

Greenhouse Emission Reduction Potential of Eco-Village Development (EVD) Solutions in South Asia



INFORSE-South ASIA
International Network for Sustainable Energy



1. Edition, July 2017

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First edition, July 2017

Authors:

Gunnar Boye Olesen, International Network for Sustainable Energy (INFORSE)

Max Vittrup Jensen, Hel-Max Miljøkonsult

Main contributors:

Kavita Myles, INSEDA / INFORSE South Asia

Jessica Brugmans, INFORSE

EVD Partners, see below

This publication was developed as part of the project "*Evidence based advocacy for low-carbon, pro-poor sustainable "Eco-Village Development"*" (EVD) in South Asia, coordinated by DIB, Denmark and supported by the Climate and Environment Fund of Civil Society in Development (CISU), Denmark.

Main partners are:

Grameen Shakti, Bangladesh

Integrated Sustainable Energy and Ecological Development Association (INSEDA), India

Women's Action for Development (WAFD), India

Centre for Rural Technologies /Nepal (CRT/N)

IDEA, Sri Lanka

Climate Action Network South Asia (CANSA)

International Network for Sustainable Energy (INFORSE and INFORSE South Asia)

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List of contents

1. Summary	page 2
2. Introduction	page 3
3. Improved cookstoves	page 5
4. Household biogas plants	page 14
5. Household scale power (solar home systems, solar lamps)	page 20
6. Village scale power (mini and micro grids)	page 22
7. Solar drying	page 25
8. Climate mitigation effects on village level	page 27
References	page 29
Appendix 1	page 32

1. Summary

This report analyse climate change mitigation effects of Eco-Village Development (EVD) Solutions that are promoted by a number of organisations to help villages in South Asia in sustainable development. Of the 12 main solutions promoted within the EVD concept and projects, the report presents analysis of five that are estimated to be of most importance on a regional scale for climate mitigation. Other solutions can be more important locally, depending in the specific local conditions.

The five selected solutions are: improved cookstoves for household use, household biogas plants, solar home systems, solar mini and micro grids, solar drying.

The result of the analysis is that for an example village with 100 households taking up the selected EVD solutions, emissions can be reduced with 500 - 600 tons of CO₂ compared with a baseline with continued traditional cooking and light + electricity from kerosene, diesel or Indian central power grid. The most important is the improvements of cooking solutions, where biogas shows the highest reductions. Second in importance for mitigation is household and village scale power with renewable energy.

Some of the emission reductions in the examples are recognised internationally today and are eligible for support for emission reductions with Clean Development Mechanism (CDM) projects. This is CO₂ emission reductions from improved cooking and introduction of solar home systems. The recognised reductions represent about half the reductions that we have identified in two examples. The main reason for the higher emission reductions identified in our analysis than in CDM methodology is the emission reductions with the improved cooking solutions of non-CO₂ greenhouse emissions. An additional difference is because of the inclusion of more solutions in our analysis, specifically solar drying.

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. The EVD involves the implementation of inexpensive, renewable energy solutions and livelihood enhancing solutions, mainly via capacity building and with aims of climate change adaptation and mitigation. EVD is an integrated approach of creating development-focused, low-carbon communities of practice in pre-existing villages. This bundle of practices includes mitigation technologies like small household size biogas plants, smokeless stoves, solar energy technology (such as solar drying units), and adaptation technologies like improved, organic farming, roof-water harvesting and others. The concept aims at the use of solutions that are low-cost, pro-poor, replicable, income generating, climate resilient, and with low emissions, both of local pollutants and of greenhouse gases. 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.

This report analyses the greenhouse emission reductions (climate change mitigation) that can be achieved on household and village level with EVD solutions. Among the many EVD solutions, five are selected for analysis in the following chapters (2-7), and in the final chapter (8) are presented possible total village level greenhouse emission reductions.

In the table 2.1 are the main EVD solutions listed with their effects on greenhouse emissions, indicating those analysed in this report.

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 projects in developing projects, these projects are well-documented according to established methodologies.

By looking at the project intervention, 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 India, Nepal and Sri Lanka, and the literature considered is predominantly specific to this area.

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*	Included in this report
Improved Cookstove (ICS)	Reduces emissions of cooking, CO ₂ and other emissions	High	Yes
Large ICS for Rural Household Industries	Reduces emissions of household industries, CO ₂ and other emissions	Medium	No
Household biogas	Reduces emission of cooking and in agriculture	High	Yes
Solar light in homes	Reduces emissions of CO ₂ from kerosene and others	High	Yes
Improved water mill	Reduces emissions of CO ₂ from electricity and diesel engines	High where streams available	No
Solar and hydro micro and mini grids	Reduces emissions of CO ₂ from electricity and diesel engines	Medium	Yes
Hydraulic Ram pumps	Replaces diesel and electric pumps, reducing CO ₂ emissions	High where streams available	No
Organic farming & gardening	Replace N-fertiliser that has greenhouse emission in production	Medium - Small	No
Compost baskets	Help organic farming	Medium-small	No
Rainwater harvesting	Replaces piped and collected water which reduce electricity for water pumping thereby reducing emissions of CO ₂	Small	No
Solar dryer	Replaces electric and fossil fuel drying, reducing emissions of CO ₂	Medium	Yes
Greenhouses	Effects not evaluated	Not evaluated	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**”, August 2016. The publication and other information EVD is available from INFORSE-South Asia: <http://www.inforse.org/asia/EVD.htm>

3. Improved cookstoves



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

3.0 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 GHG emission reductions from improved cookstove projects has been estimated as 1 gigaton of carbon dioxide equivalents (1 G CO_{2e}) per year, based on 1 to 3 tons of CO_{2e} per stove (Müller et al. 2011). Our analysis find an average reduction of global warming equivalent to 2. tons of CO_{2e} per stove of CO₂ only and more if other greenhouse gases and particles are included. 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 1/3 of the global estimate mentioned above.

Apart from the above reduction of global warming, improved cookstoves will reduce the solid biomass used for cooking and heating with around 50%, and also reduce the global warming from emissions of black carbon. Small cookstoves are estimated to contribute 25% of black carbon emissions globally (Rehman et al. 2011).

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 as detailed.

To compare cookstove performances, The Global Alliance for Clean Cookstoves has implemented the IWA 11:2012 Guidelines for evaluating cookstove performance (now part of an ISO standard). IWA 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 values determined by laboratory testing. This is expected to encourage a consumer based “selection of the fittest” development of ICS production. Unfortunately, at time of printing the stoves used in the EVD project has not been rated according to the IWA scheme.

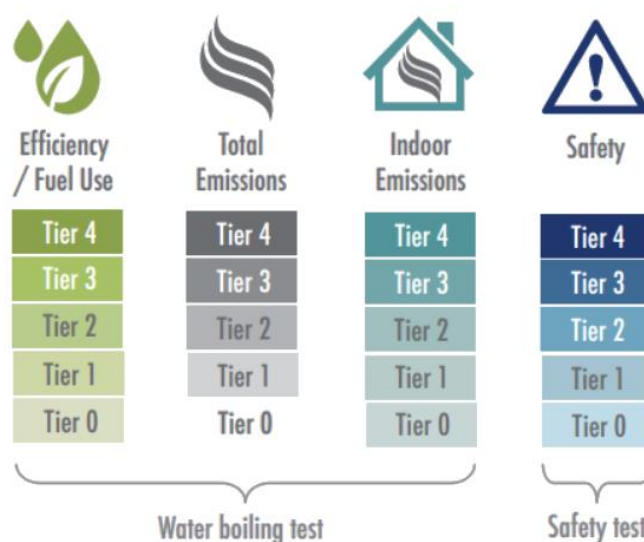


Table 3.1: Comparison of wood-burning cookstoves net greenhouse gas emissions per year

Stove and fuel type,	Net GHG emissions per year	GHG Savings over trad.stove, unsustainable wood	GHG Savings over trad.stove, sustainable wood
Traditional cookstove, unsustainable wood	6 ton CO ₂ e	0	n.a.
Traditional cookstoves, sustainable wood	3 ton CO ₂ e	3 kg ton CO ₂ e	0
Improved cookstove, tier 1	3 / 1.4 ton CO ₂ e	2.8 kg ton CO ₂ e	1.5 ton CO ₂ e
Improved cookstoves, tier 3	1.4 / 0.5 ton CO ₂ e	4.4 ton CO ₂ e	2.5 ton CO ₂ e
LPG stove	0.4 ton CO ₂ e	5.4 ton CO ₂ e	2.5 ton CO ₂ e

The data, includes CO₂, black carbon and organic gases. For improved cookstoves, the figures illustrate use of sustainable and unsustainable wood respectively, but does not including indirect land-use effects. Average figures are used and hence they contain some uncertainty, as further explained in the following pages. For charcoal stoves GHG emissions and potentials savings 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 GHG 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).¹¹ In some rural districts, firewood use can even be close to 100% (97.9% in the Indian Kolar District (in 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 is reflective of the increasing wealth of small rural households. 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).

For Nepal, India, and Sri Lanka it is the case that the greenhouse gases emitted from biomass use for cooking can be several times the greenhouse gases emitted 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 and to a lesser extent also LPG.

The prevalence of traditional stoves and fires is illustrated by figures from Bangladesh where traditional mud-constructed stoves are used by over 90% of all rural families. Similar figures are found in other South Asian countries. 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.

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	12.0	Fuelwood, dung
	Traditional Indian Chulha	12.5	Fuelwood, crop residues, dung
	Sheet metal un-insulated chulha	18.0	Charcoal
	Mud coated bucket chulha	21.0	Charcoal
Nepal	Agenu (open fire stove)	8.9	Fuelwood, residues, dung
	Chulo/mud stove	12.0	Fuelwood, residues
Sri Lanka	Single and two pot mud stove	13.0	Fuelwood-agri-residues
	Three-stone stove	8.0	Fuelwood-agri-residues
Bangladesh	Mud stove	5.0-15.0	Biomass

Data in table adapted from: (Perera and Sugathapala, 2002: 92, Bhattacharya and Salam, 2002: 308, Bond and Templeton, 2011: 349).²

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

Globally the most important greenhouse gas is CO₂, and cookstoves also emit CO₂, even though the

¹ Figures are from the 2011 National census.

² Efficiencies get determined per standard water boiling tests (as determined in the CBM methodologies).

quantities are small for each stove.

When cooking is done with wood from areas with deforestation, or with coal, the full amount of CO₂ is emitted with combustion is contributing to build-up of CO₂ 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, so the CO₂ build-up in the atmosphere is 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 CO₂ 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 has to be produced on other areas.

CO₂ emissions from combustion of coal and unsustainable biomass is around 0,39 kg CO₂/kWh.³ 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 CO₂/kWh in a 20-year perspective or less, based on the assumption that 2/3 or more of the hydrocarbons in the biomass will be converted to CO₂ and water within 20 years.

Combustion of LPG gives CO₂ emissions of 0.26 kg/kWh of gas⁴. In addition to the lower specific emission of gas compared with unsustainable biomass, LPG stoves are more efficient than biomass stoves.

Stoves emits different gases and particles that are contributing to climate change. While CO₂ is the best known, also emissions of methane (CH₄), other organic gases (NM-HC), laughing gas (N₂O) and particles of black carbon (soot) all contributes to climate change. The table below gives typical emissions and global warming potential relative to CO₂.

As illustrated in above tables 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 instead of wood).

Another major contributor to climate change is other emissions generated by inefficient combustion. Because of poor combustion, inefficient cookstoves divert a considerable portion of carbon into products of incomplete combustion (PICs), many of which have higher global warming potentials (GWPs) than CO₂(Smith et al., 2000:743).

This incomplete combustion also gives 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 traditional cooking stoves, is worldwide thought to be responsible for 2.7% of the total global burden of disease (Bond and Templeton, 2011: 349).⁵

The most important emissions from incomplete combustion are carbon monoxide (CO), laughing gas (N₂O), methane (CH₄), polycyclic aromatic hydrocarbons (PAHs) and other non-methane organic gases (NM-HC), as well as fine particulate matter including black carbon (Panwar et al., 2009: 570).

³ https://www.volker-quaschnig.de/datserv/CO2-spez/index_e.php accessed 10.07.2017

⁴ <http://www.oryxenergies.com/en/products-services/businesses/businesses-lpg/environment> accessed 10.07.2017

⁵ *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).*

CO in itself is not a direct GHG, but indirectly affects the burden of CH₄ (IPCC, 2007b). It has been proposed that CO emissions should have a GWP, but this is not (yet) the case.

Of the hydrocarbons methane have the largest GWP, 34 times CO₂. (IPCC, WG1, 2013, 100-year horizon). NM-HC is a mix of gases. As an average GWP for NM-HC has been proposed a GWP of 12 (Edwards & Smith 2002). Laboratory tests have shown that all hydrocarbon gases add around 25% to the greenhouse gas emissions of both traditional fires and improved stoves, however some improved stoves have significantly less non-CO₂ greenhouse gas emissions, in the order of 3% of total emissions. If the biomass use is sustainable, the relative effect of the non-CO₂ gases are much more important, adding 75% to the greenhouse effects for most fires and stoves and some 9% to the most clean burning ones.

N₂O is a very potent greenhouse gas with a GWP of 298 (IPCC WG1, 2013, 100-year horizon) which is formed in small quantities in cookstoves.

Fine particulate matter, especially when smaller than 2.5 micro meters (PM_{2.5}) 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. Soot from indoor smoke combines with soot from outdoor air pollution and can form brown clouds in the atmosphere (the Asian brown cloud covers large parts of South Asia in the winter season). These clouds consist of a variation of pollutants, including sulphate, nitrate, soot and fly ash. Brown clouds lead to a reduction of sunlight as well as atmospheric solar heating (Ramanathan and Balakrishnan, 2007: 3), and are overall found to have a cooling effect. In itself black carbon is detrimental to snow cover, which is both relevant on a global scale as it affects the snow cover on the poles, but also regionally in the Himalaya. Even very low concentrations of black carbon on snow trigger melting (Ramanathan and Balakrishnan, 2007: 4). Recent studies conclude that the importance of black carbon for human-induced climate change is second to only CO₂. The GWP of black carbon is still debated (no generally agreed GWP at this moment in time), estimates range from GWP = 190 to GWP = 2240 (Jacobsen M.Z. 2005 et.al.). We will use a GWP = 680 (from Bond & Haolin, 2005, 100-year 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).

Research carried out by Aprovecho Research Centre (Maccarty et al., 2009), illustrates that all emissions are significantly reduced by utilising ICS technology.

Below is given typical emissions for different greenhouse gases other than CO₂ and black carbon per kWh of fuel used.

Table 3.3: Typical non-CO₂ greenhouse emissions from different cooking options

Emissions:	Black carbon (PM _{2.5})	CH ₄	NM-HC	N ₂ O	Total non-CO ₂ greenhouse emissions
Units	g/kWh fuel	g/kWh fuel	g/kWh fuel	g/kWh fuel	Kg CO ₂ e/kWh fuel
Traditional stoves (wood)	0.5	1.9	1.0	0.014	0.40
Improved stoves (wood)	0.2 - 0.5	1.5	0.5	0.014	0.20 - 0.40
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.

* See chapter 4 for more information on total emissions from biogas plants

3.2 GHG emissions with improved cookstoves

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 design include whether they provide for one or two stoves, fuel use, 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).

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 designed stoves to use for cooking. The efficiencies of biogas stoves are comparable to those of LPG stoves. Biogas stoves can achieve efficiencies 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 CO₂ emissions given in table 3.5.

Table 3.5: CO₂ 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 and fires, sustainable biomass	0	n.a.	0
LPG stove	0.26	50	0.5

Adapted from: (Ravindranath and Balachandra, 2009). CO₂ emission reductions are calculated using data from appendix 1.

For selected projects with improved stoves in South Asia, the avoided CO₂ emissions has been estimated to be from 0.9 to 3.37ton CO₂/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.

	Number of households participating	Avoided emissions
		ton CO ₂ /year/household
JSMBT (India)	21500	1.98
Maharashtra (India)	14400	0.90
Bagepalli microstoves (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, Janara Samuha 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).⁶

As the improved stoves provide for more efficiency there are also less other 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 by The Global

⁶ *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).*

Alliance for Clean Cookstoves and others on ISO-IWA 11:2012 Guidelines for evaluating cookstove performance, the most important emissions are measured more regularly. With the IWA, 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 black carbon for the 5 IWO 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 considering, as the EVD targets those living in poverty. Because of the efficiency of the stoves and therefore smaller need for firewood, 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).⁷

Even for households that are gathering firewood and 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).

⁷ 1 euro equals around 70 Indian Rupees.

3.4. Summary of effects

While there are uncertainties of the emissions, the change from traditional to improved cookstoves consistently reduce the impact from cookstoves on their greenhouse effect on the most consistent effect is by reduction of fuel use, but also emissions of for instance black carbon are important.

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 in table 3.9. Some studies have found considerable higher wood consumptions of traditional cooking, up to more than double of these figures, see table. 4.2.

Table 3.9: Biomass stoves, comparison

Compared	Traditional stoves, unsustainable 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 black C, pm2.5, kg CO ₂ e/kWh	0.32	0.32	0.29	0.14	n.a.
Emissions CH ₄ kg CO ₂ e/kWh fuel	0.06	0.06	0.05	0.05	0.003
Emissions NM-HC kg CO ₂ e/kWh fuel	0.012	0.012	0.006	0.006	n.a.
Emissions of N ₂ O kg CO ₂ e/kWh fuel	0.004	0.004	0.004	0.004	0.002
Total emissions, unsustainable Bio., kg CO ₂ e/kWh fuel	0.79	n.a.	0.74	0.59	0.26
Total emissions, sustainable Bio, kg CO ₂ e/kWh fuel	n.a.	0.40	0.35	0.20	0.26
Emissions in kg CO ₂ e/year, unsustainable biomass	5791	n.a.	2985	1362	387
Emissions in kg CO ₂ e/year, sustainable biomass		2944	1419	467	387
Emission. reductions in kg CO ₂ e/year, unsustainable biom.	n.a.	n.a.	2806	4429	5405
Emission reductions in kg CO ₂ e/year, sustainable biomass	n.a.	n.a.	1525	2477	2558

Adapted from chapter 3.1 and 3.2:

Efficiency and CO₂: 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)

CH₄ and N₂O: 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.

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 Summary

The second of the EVD solutions this report considers is the household biogas plant (HBP), which by means of anaerobic digestion transforms cattle manure 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 BSP Nepal project has been operational since 1992 in various forms, and 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, as to provide for a five-member family with enough biogas to cook two meals a day 1.5 to 2.4 m³ gas needs to be produced, which corresponds to the fact that a 2 m³ capacity plant typically is the smallest available (Bond and Templeton, 2011: 350). As part of the EVD program, smaller plants, with a capacity of 1 m³, that only need 25 kg of manure a day (which corresponds to the daily production of two cows) have been designed and is now in use in small farms (INFORSE, 2016: 18).¹ Both household biogas plants and improved cookstoves provide significant emission reductions for rural households in South Asia.

Table 4.1: Biogas guideline data

Biogas energy	6kWh/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 Dorothee Spuhler (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 included in the calculations.

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 proportion of biomass fuels is claimed by the burning of firewood, as discussed in chapter 3, and its use is primarily for cooking.

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 of greenhouse gases and particles from use of wood fuel and LPG for cooking are given in table 3.1.

Biogas use has its own 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 CO₂ emissions from combustion of the biogas

With biogas about half of the organic material in manure and other feedstock is converted to methane and CO₂. 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 in 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 CO₂ 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 a 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 into the same day it is produced, 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 N₂O 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 Maharashtra,
- 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 small-scale 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.

4.2 Effects on GHG emissions of HBPs

The major GHG emission reduction with biogas use is the coming from the avoidance of other, more polluting, fuel-sources. Looking at the consumption of firewood (both unsustainably and sustainably harvested) 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 CO₂ 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.⁸

⁸ 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	18.000	61109
Total	17,77	26,79	47382	189.383
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 also a practice in some areas, 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 CH₄ emissions of 0.2 tons CO_{2e}/year, equal to loss of around 7% of methane.

One research project in the 1990's established that in a year the meals cooked on the 53.5 million tons of dung used in household stoves had been cooked with biogas, there would have been an annual savings of 20 million tonnes of carbon as CO_{2e}, or about 10% of the total GWC (CO₂ and CH₄) from fossil fuels in those years (Smith et al., 2000: 758).

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: Comparison of cookstoves regarding 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 cookstove, unsustainable wood	6 ton CO ₂ e	0	n.a.
Traditional cookstove, sustainable wood	3 ton CO ₂ e	3 kg ton CO ₂ e	0
Improved cookstove, tier 1	3 / 1.4 ton CO ₂ e	2.8 kg ton CO ₂ e	1.5 ton CO ₂ e
Improved cookstoves, tier 3	1.4 / 0.5 ton CO ₂ e	4.4 ton CO ₂ e	2.5 ton CO ₂ e
LPG stove	0.4 ton CO ₂ e	5.4 ton CO ₂ e	2.5 ton CO ₂ e
Biogas stove	0.02 ton CO ₂ e	6 ton CO ₂ e	3 ton CO ₂ e

The data, includes CO₂, black carbon and organic gases. 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 CO₂ 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 is not the only processes with greenhouse effect impacts. A considerable 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 has a major influence on emissions, but also the alternative use of manure by digesting it instead of burning or adding it to land unprocessed has effects on emissions. To quantify GHG emission reductions, the baseline for fertiliser and its GHG effects must be established. The baseline for these projects is the situation where, in the absence of HBPs, manure and other organic matter are left to decay partly anaerobically and methane is emitted to the atmosphere.

Data surrounding this subject are significantly less exact as compared to the direct emissions, 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 (N₂O) is the most significant GHG associated with the production of nitric acid. N₂O is a highly potent greenhouse gas, with a global warming potential 298 times greater than CO₂ (IPCC, 2013). This report considers N, P, and K fertilisers.¹ N fertilisers are however the main source of GHG emissions, so this where the focus lies. First, the consumption of fertiliser in the project countries should be noted. In all of India the use of N, P₂O₅ and K₂O fertiliser 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, but it is large quantities that are under consideration.

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 swine 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 released. 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 there are relatively easy fixes to curb these emissions and logically it is in the interest of the user to minimise gas loss, as the gas is a valuable energy resource. The replacement of artificial fertiliser with for 2 m³ biogas plant with input of 50 kg manure/day reduces production emission of fertiliser in the order of 0.1 - 0.15 ton CO₂e/year. This effect is negligible 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). Due to climatic variations that number might however be smaller for South-Asia, but still in the same range. If 25% of the carbon in biogas digestate becomes stable soil organic carbon, the reduced emissions are in the order of 0.1 - 0.15 ton CO₂/year. This effect is negligible compared with the emission reductions given in table 4.3 and will not be included.

4.4 Summary of 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 0.2 ton CO₂e/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 and from increased soil organic carbon. 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 cookstove , unsustainable wood	6 ton CO ₂ e	0	n.a.
Traditional cookstoves, sustainable wood	3 ton CO ₂ e	3 kg ton CO ₂ e	0
Improved cookstove, tier 1	3 / 1.4 ton CO ₂ e	2.8 kg ton CO ₂ e	1.5 ton CO ₂ e
Improved cookstoves, tier 3	1.4 / 0.5 ton CO ₂ e	4.4 ton CO ₂ e	2.5 ton CO ₂ e
LPG stove	0.4 ton CO ₂ e	5.4 ton CO ₂ e	2.5 ton CO ₂ e
Biogas plant and stove	0.2 ton CO ₂ e	5.6 ton CO ₂ e	2.7 ton CO ₂ e

Data from table 4.3 and methane loss from biogas plant of 0.2 ton CO₂e/year

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 CO₂ emissions from kerosene and diesel use with 344 kg CO₂/year (with 3 lamps in the house used 4 hours/day).

5.1 Baseline and proposal

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 CO₂ emissions annually by providing solar derived power for 4 hours daily to the 240.000 homes.⁹

⁹

Information derived from <http://gshakti.org/>, accessed 10.07.2017

Table 5.1: CO₂ 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
Co2 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 Co2 emission from diesel generators to charge the batteries of a household		8 kg CO ₂ /year
Total annual Co2 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 CO₂ 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.

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 CO₂ 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 CO₂/year. This is because of the high CO₂ 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 are used.

6.1 Baseline and proposal

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 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 10KW 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 RE based generation capacity of below 10KW. 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 ESCOs¹⁰. 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.

¹⁰ 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 project¹¹ sponsored by Greenpeace, which partly failed due to the use of energy-inefficient televisions and refrigerators and will potentially attract energy-hungry appliances such as rice cookers, electric water heaters, irons, space heaters and air coolers. Essentially 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 1/3 of Indian average villages according to the 2011 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: CO₂ 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 ₂ e/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 ¹² . For purpose of this calculation we use 75 kWh/month.	90000	72 ¹³
Village CO ₂ e 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.

¹¹ Elaborated in <https://www.scientificamerican.com/article/coal-trumps-solar-in-india/> Accessed 15.07.2017

¹² 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.

¹³ Data from 2010 are assumed applicable as development in energy production is assumed similar within both renewable and non-renewable source of energy
http://www.cea.nic.in/reports/others/thermal/tpece/cdm_co2/user_guide_ver6.pdf accessed 10.07.2017

From table 6.4, it is clear that there are substantial CO₂ 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, given 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 is connected, mainly for economic reasons, while others will for instance have solar lanterns, the most affordable solar electricity option.

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 CO₂ (when replacing electric drying) or 2.5 kg CO₂ (when replacing gas fired drying). On an annual basis, this can save respectively around 1 and 0.5 ton CO₂ 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% water¹⁴. 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 CO₂ emissions for drying of above-mentioned fruit and vegetables with respectively electricity from Indian power grid and with gas (LPG).

¹⁴ 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 CO₂ 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 above table is assumed a drying efficiency of 40% as for drum dryers, and an efficiency of the gas furnace of 80%.

7.2 Solar drying

Solar dryers exist in many sizes and designs., The ones used by small farmers in the EVD projects are small and inexpensive models with drying capacity around [1 kg/day of dried fruit], equal to around [6] kg of fresh fruit. If it is used half the year, 180 days/year, for various fruits, replacing drying with fossil fuel, it will reduce annual CO₂ emissions with around 1.1 tons if it replaces electric drying and 450 kg if it replaces gas-fired drying.

A good analysis of solar drying for South Asia can be found at:

www.springer.com/cda/content/document/cda_downloadaddocument/9788132223368-c2.pdf?SGWID=0-0-45-1504301-p177290270

In 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 CO₂ 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 CO₂ reductions of dried products that replace fossil fuel dried products.

8. 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 a village of 100 households, around 500 people.

Table 8.1: Greenhouse gas and particle emission reduction potential per village

Solutions	Calculations	t CO ₂ e/year
Total annual greenhouse emission reduction per village of 100 households if ICS, tier 3 replacing traditional open fire, unsustainable biomass	4.4 x 100	440
Total annual greenhouse emission reduction per village of 50 households if biogas as opposed to traditional open fire, unsustainable biomass	5.6 x 50	280
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 * 1.1	27

Data from chapter 2-7.

Table 8.2: Total reduction example village 1: ICS and SHS for all

	Savings, ton CO ₂ e/year
ICS of tier 3 in 100 households	440
SHS in 100 households	34
Solar dryers in 25 households, replacing electric drying	27
Total greenhouse emission reductions	500

Sum is rounded from 501 because data quality does not justify three digits.

Table 8.3: Total greenhouse emission reduction in example village 2: 50% biogas and 50% ICS, mini grid instead of grid electricity for all

	Savings, ton CO₂e/year
Biogas in 50 households	280
ICS of tier 3 in 50 households	220
Minigrid in 100 households	72
Solar dryers in 25 households, replacing electric drying	27
Total greenhouse emission reductions	600

Sum is rounded from 599 because data quality does not justify three digits.

The examples show that considerable reductions of greenhouse gas emissions are possible in villages in South Asia with solutions used in the EVD project. The reduction potential is in the order of 1 ton/capita. For the second example, reductions include both reductions of existing emissions from existing use of firewood + kerosene and avoided increases in emissions with development, in this case with electricity grid connections.

In practice, it will be hard to have the last household included, and households that have introduced for instance improved cookstoves will not necessarily use them all the time. On the other hand, most villages are larger than 100 households, so the greenhouse emission reductions per village can easily be higher, if the village is larger.

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. Thus, for instance when a village has installed a mini grid, it could be a suitable candidate for grid electrification as the internal network is already in place. This could improve the service for the villagers, but will increase greenhouse emissions, as long as the South Asian power supplies are as dependent on fossil fuels as they are today.

Some of the emission reductions in the examples are recognised today internationally and are for instance eligible for CDM project support. This is CO₂ emission reductions from improved cooking and introduction of SHS. In the examples above these emissions reductions are 200 - 300 ton CO₂ (2 tons/household for ICS and 4 tons/household for biogas) for improved cooking solutions and 34 tons for SHS, in total 234 ton for example 1 and 334 tons for example 2. This is about half the reductions that we have identified in the two examples.

The main reason for the higher emission reductions identified in our analysis compared to CDM methodology is the reductions in non-CO₂ greenhouse emissions from traditional cooking with the improved cooking solutions. An additional reason is the inclusion of more solutions in our analysis, specifically solar drying.

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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).

Table 1: Stove distribution in Sri Lanka

Type of stove	Rural households using stove type (%)	Percentage share of fuelwood (%)
Traditional three-stone	47	60.4
Semi-enclosed stove	32	27.4
Improved stove	21	12.2

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

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 2: Improved cookstove efficiency and fuel type

Improved cookstove design	Efficiency %	Fuel
Anagi stove - 1 & 2	18.0	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. 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, Janara Samuha 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 the chapter above also require specifically designed stoves for use for cooking. HBPs and improved cookstoves are therefore inextricably linked. 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 this information gives the following CO₂ emissions for different forms of cooking on different stoves and with different fuels:

Table 3: CO₂ emissions from cooking

	Net fuel emissions	Efficiency	Net emissions from cooking
	<i>pr kWh fuel</i>	%	<i>pr kWh useful energy</i>
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

Adapted from: (Ravindranath and Balachandra, 2009).