
Bagepalli Coolie Sangha Biogas Project (India)	3,07	3,39	18000	61109
Total			**47382**	**189383**
Average		**3,99**		

Adapted from data as presented in the following project design documents: (YEPL, 2011: 16, BSP-Nepal, 2012: 23, Bagepalli Coolie Sangha, 2012: 3, M/s G K Energy Marketers Pvt Ltd and Vitol S.A., 2012a: 17, Seva Mandir, 2013: 7, Integrated Sustainable Energy and Ecological Development Association and First Climate AG, 2014: 17, Mahasakthi MAC Samakya Ltd, 2014: 17, Somanathan and Bluffstone, 2015: 265, Bagepalli Coolie Sangha and FairClimateFund (FCF), 2016b: 13).

These reported reductions are substantial, as can be seen in the last column of Table 4.2. The disparity between the projects and expected emission reductions per installed plant is due to the differences in fuel sources that the HBPs replace, as well as the specific builds and sizes of the plants. Projects that replace dung cake burning, which is a practice in some areas, also have significant effects. In the methodology is included a reduction of 5% of the GHG savings because of methane leakages. This is for the average project equal to leakages with CH_4 emissions of 0.2 tons CO_2e/year, equal to loss of around 7% of methane. In the following is estimated than biogas stoves

Using the baseline established in chapter 3 for traditional stoves, the emission reductions with biogas stoves can be seen in table 4.3.

Table 4.3: Reductions of net greenhouse gas emissions per year with HBP

Stove and fuel type,	Net GHG emissions per year	GHG Savings over traditional stove, unsustainable wood	GHG Savings over traditional stove, sustainable wood
Traditional cookstove, unsustainable wood	4.4 ton CO_2e	0	n.a.
Traditional cookstove, sustainable wood	1.6 ton CO_2e	2,8 kg CO_2e*	0
Biogas plant + stove	0.2 ton CO_2e	4.2 ton CO_2e	1.4 ton CO_2e

Assuming change from unsustainable to fully sustainable wood.
The data include emissions of CO_2, particles (black carbon, organic carbon), organic gases, and methane. For improved cookstoves, the figures illustrate use of sustainable and unsustainable wood respectively. Average figures are used and hence they contain some uncertainty. Data from table 3.9 above, for biogas from table 3.3 and assumption of no net CO_2 emissions and use of 1500 kWh gas/year, similar to LPG use in table 3.9.

4.3 Manure, Fertiliser and Carbon Binding

Production and combustion of biogas are not the only processes with greenhouse effect impacts. A source of emissions that is to be considered is fertiliser use, and the effect of the HBP on this. The role of the biogas digestate is twofold. The substitution of chemical NPK fertilisers by digestate from the HBPs reduces emissions from production of NPK fertiliser, but also the use of manure for biogas digesting it instead of burning it or adding it to land unprocessed has effects on emissions. The storage and use of unprocessed manure and other organic matter that are left to decay uncontrolled will include anaerobic processes, where methane is emitted to the atmosphere.

Data for these emissions are significantly less exact compared to the direct emissions from stoves, partly due to challenges of specific measuring, partly due to a multitude of factors such as variations in agricultural practices (for instance tillage methods and manure application), as well as differences within ammonia content of dung from various species, which in turn create variations on the actual emissions.

Emissions resulting from fertiliser use are mainly linked to the production process. Nitrous Oxide (N_2O) is the most significant GHG associated with the production of nitric acid. N_2O is a highly potent greenhouse gas, with a global warming potential 298 times greater than CO_2 (IPCC, 2013). This report considers N, P, and K fertilisers.[1] N fertilisers are however the main source of GHG emissions. First, the consumption of fertiliser in the project countries should be noted. In all of India the use of N, P_2O_5 and K_2O fertiliser are comes down to 89,8 kg/ha of farmland (Land and Plant Nutrition Management Service and Land and Water Development Division, 2005: Chapter 2). In 2011-12 the Ministry of Economics reported a production of 16363 thousand of tonnes of NPK fertilisers, imports of 13002 thousand of tonnes of fertiliser, and a consumption of 27567 tonnes of NPK fertiliser. These national numbers include both large-scale conventional agriculture, as well as small-scale agriculture.

A summary of papers shows us that the use of slurry (waste product of the biogas production) on fields leads to a 10%-50% avoidance of NPK fertilizer use.

Regarding the use of manure and digestate instead of artificial fertiliser, depending on the source of the manure the ammonia content ranges from 2,1 kg/tonne of semi-solid manure for dairy cattle manure, 2.6 kg for pig manure, and 4.6 kg for poultry manure (Atia, 2008). In general, as treated slurry or digestate is thinner than untreated manure, the slurry percolates faster into the soil, where NH_3 dissolves in water or binds to other particles. As the slurry is also more mineralised than untreated manure, resembling more synthetic fertilisers, the nutrients are more easily used by the plants. This means that in practice the volatilisation of N is not bigger for digestate than with untreated manure (Jørgensen, 2009: 30). Digested materials have emissions of methane, but with long retention times in the biogas plant these emissions are small and there are easy ways to curb them with aeration, such as compost or spreading of the digestate. The replacement of artificial fertiliser with for instance 2 m^3 biogas plant with input of 50 kg manure/day reduces production emission of fertiliser in the order of 0.1 - 0.15 ton CO_2e/year. This effect is 3-10% compared with the emission reductions given in table 4.3 and will not be included.

Adding manure to the soil instead of burning manure as a fuel is an important strategy in soil organic carbon (SOC) sequestration. Under Danish conditions it was found that 25% of the solid matter will remain carbon in the soil for at least 20 years (Olesen, 2014: 11). Unfortunately different long-term studies of SOC with soils treated with different natural and artificial fertilisers show very different results, even within the same world regions (Northen Europe). Due to climatic variations the SOC sequestration can be expected in South-Asia compared to Northern Europe. If 25% of the carbon in biogas digestate becomes stable soil organic carbon, the reduced emissions are in the order of 1.5 ton CO_2/year for a HBP with input of 50 kg manure/day[12]. This is equal to the greenhouse emission reductions from replacing traditional cooking with biomass given in table 4.3, but given the large uncertainties, including the expected differences between Danish and South Asian climates, this effect is not included in the following estimates.

4.4 Summary of Mitigation Effects

In summary, the effect of replacing traditional cooking with biogas can be estimated to an average of 4 tons CO2e/year for each household that changes to biogas as shown in table 4.2, but with considerable variations depending on the local situation, and not included all greenhouse effect from traditional cooking with biomass fire.

Typical examples of the effect of changing to biogas can be estimated using data in table 4.3 and reduced for estimated methane leakages that reduce the effect with 0.2ton CO_2e/year for each household. This include all the greenhouse effects from traditional cooking, but not the small GHG reduction from reduced use of chemical fertiliser nor the emissions from increased soil organic carbon that might be large, but where we lack evidence. The results are shown in table 4.4.

Table 4.4: Comparison of biogas with cookstoves, net greenhouse gas emissions per year

Stove and fuel type,	Net GHG emissions per year	GHG Savings over traditional stove, unsustainable wood	GHG Savings over traditional stove, sustainable wood
Traditional cookstoves, unsustainable wood	4.4 ton CO_2e	0	n.a.
Traditional cookstoves, sustainable wood	1.6 ton CO_2e	Not included	0
Improved cookstove, tier 1	2 / 0.4 ton CO_2e	2.4 ton CO_2e	1.2 ton CO_2e
Improved cookstoves, tier 3	1.1 / 0.2 ton CO_2e	3.3 ton CO_2e	1.4 ton CO_2e
LPG stove	0.4 ton CO_2e	4 ton CO_2e	1.2 ton CO_2e
Biogas plant and stove	0.2 ton CO_2e	4.2 ton CO_2e	1.4 ton CO_2e

Data from table 3.9 and 4.3

[12] *A biogas plant which is fed with 50 kg of cow manure and soft biomass with an estimated dry content of 20% received 10 kg solid matter/day. Of this 50% is turned into gas, leaving 5 kg/day in the digestate. If 25% of this is becoming stable SOC, this is 1,25 kg/day or 450 kg/year. This is primarily carbon. If this carbon was turned into CO_2 and released into the atmosphere, for instance by burning the manure, it would give 0.45 *42/12 =1.5 ton of CO_2.*

4.5 Adaptation Benefits and other Effects of Biogas

If the biogas sludge is used as organic fertiliser, there are additional benefits. The biofertilisers produced from biogas digesters helps in improved soil fertility and water retention capacity, which contributes to adaptation during drought conditions. The soil nutrients such as nitrogen, phosphorous and potassium aids in nutrient circulation in soil thus contributing to agro-ecology.

Biogas plants have the same kind of positive development effects as improved cookstoves with improved indoor air and less time to collect firewood.
Compared with improved cookstoves, there are no particle emissions from biogas, and thus it is superior in improving reducing indoor air pollution.

The time savings depends on the time saved by not collecting firewood compared with the time used to manage the biogas plant with daily feeding with manure and water. Usually there is substantial amount of time saved with this shift.

5. Household Scale Power (solar home systems, solar lamps)

Photo: Introducing Solar Home Systems in Bangladesh, photo by Grameen Shakti

5.0 Summary

The introduction of solar electricity in off-grid villages replaces kerosene for lamps, diesel for generators and others. Often the solution is solar home systems, where each family gets 2-4 lamps and connections to charge mobile phones and run radio, eventually also TV. It is estimated for Bangladesh that this reduces CO_2 emissions from kerosene and diesel use with 344 kg CO_2/year (with 3 lamps in the house used 4 hours/day).

5.1 Baseline and Proposals, Mitigation Effects

The EVD partner in Bangladesh; Grameen Shakti (a non-profit village renewable energy organisation in family with the micro credit lender Grameen Bank) has established Solar Home Systems (SHS) to supply some 1.7 million homes and small business with individual electricity systems ranging from 20 to 135 watts (by June 2017). The purpose of the SHS systems is to replace the existing kerosene lamps as well as batteries charged by fossil fuel generators used to run lights and small household appliances like TV and mobile phone charging in rural, off-grid communities. In addition to supplying more fire safe, healthier, quieter home and work environments, and a general improved standard of living, the scheme also creates local jobs and income opportunities. Some women have doubled their income and some have become micro energy distributors because of the electricity. It also aids in education as children gain better possibility to do homework.

As part of its operations, Grameen Shakti operates a micro loan scheme that enables poor households to buy a solar system in instalments as most of them cannot pay the investment up-front, typically $135.

Some of the SHS installed by Grameen Shakti are registered in a CDM project to offset *46.659 tonnes of CO_2 emissions annually* by providing solar derived power for 4 hours daily to the 240.000 homes. [13]

[13] Information derived from http://gshakti.org/, accessed 10.07.2017

Table 5.1: CO_2 gas reduction potential per household

Items	Calculations	Results
Operating hours per annum	3.5 x 340	1190 hrs
Kerosene consumption per lamp per year	0.04 x 1190s	47.6 litres/year
CO_2 emissions per litre of kerosene usage		2.36 kg CO_2/Litre
Emissions per kerosene lamp per year	47.6 x 2.36	112 kg CO_2/lamp/yr.
Annual emissions per household at an average of-3 lamps per household	3 x 112	336 kg CO_2
Annual CO_2 emission from diesel generators to charge the batteries of a household		8 kg CO_2/year
Total annual CO_2 emission savings per household	8 + 336	344 kg CO_2/year

Adapted from: Baseline data about kerosene and solar from a CPA to UNFCCC by EVD partner Grameen Shakti titled "Installation of Solar Home Systems in Bangladesh", Ref. no: 2765, February 2014.

For off-grid villages in other South Asian countries, the replacement of kerosene and diesel by SHS will have similar savings on GHG emissions from the villages.

The production of SHS have some emissions, but with modern equipment this is typically below 1 year of energy production from the SHS, and with lifetime well above 10 years for the solar panels and with recycling of batteries (that has lifetimes of 5-10 years for good equipment), the production energy is on the level of emissions of production of fossil fuels (emissions from extraction, refining and transport of fossil fuels). The production emissions are therefore not included.

In some places, solar lanterns are the preferred choice for off-grid villages. The CO_2 emission savings are the same, and in many ways the solar lanterns have the same benefits than the SHS, but they have less flexibility regarding use of larger equipment, where for instance a TV or a computer can be powered from a SHS for a shorter time on the expense of other electricity uses. This is not possible with solar lanterns.

5.2 Other Effects of Solar Home Systems

There are many development benefits of Solar Home Systems compared with kerosene lamps. They are safer, cheaper to use and give better light than kerosene lamps. They also give power for a number of uses, such as charging mobile phones and other mobile equipment as torches, powering of radios and for larger SHS also TV and computers. Thus, they can allow villagers to enter to IT Age, and as mentioned above they have a higher development potential than solar lanterns.

The small-scale PV power systems also give power for a number of small shop and micro-business uses as powering lamps and electronics.

6. Village Scale Power (mini and micro grids)

6.0 Summary

If a village is electrified with a mini or micro grid based on renewable energy, the electricity the villagers use will result in much less CO_2 emissions than if the village is electrified with connection to most central grids in South Asia. In an example village in India with 100 households connected to a mini or microgrid instead of a central grid, the savings are some 70 tons CO_2/year. This is because of the high CO_2 emissions from power production in India. With mini and micro grids, the household electricity use is considerably lower than with connections to central grids, but the difference is often partly compensated with more efficient electricity consuming equipment. In South Asia, a specific benefit of mini and micro grids is that they often provide more reliable power than the central grids. Renewable energy sources of mini and micro grids are usually micro hydro power (hydro power in the range 5 – 100 kW) or solar PV with battery back-up, but also small windpower, and (in India) motor-generator sets with biomass gasifiers.

6.1 Baseline and Proposal, Mitigation Effects

Micro and mini grids are deployed to fill in for the unreliable utility grid, reach new off-grid customers, save money, and reduce carbon emissions. Typically, Indians and others in South Asia, who could afford it, have long used diesel generators to back up the utility grid, but are increasingly moving to mini/microgrid options based on solar with energy (battery) storage. It is foreseen that India's aggressive electrical vehicle targets will contribute to microgrid growth as homes, campuses, and companies seek to ensure adequate electric supply to meet surging demand. The electric vehicle batteries themselves might play a significant role in microgrid systems, storing solar energy for when it's needed.

Micro or Mini? According to the National Policy for Renewable Energy based Micro and Mini Grids (in India), a 'Mini Grid' is defined as: "a system having a RE based electricity generator (with capacity of 10 kW and above), and supplying electricity to a target set of consumers (residents for household usage, commercial, productive, industrial and institutional setups etc.) through a Public Distribution Network (PDN)." versus a 'Micro Grid' system, which "is similar to a mini grid but having a renewable-energy (RE) based generation capacity of below 10 kW. Micro and mini grids generally operate in isolation to the larger electricity networks, but they can also interconnect with a larger grid to exchange power. If connected to grid they are termed as grid connected mini/ micro grid".

The objective of the new policy in India is to promote the deployment of micro and mini grids powered by RE sources such as solar, biomass, pico hydro (hydropower below 5 kW), wind etc. in un-served and underserved parts of the country by encouraging the development of State-level policies and regulations, that enable participation of ESCOs[14] . The Ministry targets to achieve deployment of at least 10,000 RE based micro and mini grid projects across the country with a minimum installed RE capacity of 500 MW in next 5 years (taking average size as 50 kW). Each micro and mini grid project should be able to meet the basic needs of every household in vicinity, and also aspire to provide energy for services beyond lighting such as fan, mobile charging; productive and commercial requirement.

[14] 1 ESCOs: Energy Service Companies. For the purpose of the policy, ESCO means a person, a group of persons, local authority, panchayat institution, users' association, co-operative societies, non-governmental organizations, or a company that builds, commissions, operates and maintains the mini grid.

A significant challenge for Mini/Microgrids is the "Tragedy of the Commons" dilemma, which recently was demonstrated in the "Dharnai Live" micro-grid project[15] sponsored by Greenpeace, which partly failed due to the use of energy-inefficient televisions and refrigerators and where the villagers opted for replacing the local renewable supply with grid power. Potentially minigrids can also attract energy-hungry appliances such as rice cookers, electric water heaters, irons, space heaters and air coolers. This demonstrates that a strictly enforced scheme for use of the available electricity must be implementing and policed, once a limited amount of electricity becomes shared through a grid.

The national average household size is 4.8 individuals in India, and as an example we will use 100 households per village. This corresponds to about ⅓ of Indian average villages according to the2011 census of India which showed that 69% of Indians (around 833 million people) live in 640,867 villages. The size of these villages varies considerably. 236,004 Indian villages have a population of fewer than the 500 we use as example, while 3,976 villages have a population of 10,000+.

In valorising the effect of a micro-grid based on renewable energy, we choose to omit the life cycle comparison of such installations with conventional Indian electricity generation available in national grid, partly as it is a too comprehensive task for this paper, and we expect the result to be insignificant compared to the use phase. We instead focus on the direct effect of the net electricity consumption by the rural consumer.

Table 6.1: CO_2 reduction potential per village in net electricity consumption if renewable energy systems were used as alternative to Indian national electricity mix.

	kWh/year	**ton CO_2e/year**
Village electricity consumption measured in kWh if based on use of 3 lamps and battery charging per household and used as detailed in chapter 5, all powered by renewable energy in Solar Home Systems (42 Wp each) or microgrid of comparable size.	8400	0
Village electricity consumption based on equally shared use of power generated from a 10 kW microgrid powered by renewable energy, incl. 10% power loss due to battery and transmission.	21600	0
Available data for national level electricity consumption per household connected to public grid vary from 50 to 100 kWh/month per household[16]. For purpose of this calculation we use 75 kWh/month.	90000	72[17]
Village CO_2e based on use of 3 kerosene lamps and partial use of diesel generators per household (as detailed in chapter 5, table 5.1) is converted to electricity.	n.a.	34

Adapted from: Data about kerosene and solar from CPA to UNFCCC/CCNUCC by EVD partner Grameen Shakti titled "Installation of Solar Home Systems in Bangladesh", Ref. no: 2765, February 2014.

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[15] Elaborated in https://www.scientificamerican.com/article/coal-trumps-solar-in-india/ Accessed 15.07.2017

[16] The 100 kWh/month is derived from http://ethesis.nitrkl.ac.in/4774/1/411HS1001.pdf accessed 10.07.2017. Other source claim 50 kWh/month.

[17] Data from 2010 are assumed applicable as development in energy production is assumed similar within both reneeable and non-renewable source of energy http://www.cea.nic.in/reports/others/thermal/tpece/cdm_co2/user_guide_ver6.pdfaccessed 10.07.2017

From table 6.4,it is clear that there are substantial CO_2 savings by using solar or hydro energy in a village compared with both kerosene and grid power. There are also differences in the quality of the service, where solar electricity has a higher quality of service than kerosene, but in principle a lower quality of service than grid power, which can be seen from the higher consumption that households get once connected to grid power. For two reasons, the quality of service from solar mini/microgrid is not as much lower as the difference in consumption might show:

- The reliability of power supply from well managed micro and minigrids is much better than the reliability of rural power supply from central grids
- In minigrids are often used efficient appliances, such as LED lamps instead of incandescent lamps, giving the same service (light) with much less electricity demand.

The example in table. 6.4 with all households connected to a central grid, or to a minigrid, is not very likely in a currently off-grid South Asian village, often only a part of the households become grid-connected, mainly for economic reasons, while others will for instance have solar lanterns, the most affordable solar electricity option.

6.2 Other Effects of Village Scale Power

There are many development benefits of village scale power. Compared with kerosene lamps they give safer, cheaper to use and better light.

As solar home systems (SHS), mini and micro grids give power for households and small shops, they also give power for a number of uses, such as charging mobile phones and other mobile equipment as torches, powering of radios. Larger SHS also powers TVs and computers. Thus, they can allow villagers to enter to IT Age.

Further these mini and micro grids give power for a number of productive uses, ranging from small business to water pumping, for instance for irrigation, for welding, for refrigeration and workshop machines. Often, they also power street lights, which of course also is possible with stand-alone solar street lights. Some local grids are even powering mobile phone towers.
Thus, they can give more or less the same development benefits for a village than grid power. There is, however, the limitation that power from these mini-grids is usually more expensive than power from central grids, unless there is national regulation that distribute subsidies for rural electricity in ways where local grid power get subsidised to be sold at the same price as grid power (which is also subsidized in many countries).

Compared with central grids, mini-grids are limited regarding large power users and sometimes they are slower to expand for new settlements because of the relatively high investment costs. In countries where rural grid power is unreliable with many power cuts, the mini-grids often can provide more stable power.

7. Solar Drying

Photo: Solar tunnel dryer for small farms and households. The photo shows vegetables being loaded on the dryer's trays. Photo by INSEDA, India

7.0 Summary

Solar drying is an affordable way of preserving fruit and vegetables. Solar dryers can give an additional income for farmers that can produce dried products of high quality, replacing products dried with fossil fuels in large, commercial driers. Each kg of dried fruit (mango, apple etc) from a solar drier that replaces fruit dried with electricity or fossil fuel (LPG) saves in India emissions of 6 kg CO_2 (when replacing electric drying) or 2.5 kg CO_2 (when replacing gas fired drying). On an annual basis, this can save respectively around 1 and 0.5 ton CO_2 with a small drier used whenever fresh crops are available.

7.1 Baseline

There are many ways of drying fruit and vegetables, from traditional drying on the ground to advanced drying methods with heat, vacuum, and others. The dryers used in the EVD are simple solar dryers that produce dried fruits and vegetables in a hygienic quality similar to products from commercial dryers that typically use gas or electricity. Therefore, we compare the solar dryers with electric or gas heated drum dryers. Drum dryers have an efficiency around 40% (Pragati and Birwal, 2012, 705).

Fruits as apples, pears, mango, and plums contain 83-86% water while tomatoes, popular for drying, contains 94% water[18]. Dried products should have 15% water content to be stable).

This mean that the drying process should remove about 83% of the weight of the fresh fruit for the fruits mentioned above, or 93% in the case of tomatoes, respectively 830 g water and 930 g water pr. kg of fruit input. The water requires an evaporation energy of 2.26 MJ/kg = 0.63 kWh/kg. In the table below is given energy and CO_2 emissions for drying of above-mentioned fruit and vegetables with respectively electricity from Indian power grid and with gas (LPG).

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[18] *Water quantity data from http://healthyeating.sfgate.com/list-fruits-vegetable-high-water-content-8958.html and* http://www.fao.org/3/a-au111e.pdf)

Table 7.1 Estimated energy need for drying with electricity and gas (LPG) and related CO_2 emissions

Drying energy and emissions	With electricity	With gas (LPG)
Water evaporated, fresh fruit and tomato	83 - 93%	83 - 93%
Evaporation energy, kWh/kg fresh fruit and tomato	0.51 - 58	0.51 - 58
Energy input, kWh/kg fresh fruit and tomato	1.3 & 1.4	1.6 &- 1.8
CO_2 emissions, kg/kWh electricity and LPG	0.8	0.26
CO_2 emissions, kg/kg fresh fruit & tomato	1.0 & 1.1	0.42 & 0.47
CO_2 emissions, kg/kg dry fruit and tomato powder	6 & 16	2.5 & 7

In the above table is assumed drying efficiency of 40% as for drum dryers, and gas furnace efficiency of 80%

7.2 Solar Drying, Mitigation Effects

Solar dryers exist in many sizes and designs., The ones used by small farmers in the EVD projects are small and inexpensive models. The tunnel dryer with 3 trays of 2-3 m^2 each has drying capacity around 18 kg/day of fresh fruit, equal to around 3 kg of fresh fruit. If it is used half the year, 180 days/year, for various fruits, replacing drying with fossil fuel, it will dry around 3 tons of fresh fruit annually and will reduce annual CO_2 emissions with around 3 tons if it replaces electric drying and 1.4 tons if it replaces gas-fired drying. This is for drying fruits and vegetables. if the dryer is used for spices, CO_2 savings will be less.

A good analysis of solar drying for South Asia can be found in the article Solar Drying - A Sustainable Way of Food Processing, see: www.springer.com/cda/content/document/cda_downloaddocument/9788132223368-c2.pdf?SGWID=0-0-45-1504301-p177290270

In the above example, solar drying replaces drying with fossil fuel, which is sometimes the case, but for the farmers equally important is that solar drying can generate valuable products from harvest that would otherwise be wasted because of lack of storage and processing capacity, and that it can give healthier products for own consumption than drying on the ground. In practice, only part of solar dried products will replace drying with fossil fuels, where CO_2 reductions are easy to calculate, while the effect on greenhouse gas emissions of less wasted harvest is harder to evaluate. In this example, we will only include the CO_2 reductions of dried products that replace fossil fuel dried products.

7.2 Solar Drying, Climate Adaptation Effects, and Other Effects

Climate change has negative impact on food quality, physical availability and economic access to food. In other words, it affects nutrition and food security of vulnerable people. In this context, solar drying and other food dehydration technologies assist in preserving nutrition quality and improving shelf life of fruits and vegetables of surplus food. The technologies assist in food security and nutrition security by improving physical and economical access to access to food.

The food thus preserved could be used during drought and flood conditions. It also helps adapt to volatile food prices during climate induced disasters and become a reliable source of nutritious food.

Solar drying also contributes to development in other ways. When it allows villagers to make higher quality products with larger market potentials, it contributes to income generation.

8. Organic Farming and Composting

Photo: Organic Compost-Making Baskets: These compost baskets are promoted as one of the EVD solutions in Utterakhand Stain, India by INSEDA and partners. They are made out of loosely woven bamboo. They work with natural decomposition processes to convert cow dung along with other agriculture waste and organic material into high-quality organic compost in three months. One basket provides enough compost for use on 250 square meters of land, enough for a good-sized kitchen garden. Photo by INSEDA, India

8.0 Summary

Organic farming is both a mitigation and an adaptation solution. Though hard to quantify it contributes to mitigation with collection of carbon in the soil, carbon that would otherwise be in the air as CO_2, and it eliminates use of chemical fertiliser, where in particular nitrogen fertiliser has high greenhouse gas emissions during production. It contributes to adaptation with reduced climate vulnerability, such as better drought and flood resistance, and less stress on ecosystems, that therefore better can manage climate stress.

Composting is usually an element in organic farming, turning plant residues and other organic waste into compost that both improve soil and give organic fertiliser that can replace chemical fertiliser. Many of the same benefit of organic farming can be achieved with using composting as part of other farming as well.

8.1 Mitigation Effects of Organic Farming and Composting

One main mitigation effect of organic farming is the increase of carbon in the soil with the constant use of organic fertiliser instead or chemical fertiliser. Usually the organic fertiliser is used plant residues and manure that is pre-treated in a biogas plant or with composting, or both. As discussed in chapter 4.3 the direct effect of only replacing chemical fertiliser with organic fertiliser has several uncertainties, in particular because it is not well known how long the carbon stays in the soil. In

agriculture there are also other ways of keeping more carbon in the soil, including less tilling and more permanent vegetation, as well as more trees on the fields.
The other main mitigation effect is the avoided use of chemical fertiliser. As described in chapter 4.3 this is not a large saving for one biogas plant, but for larger fields. the emission reductions can be considerably. Given the uncertainties of greenhouse emission reductions with compost, we are not quantifying climate mitigation of compost in this report. The quantitative emission reductions are similar to those of biogas, see chapter 4.

Composting is a good solution to produce organic manure. It is much cheaper than biogas and as it is aerobic it does not risk methane leakage, unless it goes bad. Of course composting does not give the useful biogas as a biogas plant gives. Instead the energy is eaten by the compost organisms.

From promoters of chemical farming, organic farming is often criticized for giving lower yields and therefore for need more land that chemical farming. If the organic farming is done well and there is used organic fertiliser needed and there are used suitable crops, including tree-crops, the yields do not have to be lower with organic farming. Good organic farming requires good farming skills, however, to give higher yields.

8.3 Adaptation Effects of Organic Farming and Composting

Organic farming improves natural processes and revives ecosystem services by improving soil carbon, water retention capacity, and soil fertility. Through better nutrient management capability, organic farming contributes to soil fertility which results in rise in crop yield, better drainage and drop in irrigation frequency. It contributes to adaptation by relying on food production locally and being independent of food import, volatility of agricultural inputs and food prices. Crop diversification and reliance on local varieties improves income sources and provides much needed flexibility to cope with adverse effects of climate variability and change. Organic farming is a low-risk faring strategy because of reduced input cost. Thus, it lowers risk from partial or total crop failure due to extreme weather events.

Organic farming assists in creating micro habitats for soil flora and fauna, restoring the natural pest management mechanisms and protects wild biodiversity. The restoration of ecosystem services act as a shield against extreme weather conditions such as water stress, heat waves, drought, erratic rainfall, and water logging. In a nutshell, organic farming is an effective adaptation strategy to improve livelihoods of agriculture-dependent population in developing countries.

Composting is a useful technology for retention of soil fertility in farming and kitchen gardening through the treatment of leaves, food waste and other organic products. Compost is useful for erosion control, water retention and reclamation of land and stream. Thus, compost would assist in adapting to erratic rainfall, heat wave and drought conditions by providing survival moisture to crop. Access to market provides an alternative livelihood option for small holder farmers which increases their adaptive capacity.

9. Climate Mitigation Effects on Village Level

Using the examples in the previous chapters, where we calculated the reduction of greenhouse emissions from individual solutions, we will here estimate typical climate effects for South Asian villages using Eco-Village Development (EVD) solutions. The emission reductions included are those quantified in chapter 3-7, while the potentially large but uncertain emissions of soil improvements with biogas and compost is not included. They might add 10-20% to the emission reductions in the examples, but further research is needed to provide sufficient evidence for this.
We estimate greenhouse effect reductions from a theoretical example as well as for actual villages that either has large use of EVD solutions or a are planning/considering to use them in the future. In this report is one theoretical example and three examples based on solutions already implemented and planned in actual villages.

9.1 Village Example, Theoretical

In this theoretical example village of 100 households there are around 500 (theoretical) people. We base the reductions on the calculations in the previous chapters, including a fuel wood consumption with traditional stove of 5 kg/day per family. Another assumption is that the saved wood is unsustainable, i.e. it contributed to deforestation before the fuel saving solutions were introduced. Savings for different EVD solutions are given in table 9.1 with these assumptions.

The introduction of EVD solutions in a village is not leading to an end point in development (as the two examples might indicate); but are steps in the development.

Table 9.1: Greenhouse gas and particle emission reduction potential per village

Solutions	**Calculations**	**t CO_2e/year**
Total annual greenhouse emission reduction per village of 100 households if ICS, tier 3 replacing traditional open fire, unsustainable biomass	3.3 x 100	330
Total annual greenhouse emission reduction per village of 50 households if biogas as opposed to traditional open fire, unsustainable biomass	4.2 x 50	210
Total annual CO_2 emission reduction per village of 100 households if SHS systems were used, replacing use of kerosene lamps and diesel generators	100 * 344	34
Total annual CO_2 emission reduction per village of 100 households if mini grid replaces grid connection		72
Total annual CO_2 emission reduction per village if 25% of households use solar food dryers and sell products, replacing electric drying	25 * 3	75

Data from chapter 2-7.

Table 9.2: Total greenhouse emission reduction in example village 50% biogas and 50% ICS, mini grid instead of grid electricity for all

	Savings, ton CO_2e/year
Biogas in 50 households	210
ICS of tier 3 in 50 households	165
Minigrid in 100 households	72
Solar dryers in 25 households, replacing electric drying	75
Total greenhouse emission reductions	**522**

The example shows that considerable reductions of greenhouse gas emissions are possible in villages in South Asia with solutions used in the EVD project. Reductions can be around 500 ton CO_{2e}/year for a village with 100 households and 500 inhabitants. Thus, the reduction potential is around 1 ton/capita.

9.2 Village Example from Nepal

One of the villages in Nepal, where EVD has been demonstrated, is the Chyamrangbesi village in Kavrepalanchok District, which is in the "mid-hill" subtropical part of Nepal. Here lives around 300 people in50 families. For cooking the families use the following installations:

- 24 family biogas plants
- 45 metal improved cookstove, provided as earthquake disaster relief and a few improved stoves made out of mud. The 26 families that do not have biogas are generally using the improved cookstoves. Around 9 (45 – 26) have improved stoves + biogas.
- 5 (approximately) traditional stoves are still in use, for instance for occasional preparation of food for animals
- 25 of the families also have LPG stoves as supplement

It is estimated that the improved cookstoves only use 1/3 of the fuel of traditional stoves and that they reduce particles with around ¾.

It is estimated that the village today use 280 kg wood/day. This is expected to be divided as follows:
26 families with improved cookstoves but without biogas use 7 kg/day = 182 kg/day
19 familiar with improved cookstoves and biogas plants use 3 kg/day = 57 kg/day
5 additional traditional stoves use 8,2 kg/day each = 41 kg/day
Total 280 kg/day

The villagers get most of the firewood from their own forests and some parts from communal forests. It is expected that this wood-use is sustainable and does not have net emissions (the trees grow as fast as the villagers cut them for fuel wood).

It is calculated that the emissions from this biomass cooking are:
Biogas plants, leakages, 0.2 ton CO_2e/year * 24 = 5 tons CO_2e/year
Improved cookstoves, -not CO_2, 26*0.6 tons + 19 * 0.24 tons =19 tons CO_2e/year
Traditional stoves, not CO2, 2. tons * 5 = 13 tons CO_2e/year
Total = 38 tons CO_2e/year

Without the biogas and improved cookstoves, the families would have used the following amount of fuel on traditional stoves for the same cooking:

50 families cooking with traditional stoves * 21 kg/day	= 1050 kg/day
5 additional traditional stoves using 8,2 kg/day each	= 41 kg/day
Total	= 1091 kg/day

It is assumed that for the extra of fuel wood 811 kg/day, the families would have to collect it from communal forests and that half of it would be unsustainable. In this way 37% of their fuel wood would be unsustainable as the first 280 kg/day is fully sustainable.

This would give the following greenhouse emissions:

50 families using traditional stoves, non CO_2, * 7 tons	= 340 tons CO_2e
5 additional traditional stoves, non CO_2, 2.7 tons * 5	= 13 tons CO_2e/year
50 families + 5 additional stoves, CO_2 from 37% unsustainable	= 230 tons CO_2/year
Total	583 tons CO_2e/year

In this example we do not expect any difference in the LPG use because of the EVD solutions.

The village has grid power and generally the villagers are not using local electricity solutions.

Thus, the total climate mitigation effect from the EVD solutions in the village is that their emissions for cooking with biomass is reduced from 583 tons CO_2e/year to 38 tons CO_2e, a reduction of 546 tons CO_2e/year, about 1.8 tons CO_2e/capita. In this example the reductions per capita are larger than in the theoretical example above. This reasons for this is larger fuel use without EVD solutions, which is expected to be because villagers cook food for their animals and because they live in the hill areas, where more heat is needed than in more southern parts of South Asia.

This example is based on changes realised with EVD solutions in a specific village, but the reductions are not measured and there are a number of uncertainties, including how large a fraction of biomass use that would be unsustainable without the improved cooking and how large the non-CO_2 greenhouse emissions really are.

9.2 Village Example from Bangladesh

From Bangladesh is an example based on a village, Sudhkhira, some 30 km from Dhaka. With help of Grameen Shakti, here 85% (60 families) have invested in solar home systems, while more than 80% use traditional stoves (chulhas) and very few use LPG stoves. For cooking, the villagers use a mixture of dung, wood, leaves, and rice-husks.

In this example, we will include that Grameen Shakti in the future could promote improved cookstoves that would reduce fuel consumption three times and reduce non-CO_2 greenhouse emissions around twice per kg fuel use. With the mixture of dung, wood, rice husks etc, we assume that half the saved fuel would lead to reduced CO_2 emissions, while the rest will decompose anyway as the leaves, a fraction of the dung and other residues will gradually decompose (a fraction of the dung become soil carbon when used for compost, but another fraction decomposes).
We assume that 80% of the villagers would change to improved cookstoves with this, equal to 56 families.
The village has a solar powered water pump for drinking water. Without the solar installation, the villagers would have used a diesel pump that would have used some 0.7 ltr diesel per day according to estimate of Grameen Shakti.

The emission reductions of the 60 families that changed from kerosene to solar home systems can be estimated to have been 60 * 0,344 tons CO_2/year = 20 tons CO_2/year

The (coming) reduction of the fuel use with the improved cookstoves will be a reduction from 3 kg fuel/day per family today to 1 kg fuel/day. With 50% of fuel leading to net CO_2 emissions, this will reduce annual emissions of CO_2 with 48 tons in the village (half of the CO_2 emissions from the fuel use before introduction of ICS) and emissions of other greenhouse emissions from 55 to 9 tons CO_2e/year (fuel use reduced with three times, emissions/kg fuel halved, in total emission reductions of non-CO_2 greenhouse emissions is a factor 6), equal to a reduction of 93 tons CO_2e/year.

The reduction of diesel use with the solar pump is 0.7 * 365 = 256 lt. diesel/year. With emissions of 2.7 kg CO_2/lt. diesel, this is equal to 0.7 tons of CO_2/year.

This the total reductions with EVD solutions will be 20 + 93 + 1 tons CO_2e/year = 114 tons CO_2e/year.

In this example the reductions are smaller than in the other examples. This is mainly because the fuel use is quite small, compared with the other villages.

This example has a number of uncertainties, as the other examples. In this case one of the solutions, the improved cookstoves, are not implemented yet. In addition, it should be noted that after the village was electrified with SHS, it has been electrified with electricity from national grid. Even though it seems that the villagers are keeping their SHS, they will not save as much CO_2 as before with them.

9.3 Village Example from India

This example includes the results of the Eco-Village Development (EVD) project in three smaller villages in the Tehri District in the Indian state of Uttarakhand in the Himalaya foothills. Within the EVD activities are currently installed 15 Improved Cooking Stoves (ICS) and one solar dryer as well as a number of other solutions with less direct climate mitigation effects. There is a great local interest in more ICS and solar dryers and in the pipeline there are four projects for installation of 240 ICS and 30 solar dryers. These projects are expected to be implemented during 2018 and 2019. If the projects are realised as expected, by the end of 2019 there will be 255 ICS and 31 solar dryers in use in the villages. These numbers are used for the calculations for the emission reductions in this example.

The ICS introduced is a Hybrid Improved Cookstove developed for colder climate areas. This ICS, named Heera is a two-pot stove with a chimney. It also includes a hot water tank that allows the villagers to avoid heating water over open fire, which they used to do. This saves additional fuel. Further the Heera stove provides heating of the room and it has a solar PV module and a battery that provides light and mobile charging.
The experience is that the Heera stove, in the specific area, reduces demand of wood fuel in each household from 27 kg/day to 9 kg/day. Because of the better combustion, we assume that it cuts the non-CO_2 greenhouse emissions per kg fuel with a factor 2, similar to a Tier 1 ICS (see chapter 3 regarding tiers). In total non-CO_2 greenhouse emissions will then be reduced with a factor 6.

For the solar dryers, it is expected that they will be used to make products that will replace electric drying, saving 3 tons of CO_2/year, as in above examples.

We assume that all the firewood used in the district is sustainable, both before and after the introduction of the ICS. Therefore, CO_2 emission reductions are not included, even though the reduction of firewood will increase CO_2 uptake of trees in a traditional period. The introduction of ICS will reduce non-CO_2 GHG with a factor 6 from 2100 tons CO_2e/year with combustion of 2400 ton of wood fuel to 350 tons CO_2e/year with combustion of 800 tons of wood fuel with half the specific emissions. This is a reduction of 1750 tons CO_2e/year.

The 30 solar dryers will reduce emissions with 30 * 3 tons CO_2/year = 90 tons CO_2/year.

The total emission reductions will then be around 1840 tons CO_2e/year for the project area. This is much larger reduction than in the other examples. One reason for this is the high wood use in the area, because it is a cold climate, and probably also because wood is relatively abundant in the area. Another reason is simply that this case covers several villages, where the others just cover one village each.

Like the other cases, this case also has a number of uncertainties, including if the villagers who will get the ICS in the future would save as the much as the ones who uses it today, and if the fuel used is really sustainable both today and in the future.

9.4 Comparison with Other Emission Estimates

Some of the emission reductions in the examples are recognised today internationally and are for instance eligible for Clean Development Mechanism (CDM) project support. This is CO_2 emission reductions from improved cooking with ICS and biogas, as well as reduced CO_2 from introduction of solar home systems.

In the examples above, the emission reductions for each village are from around 100 to 500 ton CO_2e for improved cooking solutions and 20 tons for solar home systems. Thus, the total reductions per village are ranging from above 100 to around 550 tons CO_2e per year, equal to emission reductions ranging from 2 to 11 tons CO_2e per involved family per year. The higher figures are somewhat bigger than the figures currently included in CDM projects. See table 3.6 and 4.2. The main reasons for this is the inclusion of non-CO_2 greenhouse emissions (gases and particles), as well as high wood fuel use in two of the three cases that are in colder, mountainous climates.

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Appendix 1: GHG Emissions with Improved Cookstoves

By Jessica Brugmans

Indian surveys put the rural households that use improved cookstoves somewhere between 5% and 7% (M/s G K Energy Marketers Pvt Ltd and Vitol S.A., 2012a: 2). In Sri Lanka, it is estimated that around 41% of fuelwood could be saved by disseminating improved cookstoves (Perera and Sugathapala, 2002: 85). A substantial part of this potential has now been harnessed with the dissemination of the Anagi stove.

There is a wide variety of improved cookstoves on the market, and per project location some are more suitable than others. Variations are in design including whether they provide for one or two stoves. The following table provides an overview of popular improved stoves in South Asia, the fuel type used, and the efficiency percentage.

Table A1: Improved Cookstove Efficiency and Fuel Type

Improved cookstove design	Efficiency %	Fuel
Anagi stove - 1 & 2	21.0	Fuelwood
Ceylon charcoal stove	30.0	Charcoal
Sarvodaya two-pot stove	22.0	Fuelwood
CISIR single-pot stove	24.0	Fuelwood
IDB stove	20.0	Fuelwood
NERD stove	27.0	Fuelwood

Adapted from: (Perera and Sugathapala, 2002: 92).

Not all projects considered use the above stoves, there are other designs in use as well and new ones have been developed. For all, however, the efficiency rates lie well above the averages for traditional cooking methods. It ranges between around 20%, 30%, 40% depending on the stove. (Egluro UK and Centre for Rural Technology Nepal, 2011: 4, JanaraSamuha Mutual Benefit Trust, 2011: 3, SAMUHA, 2011: 4, Bagepalli Coolie Sangha, 2012: 2, M/s G K Energy Marketers Pvt Ltd and Vitol S.A., 2012a: 16, Seva Mandir, 2013: 4, Integrated Sustainable Energy and Ecological Development Association and First Climate AG, 2014: 9).

Household biogas digesters, as discussed at length in chapter 4, also require specifically designed stoves for using the gas for cooking. The efficiencies of biogas stoves are comparable to those of kerosene or LPG stoves. Biogas stoves can achieve efficiencies varying between 40% and 65% (Bhattacharya and Salam, 2002: 310). Bhattacharya employs an efficiency rate of 55% percent for LPG and biogas stoves. This information compiled and compared with the traditional stoves gives the following CO_2 emissions for different forms of cooking on different stoves and with different fuels:

Table A2: CO_2 Emissions from Cooking

	Net fuel emissions	Efficiency	Net emissions from cooking
	pr kWh fuel	*%*	*pr kWh useful energy*
Traditional fire, unsustainable biomass	0,39	15	2,6
Traditional fire, biomass by-product*	0,13	15	0,9
Improved stove, unsustainable biomass	0,39	30	1,3
Improved stove, biomass by-products*	0,13	30	0,4
All biomass stoves and fires, sustainable biomass	0	n.a.	0
LPG stove	0,26	50	0,5

**Assuming the effective CO2 emissions, compared with composting of the materials, is 1/3 of unsustainable biomass*

Adapted from: (Ravindranath and Balachandra, 2009).

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