**Greenhouse Emission Reduction potential of Eco-Village Development (EVD) Solutions in South Asia**  
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**List of contents**

1. Summary
2. Introduction
3. Improved cookstoves
4. Household biogas plants
5. Household scale power (solar home systems, solar lamps)
6. Village scale power (mini and micro grids)
7. Solar drying
8. Climate mitigation effects on village level

References

Appendix

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 with 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. Other solutions can be more important locally, depending in the specific local conditions.

The five solutions selected are improved cookstoves for household use, household biogas plants, solar home systems, solar mini and micro grids as well as 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, followed by solar electricity.

Some of the emission reductions in the examples are recognised today internationally and are for instance 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 about half the reductions that we have identified in the two examples. The main reason for the higher emission reductions identified in our analysis than in CDM methodology is the reductions with the improved cooking solutions in 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 technology and capacity building activities for 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 include 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 analysis 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) is presented possible total village level greenhouse emissions reduction.

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

### 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  This report |
| Improved Cookstove (ICS) | Reduces emissions of cooking, CO2 and other emissions | High | Yes |
| Large ICS for Rural Household Industries | Reduces emissions of household industries, CO2 and other emissions | Medium | No |
| Household biogas | Reduces emission of cooking and in agriculture | High | Yes |
| Solar light in homes | Reduces emissions of CO2 from kerosene and others | High | Yes |
| Improved water mill | Reduces emissions from electricity and diesel engines | High where streams available | No |
| Solar micro and mini grids | Reduces emissions from electricity and diesel engines | Medium | Yes |
| Hydraulic Ram pumps | Replaces diesel and electric pumps | 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 | Small | No |
| Solar dryer | Replaces electric and fossil fuel drying | 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

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.

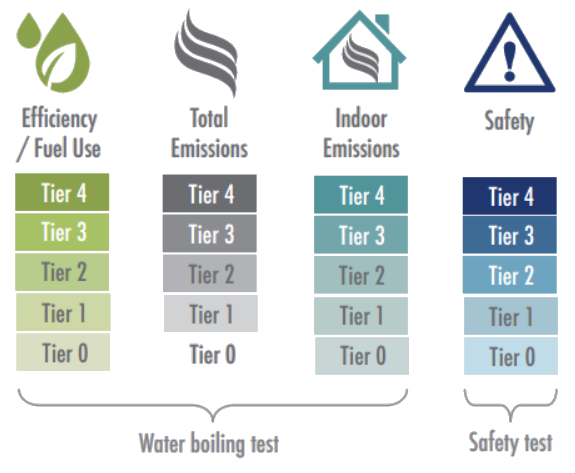
By looking at the project intervention, and its effects on unsustainable fuel use, emissions and related issues, a comparison can be made between the more traditional development route or lack of development, and the gains of implementing EVD solutions. The report takes project examples from India, Nepal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

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**



***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 CO2e) per year, based on 1 to 3 tons of CO2e per stove (Müller et al. 2011). Our analysis find an average reduction of global warming equivalent to 2.04 tons of CO2e per stove of CO2 and other greenhouse gases. As it is estimated that as much as 66% of India's 255 mio households (2011 census) still rely on traditional biomass for cooking (IEA 2012), an average of 2.04 ton of CO2e reduction per cookstove will represent a national reduction of *343 mio tons of CO2e emissions* -or about ⅓ of the global estimate.  
  
Apart from the above reduction on global warming, improved cookstoves will reduce the solid biomass used for cooking and heating with 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), a figure expected to increase to half of all global black carbon emissions until 2030, if not addressed on a large scale, due to planned emission reductions in the transport sector (UNEP and WMO 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 CO2e | 0 | n.a. |
| Traditional cookstoves, sustainable wood | 3 ton CO2e | 3 kg ton CO2e | 0 |
| Improved cookstove, tier 1 | 3 / 1.4 ton CO2e | 2.8 kg ton CO2e | 1.5 ton CO2e |
| Improved cookstoves, tier 3 | 1.4 / 0.5 ton CO2e | 4.4 ton CO2e | 2.5 ton CO2e |
| LPG stove | 0.4 ton CO2e | 5.4 ton CO2e | 2.5 ton CO2e |

*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 detailed 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.

The indirect land-use effect 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 are used 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 described above.

***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).1[[1]](#footnote-1) 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 focus 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% (Bond and Templeton, 2011: 349), but can be up to above 25% (RTKC, 2017).

The following table outlines the prevalent traditional stoves in the South Asia, and their efficiency rates. As can be noted these cooking solutions that 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 |

*Adapted from: (Perera and Sugathapala, 2002: 92, Bhattacharya and Salam, 2002: 308, Bond and Templeton, 2011: 349).[[2]](#footnote-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 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 used derives 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 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]](#footnote-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, based on the assumption that 2/3 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 gas[[4]](#footnote-4). In addition to the lower specific emission of gas compared with unsustainable biomass, LPG stoves are more efficient than biomass stoves. LPG stoves have an efficiency around 50%.

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 close to double the cooking efficiency from around 11-19% for a simple fireplace to around 19-27%. In addition ICS reduce the use of fuel for cooking, 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]](#footnote-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).

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 timeframe), 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 biomasse 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 timeframe) which is formed in small quantities in cookstoves.

Fine particulate matter, especially when smaller than 2.5 micrometers (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. 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. Even the GWP of black carbon is still debated (no generally agreed GWP at this moment in time), estimates ranges from GWP = 190 to GWP = 2240 (Jacobsen M.Z. 2005 et.al.). We will use a GWP = 680 (from Bond & Haolin, 2005, 100 year timeframe) Around 30% of global human induced black carbon emissions are caused by household biomass combustion (Preble et al., 2014: 6484).

Research carried out by Aprovecho Research Center (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 | | | | |  |
| Cooking options | Black carbon (PM2.5) | CH4 | NM-HC | N2O | Total non CO2 greenhouse emissions |
|  | g/kWh fuel | g/kWh fuel | g/kWh fuel | g/kWh fuel | Kg CO2e/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. In general, the efficiency of improved stoves ranges between around 20%, 50%. See references for stove research in the appendix??. 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 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 3.5: CO2 emissions from cooking | | | |
|  | Fuel Emissions, CO2 | Efficiency | Emissions from cooking, CO2 |
|  | 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 |

*Adapted from: (Ravindranath and Balachandra, 2009). CO2 emission reductions are calculated as outlined in appendix by Jessica Brugman; see appendix.*

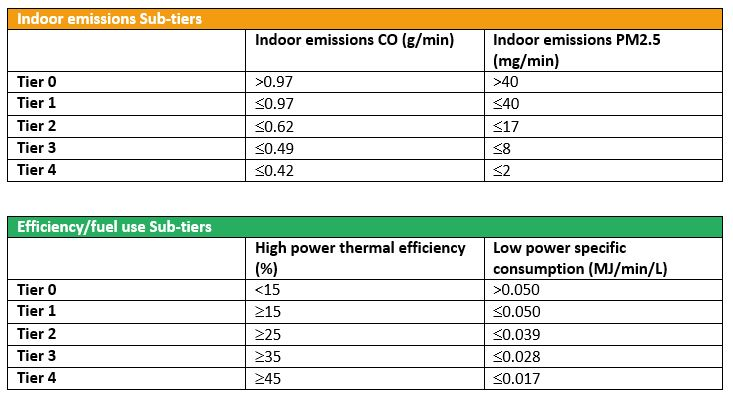
For selected projects with improved stoves in South Asia, the avoided CO2 emissions has been estimated to be from 0.9 to 3.37 ton CO2/year per households with an average of 2 ton, see table 3.6:

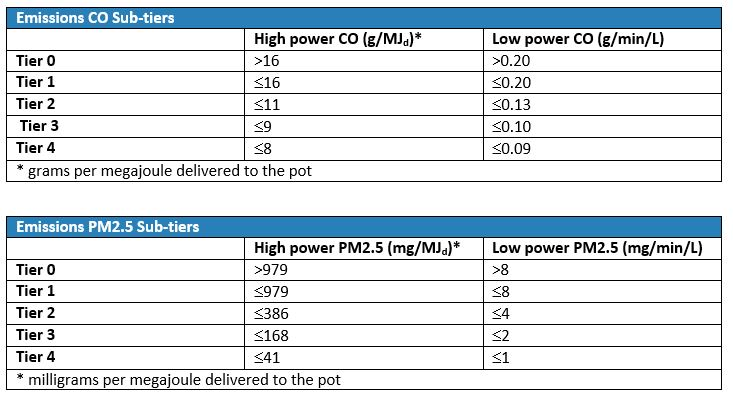
|  |  |  |
| --- | --- | --- |
| Table 3.6: Avoided emissions per household of participating communities in six South Asian Clean Development Mechanism (CDM) projects. | | |
|  | Amount of households participating | Avoided emissions |
|  |  | ton CO2/year/household |
| JSMBT (India) | 21500 | 1.98 |
| 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]](#footnote-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 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 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). 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 Emissions of black carbon and energy efficiency for the 5 IWO tiers for cookstoves |





From http://cleancookstoves.org/technology-and-fuels/standards/iwa-tiers-of-performance.html

There are also financial gains to be taking into account, 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 levelised 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]](#footnote-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).

***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 in a traditional fire, the alternatives gives the emissions and energy uses in table 3.9. Some studies have found considerable higher wood consumptions, up to more than double of these figures, see table. 4.2.

### Table 3.9: Biomass stoves, comparison

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 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 CO2/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 CO2e/kWh | 0.32 | 0.32 | 0.29 | 0.14 | na. |
| Emissions CH4  kg CO2e/kWh fuel | 0.06 | 0.06 | 0.05 | 0.05 | 0.003 |
| Emissions NM-HC  kg CO2e/kWh fuel | 0.012 | 0.012 | 0.006 | 0.006 | na. |
| Emissions of N2O  kg CO2e/kWh fuel | 0.004 | 0.004 | 0.004 | 0.004 | 0.002 |
| Total emissions, unsustainable Bio., kg CO2e/kWh fuel | 0.79 | na. | 0.74 | 0.59 | 0.26 |
| Total emissions, sustainable Bio, kg CO2e/kWh fuel | na. | 0.40 | 0.35 | 0.20 | 0.26 |
| Emissions in kg CO2e/year, unsustainable biomass | 5791 | na. | 2985 | 1362 | 387 |
| Emissions in kg CO2e/year, sustainable biomass |  | 2944 | 1419 | 467 | 387 |
| Em. reductions in kg CO2e/year, unsustainable bio. | na | na | 2806 | 4429 | 5405 |
| Em. reductions in kg CO2e/year, sustainable bio. | na. | na. | 1525 | 2477 | 2558 |

*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*](http://cleancookstoves.org/technology-and-fuels/standards/iwa-tiers-of-performance.html) *(Accessed 15.07.2017)  
CH4 and N20: 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 Center, OR, USA, et.al.*

**4. Household Biogas Plants**

***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 bioslurry that can be used as an agricultural fertiliser. This dual use is what makes for the emission reductions created by HBPs substantial beyond the provision of alternative cooking fuel as the plants reduce the use of unsustainable energy sources such as firewood and LPG, by using manure, which in itself emits greenhouse gasses. 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).

Biogas programs for household levels have been implemented in South Asia for the last several decades, providing measurable data in regards to 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 in order 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/m3 = 0.61 L diesel fuel |
| Biogas generation | 0.3 – 0.5 m3 gas/m3 digester volume per day |
| Digestate generation | 58 kg per m3 biogas |
| Cow yields | 0.4 m3/kg dung per animal per day |
| Gas requirement for cooking | 0.3 to 0.9 m3/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).*

In order to create a complete picture of the effects on GHG of the plants, the emissions generated by the HBPs in operation are taken into account. 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 are 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 it 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 greenhouse gases and particles from use of wood fuel and LPG for cooking are given in table 3.1.

Biogas use has itself greenhouse gas emissions, and the introduction of biogas has a number of effects related to greenhouse gas emissions, as summarised in the following. 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 on forms that are easily degradable, also in a soil environments (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.a. 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 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 is well made and maintained, but for a less well made and maintained few 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 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 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 big GHG reduction following from HBP use is that the net CO2 emissions from the combustion of the biogas are compensated. This is a major GHG emission reduction with biogas use, following from the avoided consumption of other, more polluting, fuel-sources. Looking at the consumption of firewood (both unsustainably and sustainable harvested) and the effect of a HBP on the consumption as given by CDM projects, emission reductions are 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]](#footnote-8)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 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 | tCO2e/year | amount | tCO2e/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 CO2e/year, equal to loss of around 7% of methane. .

One research project in the 90s 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 CO2e, 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, 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 CO2e | 0 | n.a. |
| Traditional cookstoves, sustainable wood | 3 ton CO2e | 3 kg ton CO2e | 0 |
| Improved cookstove, tier 1 | 3 / 1.4 ton CO2e | 2.8 kg ton CO2e | 1.5 ton CO2e |
| Improved cookstoves, tier 3 | 1.4 / 0.5 ton CO2e | 4.4 ton CO2e | 2.5 ton CO2e |
| LPG stove | 0.4 ton CO2e | 5.4 ton CO2e | 2.5 ton CO2e |
| Biogas stove | 0.02 ton CO2e | 6 ton CO2e | 3 ton CO2e |

*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. In order 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 (fx. 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 takes into account N, P, and K fertilisers.1 N fertilisers are however the main source of GHG emissions, so this where the focus lies. First of all 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 thousands of tonnes of NPK fertilisers, imports of 13002 thousands 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 paper, included as Annex A (see below) shows us that the use of slurry (waste product of the biogas production) on fields leads to a 10%-50% avoidance of NPK fertilizer reduction.

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 NH3 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 artifical 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 neglible 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 neglible 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 reduce 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 trad.stove, unsustainable wood | GHG Savings over trad.stove, sustainable wood |
| Traditional cookstove , unsustainable wood | 6 ton CO2e | 0 | n.a. |
| Traditional cookstoves, sustainable wood | 3 ton CO2e | 3 kg ton CO2e | 0 |
| Improved cookstove, tier 1 | 3 / 1.4 ton CO2e | 2.8 kg ton CO2e | 1.5 ton CO2e |
| Improved cookstoves, tier 3 | 1.4 / 0.5 ton CO2e | 4.4 ton CO2e | 2.5 ton CO2e |
| LPG stove | 0.4 ton CO2e | 5.4 ton CO2e | 2.5 ton CO2e |
| Biogas plant and stove | 0.2 ton CO2e | 5.6 ton CO2e | 2.7 ton CO2e |

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)**

***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 watt (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 as a result 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]](#footnote-9)

### **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 CO2/Litre |
| Emissions per kerosene lamp per year | 47.6 x 2.36 | 112 kg CO2/lamp/yr |
| Annual emissions per household at an average of-3 lamps per household | 3 x 112 | 336 kg CO2 |
| Annual Co2 emission from diesel generators to charge the batteries of a household |  | 8 kg CO2/year |
| Total annual Co2 emission savings per household | 8 + 336 | 344 kg CO2/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, the electricity they villager 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 microgrud 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.

***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 backup 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, 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[[10]](#footnote-10) . 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.  
  
A significant challenge for Mini/Microgrids is the "Tragedy of the Commons” dilemma, which recently was demonstrated in the “Dharnai Live” micro-grid project[[11]](#footnote-11) 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 in an example we will use 100 households per village. This corresponds to about ⅓ of Indian average villages according to the [2011 census of India](https://en.wikipedia.org/wiki/2011_census_of_India) which showed that 69% of Indians (around 833 [million](https://en.wikipedia.org/wiki/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 valorizing 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 netto 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 CO2e/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 similar 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]](#footnote-12).  For purpose of this calculation we use 75 kWh/month. | 90000 | 72[[13]](#footnote-13) |
| Village CO2e 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.*

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

**7. Solar drying**

Two types of small solar dryers for small farms and households. 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 xx and xx ton CO2 with a small drier used during fruits harvest seasons.

**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[[14]](#footnote-14). 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 require 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).

### 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 |
| CO2 emissions, kg/kWh electricity and LPG | 0.8 | 0.26 |
| CO2 emissions, kg/kg fresh fruit & tomato | 1.0 & 1.1 | 0.42 & 0.47 |
| CO2 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\_downloaddocument/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 CO2e/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 CO2 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 CO2 emission reduction per village of 100 households if mini grid replace grid connection |  | 72 |
| Total annual CO2 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 CO2e/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** |

**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** |

The examples show that considerable reductions of greenhouse gas emissions are possible in villages in South Asia, and 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 grid connection.

In practice it will be hard to have the last household included, and also 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 (as the two examples could indicate), but are steps in the development. Thus, for instance when a village has installed a mini grid, it could be a good 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 is 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 than in 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**

**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 |
|  | *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 |

Adapted from: (Ravindranath and Balachandra, 2009).

1. *Figures are from the 2011 National census.* [↑](#footnote-ref-1)
2. *Efficiencies get determined per standard water boiling tests (as determined in the CBM methodologies).* [↑](#footnote-ref-2)
3. <https://www.volker-quaschning.de/datserv/CO2-spez/index_e.php> accessed 10.07.2017 [↑](#footnote-ref-3)
4. <http://www.oryxenergies.com/en/products-services/businesses/businesses-lpg/environment> accessed 10.07.2017 [↑](#footnote-ref-4)
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).*  [↑](#footnote-ref-5)
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).* [↑](#footnote-ref-6)
7. *1 euro equals around 70 Indian Rupees.* [↑](#footnote-ref-7)
8. *The considerably higher value for the Maharashtra project is due to the replacement of fossil fuels, not biomass.* [↑](#footnote-ref-8)
9. Information derived from <http://gshakti.org/>, accessed 10.07.2017 [↑](#footnote-ref-9)
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. [↑](#footnote-ref-10)
11. Elaborated in <https://www.scientificamerican.com/article/coal-trumps-solar-in-india/> Accessed 15.07.2017 [↑](#footnote-ref-11)
12. The 100 kWh/month is derived from <http://ethesis.nitrkl.ac.in/4774/1/411HS1001.pdf> accessed 10.07.2017. Other sourced claim 50 kWh/month. [↑](#footnote-ref-12)
13. 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.pdf>accessed 10.07.2017 [↑](#footnote-ref-13)
14. *Water quantity data from* [*http://healthyeating.sfgate.com/list-fruits-vegetable-high-water-content-8958.html*](http://healthyeating.sfgate.com/list-fruits-vegetable-high-water-content-8958.html) *and* <http://www.fao.org/3/a-au111e.pdf>) [↑](#footnote-ref-14)