CO-BENEFITS OF THE SICHUAN RURAL POOR-HOUSEHOLD BIOGAS DEVELOPMENT PROGRAMME BEYOND GHG EMISSIONS REDUCTION

Field Survey & Desk Study Report

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University of Science and Technology Beijing – Centre of Sustainable Environmental Sanitation

Abstract

The Centre for Sustainable Environmental Sanitation (CSES) at the University of Science and Technology Beijing (USTB) was appointed by UPM Umwelt-Projekt-Management GmbH (UPM) to evaluate critically the actual and potential co-benefits resulting from the Sichuan Rural Poor-Household Biogas Development Programme beyond its main purpose, the reduction of GHG emissions.

The study was led by CSES director and environmental sanitation expert Prof. Dr. Ing. Zifu Li (scientific supervisor) and German CSES guest professor and leading international biogas technology expert Dipl.-Ing. Heinz Peter Mang (study coordinator), whereas research work was conducted by a team of CSES senior and junior professionals. The timeline for the entire study project ranged from 11 September 2015 to 21 February 2016.

The twofold methodological approach of the study compares the empirical data collected during the field survey carried through in November 2015 at 20 randomly selected PoA households in Sichuan's counties Fucheng and Dongpo with the findings of hundreds of evaluated national and international scientific publications about household biogas programmes.

This publication is the long version of the CSES field survey and the complementary desk study report about the co-benefits of UPM's Sichuan Household Biogas PoA.

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List of Abbreviations

AD	Anaerobic Digestion
ALRI	Acute Lower Respiratory Infection
As	Arsenic
avg.	average
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
CBD	Convention on Biological Diversity
Cd	Cadmium
CDM	Clean Development Mechanism
CO	Carbon monoxide
COD	Chemical Oxygen Demand
COPD	Chronic Obstructive Pulmonary Disease
Cr	Chromium
CSES	Centre for Sustainable Environmental Sanitation
CSR	Corporate Social Responsibility
Cu	Copper
d	day
DDT	Dichlorodiphenyltrichloroethane
DM	Dry Matter
et al.	and others
F	Fluorine
FAO	United Nations Food and Agriculture Organization
ha	Hectare(s)
GHG	Greenhouse Gas
H_2S	Hydrogen sulphide
Hg	Mercury
HH, HHs	Household, Households
IAP	Indoor Air Pollution
IAS	Invasive Alien Species
IAS_P	Invasive Alien Species of plants
IUCN	International Union for Conservation of Nature
kgCe	Kilogram of Coal equivalent
L	Litre
LPG	Liquefied Petroleum Gas
n.d.	No date
N_2O	Di-nitrogen monoxide, also called nitrous oxide
NH_3	Ammonia
Ni	Nickel
NO_x	Generic term for the mono-nitrogen oxides NO and NO_2
NPK	Nitrogen – Phosphorous – Potassium *(fertilizer formula)*
O_3	Ozone
Pb	Lead
PIC	Product of Incomplete Combustion
PM	Particulate Matter
PoA	(Sichuan Rural Poor-Household Biogas Development) Programme of Activities
PSD	Pig Slurry Digestate

RRL	Renewable Resource Laboratory
SD tool	Sustainable Development tool
SO_2	Sulphur dioxide
SREO	Sichuan Rural Energy Office
t	tonnes
TCe	Tonnes of Coal equivalent
tCO_2e	Tonnes of carbon dioxide equivalent
TK	Total Potassium
TN	Total Nitrogen
TP	Total Phosphorous
TVS	Total Volatile Solids
UNFCCC	United Nations Framework Convention on Climate Change
UPM	UPM Umwelt-Projekt-Management GmbH, Germany & China
USTB	University of Science and Technology Beijing, China
VOC	Volatile Organic Compound
VS	Volatile Solids
WHO	World Health Organisation
WWF	Worldwide Fund for nature
y	year
Zn	Zinc

EXECUTIVE SUMMARY

Rationale, methodology and scope of the study

The Centre for Sustainable Environmental Sanitation (CSES) at the University of Science and Technology Beijing (USTB) was appointed by UPM Umwelt-Projekt-Management GmbH (UPM) to evaluate critically the actual and potential co-benefits resulting from the Sichuan Rural Poor-Household Biogas Development Programme beyond its main purpose, the reduction of GHG emissions.

The Sichuan Rural Poor-Household Biogas Development PoA (CDM PoA 2898, GS 1239) aims to support up to one million low-income rural households in China's Sichuan province with the installation of advanced biogas digesters and smoke-free biogas cook stoves. The proven and reliable household size biogas digesters avoid methane emissions from animal manure and carbon dioxide emissions from solid fuels, such as coal and firewood, by producing clean, renewable and free biogas to be used conveniently by participating households for cooking, heating, and lighting.

To date, the Sichuan Household Biogas PoA has included nearly 400,000 rural Sichuan households with an average of 4.2 family members. Thus, a total of 1.68 million people are already benefitting from this PoA, thereof 49.36% or around 830,000 women and girls. At current scale, the PoA avoids nearly 900,000 tCO_2e per year.

To verify the PoA's co-benefits, the independent scientific study addresses the following nine key sustainability issues:

Does the PoA have any verifiable co-benefits for

1. natural resources efficiency,
2. biodiversity and habitat conservation,
3. air quality,
4. water quality,
5. soil quality,
6. living conditions and human health,
7. local economic development and employment,
8. energy self-reliance,
9. gender equality and women empowerment,

in the programme's Sichuan target regions, and, if so, to what extent (low, moderate, high)?

The study project was led by CSES director and environmental sanitation expert Prof. Dr. Ing. Zifu Li (scientific supervisor) and German CSES guest professor and leading international biogas technology expert Dipl.-Ing. Heinz Peter Mang (study coordinator), whereas research work was conducted by a team of CSES senior and junior professionals. The timeline for the entire study project ranged from 11 September 2015 to 21 February 2016.

The twofold methodological approach of the study compares the empirical data collected during the field survey carried through in November 2015 at 20 randomly selected PoA households in Sichuan's counties Fucheng and Dongpo with the findings of hundreds of evaluated national and international scientific publications about household biogas programmes.

Main findings

➢ Robust evidence for the PoA's many advantages for poor rural households in Sichuan

The primary purpose of this mainly explorative PoA co-benefits analysis is to build the basis for future in-depth investigations and quantifications of the programme's sustainability effects. The study does not claim to be representative or deliver statistically significant results. Nonetheless, this programme evaluation provides robust evidence for the PoA's many advantages for the participating poor rural households in Sichuan and delivers a plausible estimate for the extent of the PoA's contribution to meeting some essential sustainability criteria.

These findings prepare the ground for many pragmatic recommendations to the PoA developers and identify urgent needs for additional scientific research that might help to further improve the performance of the Sichuan Household Biogas PoA and enhance its contribution to a sustainable development in rural China.

The next table provides an overview of the most important findings of this PoA co-benefits study.

Table 1: The co-benefits of the Sichuan Household Biogas PoA

A. Environmental PoA co-benefits				
Area	**Indicator**	**Level of PoA co-benefits**		
		Low	**Moderate**	**High**
Natural Resources Efficiency	Reduction of coal use			•
	Reduction of firewood use			•
	Reduction of synthetic fertilizer and pesticide use			•
Biodiversity and Habitat Conservation	Reduction of deforestation	•		
	Use of Invasive Alien Plant Species as biodigester feedstock	•		
Air Quality	Reduction of indoor air pollution			•
	Reduction of outdoor emissions			•
Water Quality	Improved storage of human excreta, animal waste and digestate			•
	Improved disposal and use of human excreta, animal waste and digestate			•
Soil Quality	Improved fertilizing practices and soils			•
	Reduction of soil contamination with harmful substances		•	

B. Socio-economic PoA co-benefits				
Area	**Indicator**	**Level of PoA co-benefits**		
		Low	**Moderate**	**High**
Living Conditions and Human Health	Improved indoor air quality			•
	Improved sanitary situation			•
	Reduction of pesticide use			•
Local Economic Development and Employment	Employment and income generation for biogas technicians and construction workers			•
	Cost savings due to substitution of traditional fuels (mainly coal)			•
	Cost savings due to substitution of electricity and natural gas as cooking fuel	•		
	Additional income from carbon credit sales	•		
	Additional income from digestate sales	•		
	Cost savings due to fertilizer substitution		•	
	Cost savings due to pesticide substitution		•	
	Reduction of medical expenses		•	
	Reduction of cooking time		•	
	Reduction of time for firewood collection	•		
	Productive use of saved time		•	
Energy Self Reliance	Avoidance of increased energy consumption (due to suppressed demand)			•
	Increase of energy self reliance			•
Gender Equality and Women Empowerment	Improved living conditions and health for women and girls			•
	Reduced workload and time savings for women		•	
	New job opportunities for women	•		
	Better education and training for women	•		
	Increased participation and involvement of women		•	
Animal Welfare	Improved living conditions for animals (pigs)		•	
	Improved animal health and welfare		•	

➢ UPM's Sichuan Household Biogas PoA contributes verifiably to the achievement of 14 out of 17 UN Sustainable Development Goals

The UN Sustainable Development Goals (SDGs), adopted on 25 September 2015, and its set of specific targets and indicators have not been fully available at the start of work for this PoA study. Due to the importance of this emerging global sustainability assessment standard, the present study has added a tentative translation of its results a posteriori into the methodological approach of the new UN SDGs. Thus, it is possible to obtain a preliminary assessment of the PoA's contribution to the achievement of these new sustainable development goals although this attempted alignment, of course, needs to be further substantiated and quantified by additional scientific research (see Figure 1).

Figure 1: The contribution of the Sichuan Household Biogas PoA to the achievement of the UN SDGs

Source: UN SDG website: https://sustainabledevelopment.un.org/sdgs, modified by CSES study team

The PoA's UN SDG score card shows that the programme achieves a high score for eight UN SDGs and a medium score for six UN SDGs. There are only three UN SDGs in which the PoA has only a minor effect or is not applicable.

With this outstanding and well-balanced sustainability performance it ranks among the top household biogas programmes worldwide.

1. Introduction

1.1 Rationale and scope of the study

The Sichuan Rural Household Biogas Programme of Activities (PoA) is a Programme of Activity under the Clean Development Mechanism (CDM) and the Gold Standard. The programme is executed by UPM Umwelt-Projekt-Management GmbH (UPM) in cooperation with Chengdu Oasis Science & Technology Co., Ltd, while the Sichuan Rural Energy Office (SREO) is the local partner and implementer (www.upm-cdm.eu).

The PoA aims to reduce carbon dioxide emissions, mitigate climate change and improve the local conditions of poor people in Sichuan. Whether it is the improvement of indoor air quality, the convenient availability of cooking fuel or the reduced spending on coal and other fuels, the households enjoy a number of co-benefits from joining the PoA and installing a biogas digester. Co-benefits or secondary benefits are defined here as any benefit other than reduced greenhouse gas emissions that are accounted for by emission reduction certificates.

UPM sells emission reduction certificates from this PoA and is often confronted with an extensive due diligence regarding the Sichuan Rural Poor-Household Biogas Programme. Among other issues the co-benefits of the PoA are queried. Recently, customers of emission reduction certificates require more and more scientific proof of the co-benefits in order to guarantee the indefeasibility of their commitment.

The rationale of the present study is to find scientific evidence for the impact the Sichuan Rural Poor-Household Biogas Programme of Activities (*abbreviated as PoA in the report*) has on co-benefits beyond GHG emissions reduction.

The scope of work and the hierarchy of the single work steps were defined as follows:

1. To carry through both, a scientific desk and a field study, during which the listed co-benefits and research questions are analysed and, if possible, underpinned with evidences.
2. To refer the co-benefits to a list of recognized third-party research sources (scientific articles and studies) and possibly other gathered co-benefit publications, and to provide a short summary of key-findings for each co-benefit.
3. To identify necessities for additional investigation and research for certain co-benefits or critical aspects.
4. To detect and describe new aspects or co-benefits that were not considered before, but emerged during the study and should be duly recorded.
5. To set up a database of PoA photos to further substantiate evidence for any specific co-benefit.
6. To prepare additional suggestions about how and where the project partners involved could improve the PoA's co-benefit performance.

The purpose of this study is to analyse and verify the co-benefits of the Sichuan Rural Poor-Household Biogas PoA. The report is structured according to the following nine key sustainability issues:

Does the PoA have any verifiable co-benefits for

1. natural resources efficiency,
2. biodiversity and habitat conservation,
3. air quality,

4. water quality,
5. soil quality,
6. living conditions and human health,
7. local economic development and employment,
8. energy self-reliance,
9. gender equality and women empowerment,

in the programme's Sichuan target regions, and, if so, to what extent (low, moderate, high)?

These crucial aspects for determining the sustainability contribution, quality and performance of GHG emission reduction projects or programmes are also covered in the Sustainable Development Indicator List published by UNFCCC at its CDM Sustainable Development co-benefits website (UNFCCC CDM, 2014), in the Gold Standard Sustainable Development Indicator Guidance (Gold Standard, 2012) and the currently prepared Gold Standard 3.0 (Gold Standard, 2016), and are also highly relevant for the new UN Sustainable Development Goals (SDGs) that were adopted in September 2015 (UN, 2015).

A separate chapter is dedicated to each of these questions, including results from both desk and field studies and a summary of conclusions and recommendations, which is also reflected in the EXECUTIVE SUMMARY. The final chapter is dedicated to the co-benefit of animal welfare, which was discovered during the investigation and is a relevant addition to the above-mentioned commonly known co-benefits.

1.2 Methodology

The study focuses on the co-benefits of the PoA beyond GHG emissions mitigation. The methodological approach combines an assessment of indications described in literature (desk study) and empirical evidence found during field research (household survey). The timeline for the entire study project ranged from 11 September 2015 to 21 February 2016, including three workshops:

1. Kick-Off workshop on 11 September 2015:
   - Identification of tools for conducting the study:
     - Literature review of Chinese and international sources, including the Statistical Yearbook of Sichuan Province, WHO, FAO and World Bank
     - Field study in Sichuan Province for collection of PoA specific data and samples
     - Provision of evidences referring to the 11 questions in the Sustainable Development Indicator List published by UNFCCC
   - Definition of milestones:
     - three weeks before the field trip, a questionnaire and the criteria for the selection of households were submitted to UPM for acceptance, as well as a list of logistic issues to be arranged
     - End of September 29th, 2015: Inception Workshop at USTB
     - Mid/end October 2015: field visit in Sichuan
     - In first week of November 2015: agreement of the final structure of the study report
     - December 18th: Final Workshop
     - End of January 2016: draft final report for comments.
2. Inception workshop on 29 September 2015 at USTB
   - Criteria for household selection:

- Criteria for area selection as proposed on September 23rd, 2015: (1) average number of pigs; (2) average number of household members; (3) location near to Chengdu; (4) operation period of 2-4 years since digester installation; and as additional criteria (5) PoA household density (=share of PoA households among all households in a county).
- To allow comparisons, it was proposed that both, households in an area with a small density of biogas plant distribution and households in an area with a high density of biogas plant distribution should be visited. It is assumed that households in areas with dense biogas coverage have more similar framework conditions (family size, animal numbers, field area, market access) than in areas where biogas plants are rarely installed, as these are more individually designed. But, because of logistical constraints (distances to travel, and more complicated visiting permit clearing procedure from the Chinese Public Security office for foreign visitors), this selection criteria was not followed by SREO. The sample of households was selected out of areas with average density.

- Participants in the field trip:
  - Ms. Marie Reysset, UPM
  - Mr. Joycel Verde, CSES
  - Ms. Pamela Perez, CSES
  - Ms. Annika Reichert, CSES
  - Ms. Andrea Stubbusch, CSES
  - Ms. Ruiling Gao, CSES, or local translator
  - Prof. Heinz-Peter Mang, CSES
  - Dr. Shikun Cheng, CSES
  - Representative of SREO

- Field survey details:
  - In order to be able to interview more households, it was agreed to split the study team into two sub-teams after the first day of survey, and to clearly assign the tasks, such as housewife / biogas user interview, technical measurements, and completing the observation check list.
  - Required measurements were outlined; if possible, these measurements should be taken at each surveyed biogas plant:
    - Check methane content in biogas, dust particles (PM10), and H_2S concentration in kitchen air
    - Measure temperature in the digester through the exit shaft by using a digital thermometer
    - Take qualified mixed samples of effluent to determine NPK in the laboratory
    - If the survey proves the existence of invasive plant species (i.e. as weed), samples should be collected in sealed plastic bags in order to determine their biogas production potential in the USTB laboratory.

- The following documents were shared for appropriate use during the field data collection:
  - List of counties nearby Chengdu, sorted according to their PoA household density, which could be used for selecting villages for data collection during the field trip;
  - The questionnaires for household interviews;
  - Interviewer training handout, which explains the relevance of, and the rationale for each question, and potential sources for verification of the information given by the respondents.

3. Field Study

The field study was conducted from November 09th to November 12th, 2015. The Sichuan Rural Energy Office (SREO) as the local authority responsible for the implementation of the PoA defined the random sample size and sites of 20 households, and SREO officials accompanied the entire field survey process. Table 2 provides the planned schedule of the on-site data and evidence collection.

Table 2: Planned Schedule for field survey

MONDAY, NOVEMBER 9th, 2015	
11:45am	Meeting at SREO
02:00pm	Departure to Mianyang, Fucheng County
04:30pm	Arrival in Mianyang; Visit 1-2 households
TUESDAY, NOVEMBER 10th, 2015	
Entire day	Visit of households (8-9 total) in 2 groups
WEDNESDAY, NOVEMBER 11th, 2015	
Morning	Travel from Mianyang, Fucheng County, to Meishan, Dongpo County: 230km
Afternoon	Visit 4-6 households in 2 groups
THURSDAY, NOVEMBER 12th, 2015	
Morning	Visit 2-3 households in 2 groups
Afternoon	If not finished, visits of 2 households
04:00pm	Departure from Meishan, Dongpo County to Chengdu and further to Beijing

The density of biogas households in the counties participating in the PoA, and the number of participating households in each county were calculated, refer to Table 3.

Table 3: Density of biogas plants constructed within the PoA in the respective counties

County	Population	Total no. of HH	PoA HH	Biogas plant density
Renshou	1,596,000	413,472	6,133	1.48%
Qingshen	197,000	51,036	934	1.83%
Yanjiang	1,099,000	284,715	5,384	1.89%
Pengshan	333,000	86,269	2,572	2.98%
Jianyangshi	1,481,000	383,679	11,834	3.08%
Yanting	599,000	155,181	4,954	3.19%
Anyue	1,617,000	418,912	15,314	3.66%
Dongpo	**865,000**	**224,093**	**10,152**	**4.53%**
Lezhi	862,000	223,316	10,357	4.64%
Pingwu	184,000	47,668	2,260	4.74%
Hongya	350,000	90,674	5,334	5.88%
Fucheng	**692,000**	**179,275**	**11,304**	**6.31%**
Santai	1,473,000	381,606	25,717	6.74%
Jiangyoushi	887,000	229,793	17,591	7.66%
Beichuan Qiang Aut.	241,300	62,513	5,621	8.99%
Danleng	163,000	42,228	3,859	9.14%
An	443,000	114,767	12,355	10,77%

County	Population	Total no. of HH	PoA HH	Biogas plant density
You	549,000	142,228	25,369	17.84%
Zitong	386,000	100,000	19,933	19.93%

4. Final workshop: 18 December 2015
   - The workshop participants discussed the relevant findings of the study and agreed on how and when to draft the report and all its attachments until the deadline by end of January 2016.
   - All documents used and listed in the bibliography have been uploaded into an OneDrive cloud folder. Prof. Mang and Ruiling Gao supported anyone who encountered difficulties to access these sources of background information.
   - It was agreed that after receiving comments in the team, the final draft version – without Chinese summary - will be prepared by the study team for end of February 2016. The Chinese summary will be prepared by UPM and Oasis once the final text of the study is confirmed.

1.3 Study team

A team of senior and junior professionals selected and trained by the Centre for Sustainable Environmental Sanitation (CSES) carried out the desk study, the field survey and the corresponding measurements. For more information about the professional background of the team members, please refer to Attachment 1.

CSES is affiliated to the University of Science and Technology Beijing (USTB) (www.ustb.edu.cn) and was established in 2008 with the objective to build capacity among young professionals (Chinese and international) in the interrelated sectors of sustainable environmental sanitation, food security, bioenergy and climate protection. Today, about 30 master and PhD candidates (about 50% of them female) do their research and project work in the CSES under guidance from Prof. Dr.-Ing. Zifu Li, environmental sanitation expert, Guest Professor Dipl.-Ing. Heinz-Peter Mang, ecological sanitation and bioenergy expert, and the two Junior Professors and lecturers Lei Zhang and Shikun Cheng, both PhDs. The Chinese master and PhD students are coming from different Chinese provinces and different economic groups of the Chinese population: daughters and sons of workers, farmers, entrepreneurs and academics.

Table 4: CSES study team

Name	Expertise	Contribution to the study
Prof. Dr.-Ing. Zifu LI	Environmental Science	Scientific supervisor
Prof. Dipl.-Ing. Heinz-Peter MANG	Biogas technology	Study coordinator
Dr. Shikun CHENG	Biogas technology	Measurement support
Ruiling GAO	Environmental engineering	Chinese literature research; household surveys
Joycel VERDE FERNÁNDEZ	Energy engineering	Performance analysis of biogas plants
Pamela PÉREZ HIDALGO	Environmental engineering	Household survey, natural resource efficiency, biodiversity and habitat conservation
Annika REICHERT	Environmental	Household survey, overall co-benefits

Name	Expertise	Contribution to the study
	Engineering	analysis, reporting
Andrea STUBBUSCH	Environmental Engineering Sciences	Household survey, overall co-benefits analysis, reporting
Elisabeth M. HUBA	Social Science	Backstopping and final editing

2. Technical terms and definitions

The following definitions are used as technical terms in the present report:

- **1-log, 2-log or 3-log Pathogen Reduction:** “Log reduction” is a mathematical term (as is "log increase") used to show the relative number of live microbes eliminated from a surface by disinfecting or cleaning. A 1-log pathogen reduction means the number of pathogens is 10 times smaller, a 2-log pathogen reduction means the number of pathogens is 100 times smaller, and a 3-log pathogen reduction means the number of pathogens is 1,000 times smaller.
- **Afforestation:** conversion from other land uses into forest, or the increase of canopy cover to the 10% defined threshold for forests (FAO, FRA 2000).
- **Biomass:** biological material derived from living, or recently living organisms. In the context of biomass for energy, this is often used to describe plant based material, but the term biomass can equally apply to material derived from both animals and vegetation. (http://www.biomassenergycentre.org.uk/portal/page?_pageid=76,15049&_dad=portal)
- **Biodiversity:** According to the Convention on Biological Diversity (CBD, 1992), the term ‘biological diversity’ and its contracted version ‘biodiversity’ refers to “the variability among living organisms from all sources including, inter alia*,* terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species, and of ecosystems”.
- **Canopy or forest coverage:** percentage of land covered by forest canopy – refer to FAO definition of forest and forest area.
- **Digestate:** The terms ‘digestate’, ‘(bio-)slurry’ and ‘(bio-)sludge’ are often used synonymously in literature. A clear distinction and definition is missing in most cases, making it difficult to identify with which non-gaseous end product of anaerobic digestion studies are dealing. In the present report, the definitions of the Chinese Technical Code for the application of anaerobic digestate fertilizer (NY/T 2065-2011) is applied. It defines ‘digestate’ as the non-gaseous residue from anaerobic fermentation of biodegradable organic material, which consists mainly of digested effluent (liquid residues) and digested sludge (solid residues).
- **Forest area:** land under natural or planted stands of trees of at least 5 meters in situ, whether productive or not, and excludes tree stands in agricultural production systems (for example, in fruit plantations and agroforestry systems) and trees in urban parks and gardens (FAO, FRA 2002).
- **Habitat conservation:** As a result of human population growth and increase of land usage, wild species have less area to inhabit. More than half of earth's terrestrial surface has been altered due to human activity causing drastic deforestation, erosion and loss of topsoil, as well as biodiversity loss and species extinction. Protecting habitats is essential to preserving biodiversity (Marine Bio Conservation Society, http://marinebio.org/oceans/conservation/habitat-conservation/). Habitat conservation is

therefore defined as the management of land and water bodies that pursues conservation, protection and restoration of habitat areas for wild plants and animals to prevent their extinction, fragmentation or range reduction.

- **Natural resources:** As stated by Evert (2010), the term ‘natural resources’ can be described as materials or organisms in the natural environment that are available and can be used by human beings. It includes renewable resources, such as plants, water, air, wildlife, soils, and non-renewable resources, such as coal, oil, natural gas and mineral ores.
- **Pesticide:** The generic term ‘pesticide’ covers all chemicals used to kill or control pests. Pests include plants, insects, fungi, nematodes and others; consequently, pesticides include herbicides, insecticides, fungicides, nematocides and others (FAO, 2013).
- **Synthetic fertilizer:** This term covers all chemically produced fertilizers, which provide nitrogen (N), phosphorous (P) and/or potassium (K). It is synonymous with the term ‘chemical fertilizer’ and the opposite of ‘organic fertilizer’, which are all materials from plant or animal origin that are added to the soil in order to increase its fertility (de Groot & Bogdanski, 2013).

3. PoA co-benefits for natural resources efficiency

3.1 Reduction of coal and fuel wood use

One of the environmental co-benefits of biogas technology implementation in rural households is the use of cleaner fuel sources with the intention to lower coal and fuel wood consumption for cooking and heating needs. This topic is dealt with from different perspectives in various studies; some of these are discussed here to give an overview of the current situation at diverse locations including China.

- Jiang & O'Neill (2004) described that fire wood, straw and stalks are the main sources of rural energy consumption for two-thirds of rural households in China.
- Wang & Li (2005) noted that the rural household energy consumption in Lianshui County (Jiangsu Province) depends mostly on local biomass energy. Therefore, biogas as cooking fuel predominantly replaces stalk and straw as well as firewood, but in the specific case of Lianshui County it did hardly substitute other forms of energy sources, especially commercial ones, because they were not available. It has to be emphasized that Lianshui County conditions are quite different from those in the PoA area, where commercial energy sources such as coal and LPG are available in the local market.
- W. Wu (2006) investigated the per capita rural household energy consumption of households with and without biogas digester in 2003. The results show less annual fuel wood consumption by households with digesters than by those without it: 115.55 kg of coal equivalent (kgCe) in contrast to 316.25 kgCe.
- Wang et al. (2007) compared consumed types of energies in the counties of Lianshui and Guichi in Jiangsu and Anhui Province, respectively. The paper describes how Lianshui depends mainly on biogas, firewood, stalk and straw, whereas Guichi depends more on firewood and biogas since Guichi farmers have access to a great amount of firewood. For this reason and because it is more convenient to use, they prefer firewood to straw and stalk. Consequently, biogas replaces a large quantity of firewood in Guichi: households with and without biogas digester consumed yearly 114.03 and 314.42 kgCe of firewood, respectively.
- Y. Liu et al. (2008) stated that the utilization of biogas in rural China has experienced considerable development ever since the government popularized the household-scale biogas digesters for meeting the rural energy requirements in the 1970s. In their research, the energy sources replaced by biogas in rural areas of China were analysed based on the amount of consumption in a time range from 1991 to 2005. The main findings concerning conventional or traditional fuel reduction and substitution show that biogas effectively reduces the per capita consumption of traditional fuel in rural families by replacing coal, oil, fuel wood, and straw. A large amount of energy from straw and fuel wood is lost due to low efficiency of direct combustion in traditional stoves; by transforming biomass into biogas, biomass energy content can be utilized more efficiently.
- Tang et al. (2010) show the per capita consumption of energy carriers such as fuel wood, coal and biogas, comparing households with and without biogas digester in 2007. The

results are presented in Table 5, revealing in form of a household energy supply mix how the use of conventional energies is reduced when a biogas plant is operated: annually, one person with biogas digester used 2.8 kg of fuel wood while a person without biogas digester used 5.4 kg. In the case of coal, the figures show a usage of 40.5 kg and 66.4 kg for a biogas user and non-user, respectively.

Table 5: Energy consumption per capita by biogas adopters and non-adopters in 2007 (standard coal equivalent)

Energy type (kgCe)	With biogas digester	Without biogas digester
Fuel wood	2.8	5.4
Coal	40.5	66.4
Biogas	46.3	-
Crop straw	23.4	28.5
CNG	1.8	7.5
Total	114.8	107.7

Source: Tang et al. (2010)

- In 2012, a research paper published by the World Bank co-founded eco-farming project analysed a comprehensive survey of 2,700 households from 225 villages in five provinces in rural China (Christiaensen & Heltberg, 2012). The document elaborates on how fuel use patterns vary by location, mainly because of different climates and seasons, but also due to differences in the convenience of buying coal and gathering fuel wood. For example, in Anhui, Chongqing and Guangxi fuel wood and crop residues are the two most common fuels, while biogas and other clean energies are also used.

  Christiaensen & Heltberg (2012) also compared the energy consumption among biogas users and non-users households, discovering a significant degree of fuel switching. The annual coal consumption was reported to be 95 kg/year among biogas adopting households, against 290 kg/year in non-adopting ones. Biogas adopters also use 157 kg less of fuel wood and 347 kg less crop residues per year on average. These numbers (refer to Table 6) indicate a substantial replacement of traditional and conventional fuels by biogas, being largely comparable to the PoA area and households.

Table 6: Household average energy consumption among biogas users and non-users

Average use per year	Entire sample	With biogas	Without biogas
Coal (kg)	246	95	290
Charcoal (kg)	29	38	26
Fuel wood (kg)	2721	2599	2756
Crop residues (kg)	793	524	871
LPG (kg)	12	12	12
Electricity (hours)	362	390	354
Biogas (hours)	-	535	-

Source: Christiaensen & Heltberg (2012)

Also for other places beyond China, similar studies also confirm the trend derived from the Chinese studies addressed here, which point out the reduction of coal and fuel wood by the use of biogas. The majority of the studies found (even the ones not included) did not mention an increased use of these specific energy sources after the construction of the biodigester. For example:

- In Nepal, household-size biogas digesters located in the valley region led to reduced consumption of firewood by 53%, estimating that a household with biogas saves about 250 kg of firewood per month, resulting in 3000 kg (3 t) per year, while the usage of coal decreased by 43%, all this due to a better performance of the biogas system (Katuwal et al., 2009).
- A biogas user survey 2011 in Bangladesh confirmed that the average quantity of firewood savings is about 250 kg per household per month. However, only a fraction of the saved wood remained in the forest and benefitted environmental conservation. Another fraction was still collected and sold, thus contributing to on-going deforestation (IDCOL, 2011). In Sichuan, there is no fuel wood trade established in the villages.
- A study performed in the Peruvian Andes by Garfí et al. (2012) involved 12 rural families in a project to replace firewood by biogas. It was determined that with the biogas production at the moment of the study (0.53 m^3 biogas/day), firewood consumption reduction was about 1,880 kg/year (1.88 t/year) per HH, which accounts for 53% of the total amount of firewood used before the installation of a biogas digester. Accordingly, the authors affirm that the application of biogas technology contributes to reducing deforestation. The dissemination of biogas digesters in the Peruvian Andes could slow down negative environmental changes, such as deforestation and consequently an increased risk of flooding for downstream villages and agricultural fields, with flooding happening regularly in the Peruvian Andes especially during the rainy season (CEPES, 2000 cited by Garfí et al, 2012).

  Although conditions in the Peruvian Andes differ to some extent from the ones present in the PoA region, deforestation and related erosion is also an environmental issue in Sichuan province. It is as well useful to take case studies other than the current one, in order to support the range of benefits and co-benefits obtained from biogas utilisation towards natural resources efficiency.

Literature reveals that both in China and in other countries, there has been an evident reduction of fuel wood and coal usage but not yet to the extent of a complete substitution, as highlighted in many of the discussed research papers. This is also due to traditional recipes, which could not be prepared on biogas stoves, neither on electrical or LPG stoves, but only on open fire or charcoal. Replacing wood or coal stoves should always be accompanied in the provision of heating and cooking devices, or lighting and cooking devices, considering seasonally and climate specifics. In the here analysed PoA villages biogas is only used for cooking and hot water preparation.

3.2 Fuel wood and coal consumption in Sichuan before and after the PoA

During a survey among biogas users in Sichuan Province by Remais et al. (2009) significant changes in fuel usage were attributed to the installation of biogas plants: households reported a decrease in coal usage by 68%, reduction in fuel wood by 74% and a 6% drop in crop waste usage.

Li (2013) reported about the energy consumption of rural households in Danling County, Sichuan Province, during the period 2008 to 2011. The numbers state a reduction of conventional and commercial energies such as coal and fuel wood, while biogas use increased, as displayed in Table 7.

Table 7: Energy consumption of rural households in Danling County (Sichuan) from 2008 to 2011 in tonnes of coal equivalents (tCe)

Energy type	2008	2009	2010	2011
Biogas (tce)	6,648.768	7,779.74	8,929.284	9,361.86
Coal (tce)	4,495.09	4,010.08	3,361.496	3,326.495
Firewood (tce)	2,193.782	2,091.573	1,862.602	1,820.348

Source: Danling County Government (2011) in Li (2013)

Similar data, specifically on coal consumption, are given in the Sichuan Statistical Yearbook 2013, 2014 and 2015. The yearbook reports the total residential coal consumption for the entire province from 2009 to 2014. The continuous reduction of coal consumption is evident by the decrease of 3,965,600 tons between 2009 and 2014, which is more than 50% of the consumption in 2009 (Statistical Bureau of Sichuan, 2013 and 2015 – refer to Table 8).

Table 8: Sichuan's residential coal consumption 2009-2014

Year	2009	2010	2011	2012	2013	2014
Consumption (tons)	6,729,600	5,940,000	5,377,800	3,402,000	2,843,000	2,764,000

Adapted from: Statistical Bureau of Sichuan (2013) / (2014) / (2015)

According to this report's field survey, before the installation of the biogas digesters, all households used coal for cooking as primary energy source but the majority of the households also used different quantities of firewood and other biomass. After biogas implementation, 94% of the interviewed PoA households decreased their solid fuel use largely to less than once a month (Refer to Figure 2).

Figure 2: Different kinds of biomass (straw, wood) used in households for cooking (and rarely for heating)

The field survey findings are in line with the results from the representative PoA baseline survey (SREO, 2012) carried through in 2012 among 2,000 randomly selected Sichuan rural households (one group of 1,000 households with digesters is contrasted to another group of 1,000 households without digesters). Without digesters, there was an average annual coal consumption of 970 kg (0.97 tons) per household. In contrast, the average annual coal consumption per household fell to only 27 kg (0.027 tons) with operating digesters. This means that households with biogas digesters reduced their annual coal consumption by more than 97% (SREO, 2012).

The third and most recent obligatory CDM and GS Monitoring Report for this PoA from 2015 interviewed a representative sample of 200 households and also affirms this result by detecting that all sampled households have not only reduced their consumption and expenditures of coal but are also burning less firewood (UPM & Oasis, 2015).

3.3 Reduction of synthetic fertilizers and pesticides due to the use of digestate

Various studies have covered the topic of digestate usage to replace chemical fertilizers and pesticides; and several authors confirm that application of digestate may lower the required amounts of chemical fertilizers and pesticides which happen due to the digestion process that kills pathogens and improves the availability of nutrients in the manure (Gosens et al., 2013; G. Liu, 2010; Wang et al., 2007).

- Chemical fertilizers and pesticides are commonly used all around the world to improve and maintain crop productivity, but excessive usage of substances may provoke environmental disturbance and negative effects on human health (Kumari et al., 2014). The continuous application of pesticides induces the development of pest resistance, while an excessive use of synthetic fertilizer results in imperfectly synthetized protein in leaves. This is responsible for poor crops and in consequence, pathological conditions in humans and animals fed with deficient food (Talukdar et al., 2003). In addition to this, it is important to mention that phosphate rock, a major component of phosphorus fertilizer, is a limited resource and therefore has become increasingly scarce (Roy et al., 2006).
- As stated by Islam (2006), “bio-slurry is environmental friendly, has no toxic or harmful effects and can easily reduce the use of chemical fertilizers up to 50%”. The analyses of representative cow dung and poultry litter slurry samples from biogas digesters in Bangladesh were studied. It was shown that slurry contains a large amount of macro as well as micronutrients and organic matter. Moreover, the author stated that the toxic heavy metal concentration present in them was not significant. In Chapter 7.2 the effects of heavy metals in digestate are assessed in further detail.
- Gautam et al. (2009) disclosed that digestate as organic fertilizer has high concentrations of nitrogen (N), potassium (K) and phosphorus (P); therefore, it can be used as an alternative to chemical fertilizers in farmlands. In the case of Nepal, it has been estimated that there is an annual saving of 4,329 t of N, 2,109 t of P and 4.329 kg of K due to the installation of biogas digesters. Also in Nepal, Katuwal & Bohara (2009) considered digestate to be the “best” fertilizer for rural households to increase crop productivity. In addition, they stated that most of the households with biogas plants apply digestate to their land.
- A study conducted in China’s Hebei province affirms that digestate is able to increase the activity of enzymes in soils, improve soil structure, and allow the process of conversion and recycling of organic matter to be faster (Zhang et al., 2009).
- In 2009, 77% of the 610 households interviewed in five south-eastern provinces of China by Christiaensen & Heltberg (2012) used digestate as fertilizer and “almost all of them” have been able to use less chemical fertilizers; and 79% stated that they also apply less insecticide since they use digestate. About 96% of the respondents perceived this had improved the quality of their crops.

- G. Liu (2010) explains that during the fermentation of manure, pathogens can be abated due to the anaerobic environment and the resulting digestate can be considered a high quality organic fertilizer and can be irrigated directly to crops. Nonetheless, because of the nitrogen (N) and the chemical oxygen demand (COD) in digestate, the applied amount should abide the national regulations of farm irrigation according to plant categories.
- Li et al. (2012) studied the improvement impact of digestate on the soil's fertilizer and water conservation capacity, water permeability, in addition to lower soil acidification and compaction. Their results show that digestate applied to cucumber fields can improve the plants' growth by 15.9% compared to synthetic fertilizer and reduce plant diseases and the attack of pests.
- A study among Nepalese biogas users households revealed application of an average of 2,495 kg digestate per year and per hectare. The resulting average reduction in fertilizer use is 29% for urea, 18% for diammonium phosphate (DAP) and 85% for potash after the start of digestate application (MEG, 2013b).
- According to results of several studies compiled by de Groot & Bogdanski (2013), bioslurry can be utilized as an organic fertilizer for crops, as fish feed and for soil remediation. Some of the studies indicate the potential of the digestate as pesticide and fungicide, but more research maybe required to support and confirm such applications in a consistent form.
- In opposite to the Chinese and Nepalese studies and their findings, Laramee & Davis (2013) reported no significant changes in synthetic fertilizer use among households with and without biogas digesters in Tanzania. They conclude that the mean annual use of synthetic fertilizer by households with and without biogas digester was 15 kg per acre, which is 37 kg per ha (standard deviation SD=38 kg), and 23 kg per acre, which converts to 57 kg per ha (SD= 51 kg), respectively, a difference that was not statistically significant (p=0,59). However, their results could be related to significant differences in geography, climate, society, and agricultural work patterns, level of education, and cultivation conditions, and subsequently it does not appear to be comparable to the PoA region.

In order to specify results in the PoA region, and to further prove the ability of digestate to substitute chemical fertilizer, as well as for future calculations of saved fertilizer, the CSES Study Team measured the concentration of N, P and K in collected samples from the surveyed household digesters. These results are presented and discussed as follows:

1. All of the surveyed households reported that they currently apply less synthetic fertilizer than before the installation of the digester. Previously, they used 452 kg per year on average, while after operating the biogas plant they reduced the amount to an average of 196 kg per year. One household indicated that they no longer use chemical fertilizers, although they had applied 300 kg per year before the implementation of the biodigester. The households use different formulas of chemical fertilizers (refer to Figure 3) such as N-P-K percentages of 15-15-15, 23-11-6, 25-5-5, 18-16-6, 28-6-6 or 24-11-5. Sometimes they add urea and calcium dihydrogen phosphate.
2. Although and as usual, interviews with household members could not be conducted in isolation, but with the presence of other people (neighbours and officials from SREO), the figures given on fertilizer consumption before and after the construction of the biogas digester show at least a significant reduction in the amount of chemical fertilizers. 16 out of 18 interviewed households stated to apply the entire digestate production to their fields.

Figure 3: Bags of different kinds of fertilizers used in one of the households

During the field visit, samples from the digesters' outlet of 19 households were collected in bottles for analysis of total nitrogen (N), phosphorus (P) and potassium (K), as shown in Figure 4.

Figure 4: Digestate sampling and temperature measuring at a digester's outlet

The results show an average concentration of total nitrogen (TN) of 1,186 mg/L, total phosphorus (TP) 1,039 mg/L and total potassium (TK) 964 mg/L, but with high variation ranges (see Table 8). The digestate annually applied by the households amounts to an average of 13.9 m^3 per household, as the field survey showed.

Since the annually produced average amount of digestate could only be estimated, the annual average amount of animal waste and human excreta generated per household was calculated in order to verify the 13.9 m^3. This calculation follows Vinneras (2002) and Ye et al. (2007):

- Vinneras (2002) gives the annual average amount of urine and faeces produced by a person to be 550 kg and 50 kg, respectively.

- Ye et al. (2007) reports the annual average amount of pig urine to be 5,480 kg (5.48 ton) and 3,650 kg (3.65 ton) of faeces.
- The average number of 4.2 residents per household (which differs from the official statistics – refer to Table 2) and the average number of pigs per household utilized for the calculation were those obtained during the orientation survey. It should be noted that the average number of 3.1 pigs are only adult pigs. Piglets were excluded from the calculation because the small amount of excreta they generate.

Therefore, the calculation is based on the following figures:

- Annual avg. amount of urine per person: 550 kg
- Annual avg. amount of faeces per person: 50 kg
- Annual avg. amount of urine per adult pig: 5,480 kg
- Annual avg. amount of faeces per adult pig: 3,650 kg
- Avg. # of residents/HH: 4.2
- Avg. # of pigs/HH: 3.1

Formula:

((Annual Avg. Human urine + Annual Avg. Human faeces) x (Avg. # residents/HH)) + ((Annual Avg. Pig urine + Annual Avg. Pig faeces) x (Avg. # of pigs/HH)) = **Annual Avg. # excreta / HH**

➢ **((550 kg + 50 kg) x (4.2)) + ((5,480 kg + 3,650 kg) x (3.1)) = 30,823 kg**

Conversion:

Given the lack of data on faeces density, and assuming the density of urine to be the same as water, even when only urine is accounted in the equation:

➢ **((550 kg) x (4.2)) + ((5,480 kg) x (3.1)) = 19,298 kg**

19, 298 kg = 19, 298 L

19, 298 L = **19.298 m³**

It can be observed that the so obtained volume is bigger than the 13.9 m^3 reported in the orientation survey. This is probably only partly due to a slight volume reduction during the digestion process. It might mean that households do not insert all their human (the persons are not present 24 h/d at home) and pig (not having pigs 12 month per year) excreta into the digester. What is also possible that the number of 13.9 m^3 was a wrong estimation out of the household questionnaires.

3.4 Conclusions and recommendations

According to this report's field survey, before the installation of the biogas digesters, all households used coal for cooking as primary energy source but the majority of the households also used different quantities of firewood and other biomass. After biogas implementation, 94% of the interviewed PoA households decreased their solid fuel use largely to less than once a month.

The field survey findings are in line with the results from the representative PoA baseline survey (SREO, 2012) carried through in 2012 among 2,000 randomly selected Sichuan rural households (one group of 1,000 households with digesters is contrasted to another group of 1,000 households without digesters). Without digesters, there was an average annual coal consumption of 970 kg (0.97 tons) per household. In contrast, the average annual coal consumption per household fell to only 27 kg (0.027 tons) with operating digesters. This means that households with biogas digesters reduced their annual coal consumption by more than 97%.

The third and most recent obligatory CDM and GS Monitoring Report for this PoA from 2015 interviewed a representative sample of 200 households and also affirms this result by detecting that all sampled households have not only reduced their consumption and expenditures of coal but are also burning less firewood.

Both our field survey for this study and the 2015 PoA Monitoring Report come to the conclusion that 100% of the interviewed households apply the produced digestate to their fields, whereas reports from other biogas programs indicate a range of digestate utilization spanning from 77% to 94%.

Moreover, all of the PoA households surveyed by our team reported that they currently apply less synthetic fertilizer than before the installation of the digester. Previously, they used 452 kg per year on average, while after operating the biogas plant they reduced the amount to an average of 196 kg per year.

The average annual 13.9 m^3 effluent calculated based on local household data is considerably lower than the theoretically possible average annual substrate volume of 19.3 m^3. This is probably due to the fact that the households are not at home the entire day resulting in less human excreta input and do not keep pigs throughout the whole year, as the majority of the animals are kept for fattening during up to 11 months and are sold as soon as they have reached the slaughter weight.

Digestate applied by PoA households contains far less nutrients than the amount included before in saved chemical fertilizer and thus the PoA effectively helps to avoid considerable fertilization of agricultural land, water pollution and food contamination.

Applying a conservative approach, nutrient calculations are based on the average annual amount of 13.9 m^3 bio-slurry applied annually in gardening, fruit and grain production.

The results obtained for TN, TP and TK, and considering the annual 13.9 m^3 of digestate allowed estimating the amount of nutrients in the digestate and comparing it with the estimated amount of nutrients both in the used and in the saved chemical fertilizer. The obtained values are presented in Table 9: the amount of N, P and K in digestate is small in comparison with the amount provided by the saved chemical fertilizer, a fact, which can be interpreted in several ways:

- Less nutrients are applied by digestate than are saved by reduction of synthetic fertilizer. This could result from a severe use of synthetic fertilizer before digester installation. However, it has to be emphasized that nitrogen provided by fermented bio-slurry is absorbed better and faster by plant roots than mineral nitrogen, which has first to be decomposed by soil bacteria into soluble and absorbable nutrients.
- Households might have over- or underestimated their current and former use of synthetic fertilizer.
- General information from agricultural statistics (Yuan, 2010) stresses that Chinese farmers tend to fertilize their agricultural land with chemical fertilizers; in excesses, this could lead to groundwater pollution and contaminated food products *(*nitrogen run-off) (Pan, 2014).

Table 9: N, P and K of digestate samples compared to the estimated amount of the same elements in chemical fertilizer

	Average concentration (mg/L)	Standard deviation	Estimated annual amount of nutrients in digestate (kg)	Estimated annual amount of nutrients in used chemical fertilizer (kg)	Estimated annual amount of nutrients in saved chemical fertilizer (kg)
Total nitrogen	1,186	482	16.50	45.6	45.9
Total phosphorous	1,039	455	14.45	29.0	33.7
Total potassium	964	559	13.41	21.4	25.0

As there is still considerable uncertainty about the actual fertilizer use practices of Sichuan rural households, UPM should undertake further in-depth studies to measure the bio-slurry output of the digesters and its use by the PoA farmers more exactly and to gain more reliable data about the application or substitution of chemical fertilizer. The obtained results should ideally be contrasted to the fertilization habits of non-PoA rural households.

4. PoA co-benefits for biodiversity and habitat conservation

The environmental co-benefits associated to biodiversity and habitat conservation are often difficult to detach as their effects overlap each other.

4.1 Impact of chemical fertilizers and pesticides on biodiversity and habitat conservation

The environmental effect of the substitution of chemical fertilizers has already been described in the previous chapter 3.3 considering their impacts on natural resources efficiency, but again, it is hard to unlink the impact that this substitution has towards biodiversity. For instance, FAO (2013) reported in its "Guidelines to control agricultural water pollution in China", that some pesticides threaten the long-term survival of major ecosystems due to the interruption of predator-prey relationships and loss of biodiversity.

Pesticides can drift to other places when they are suspended in the air as particles carried by wind. As a result, pesticides are one of the causes of water contamination affecting aquatic flora and fauna, and some of these substances are persistent organic pollutants that contribute to soil contamination (Rozaq & Sofriani, 2009).

The following examples of the negative impacts of pesticides on ecosystems are based on FAO publications (2013):

- The widespread use of the pesticide Atrazine causes male frogs to develop female features or "feminization" at very low concentrations in water.
- Glyphosate as widely used herbicide is particularly toxic to amphibians (e.g. frogs), causing mortality and defective growth and development, which constitutes a problem encountered in wetlands near farms.
- In China, as well as other rice-growing countries, spiders and other insects classified as "beneficials", are especially effective in controlling major rice pests, while chemical pesticides disturb their natural balance by frequently producing pests more than controlling them.

The importance of reducing or replacing chemical fertilizers and pesticides is highlighted in the sub-section 3.3. and aspects of biodiversity and habitat conservation are discussed, specifically fuel wood reduction and its possible effect on deforestation decrease, as well as the role of invasive alien species of plants (IAS_P), their potential for biogas production and the impact that this could entail.

4.2 Decrease in fuel wood consumption and its potential contribution to the reduction of deforestation rates and the improvement of biodiversity

The excessive extraction of fuel wood has caused the degradation of ecosystems, leading to biodiversity loss and deterioration of other ecosystem services. According to Biba (2012), "if the intensity of deforestation in India and other countries in Asia increases in near future, the implementation of biogas plants in rural areas could certainly save enormous amounts of forest trees and biodiversity".

- Gautam et al. (2009) describe that in the year 2004, almost 10,000 ha of forest in the Southern plain region of Nepal were lost due to fuel wood collection activities (MOES, 2006). However, since the introduction of biogas digesters an annual saving of 2 tons of firewood per household occurred, meaning a nationwide saving of more than 200,000 tons of fuel wood per year (East Consult, 2004).
- Wang et al. (2012) present strong evidence to support the argument that “changes in the livelihoods or rural households lead to fuel wood substitution and finally, hilly ecosystem restoration”. The study was conducted in Chang Ting County, rural Southeast China, based on 358 respondents and additional statistical data. Due to poverty and energy scarcity, biomass fuel, primarily fuel wood, is historically the principal cooking energy for rural households in the area. Under pressure from a rapidly increasing rural population, the exploitation of the remaining forest vegetation exceeded the degradation verge of the hilly ecosystem, causing serious forest degradation and soil erosion. Only towards the end of the 1990s fuel wood started to be replaced by commercial energies for cooking, and in consequence, restoration of hilly ecosystems began.
- Rana et al. (2014) carried out a study on reducing pressure on forests in Nepal. In an area where trees are regularly cut down to meet fuel wood supply needs, 60% out of 150 respondents adopted biogas as a result of firewood scarcity and the difficulties involved in collecting it. All the households have used firewood as the main energy source for cooking before the construction of a biogas digester; about 60% of them totally stopped using firewood thereafter.
- Ghimire et al. (2015) observed that more than 95% of the local people of a study area in Nepal were using firewood as a main source of energy, amounting to 510,570 t/y. Breaking down these data to household level, the study concludes that if the annual savings of firewood constitute 2.278 t/household, biogas plants could save 34.40% of fuel wood, which conserves 5,415 ha of forest.
- Another survey conducted in Nepal on the forest coverage change showed contrasting views on the reduction of firewood consumption. The document informs about the change in the respondent’s surroundings over the past few years and in two different reference periods: in year 2000 compared to 1989 and in year 2013 compared to year 2000. Unlike other studies, most of the surveyed households asseverated that the forest area has decreased and it was reported that in fact, the shrub area had increased in recent years. Thus, there is a high probability that the firewood used by the households contains non-renewable type, but this fraction has continued to be replaced by the use of biogas digesters (MEG, 2013a).

Statistical data on the forest coverage change before and after biogas digester implementation in PoA specific locations could not be found. Data at provincial level is presented in Table 10, which provides an overview of forest coverage, area and afforestation situation for the entire province before and after the implementation of the PoA in 2010. Although an increment in forest coverage from 30.3% in 2008 to 35.5% in 2013 could be observed, applying the FAO definitions (refer to Chapter 2) leads to the following conclusions:

- Forest or canopy coverage increased slowly as trees continue to grow, a continued trend also after the tremendous earthquake that hit Sichuan province in 2008. However, the expansion of forest coverage fell sharply to just 0.1% between 2009 and 2012, respectively to 0.2% between 2012 and 2013, compared to nearly 5% between 2008 and 2009 because of larger timber consumption after the natural disaster.

- Forest area was drastically reduced, because after the 2008 earthquake new housing areas were constructed in former forest areas, and the demand for construction timber increased, too.
- Afforestation refers to changes in land use towards forest plantation; the 2008 disaster and the following re-construction need in Sichuan province are reflected in these figures, too.

Table 10: General forest data for Sichuan Province

	2008	2009	2012	2013
Forest coverage (%)	30.3***	35.2***	35.3*	35.5**
Forest area (ha)	22,660,200***	23,282,600***	17,140,600*	17,257,200**
Area under afforestation (ha)	574,600**	487,800**	112,200**	126,200**

Sources: * Statistical Bureau of Sichuan (2013); ** Statistical Bureau of Sichuan (2014); ***National Bureau of Statistics of China (n.d.)

According to FAO definitions and referring to forest coverage, almost no or only minor deforestation took place in the PoA area even despite the enormous re-construction efforts after the devastating earthquake. Due to this dominating force majeure impact, it is difficult to isolate any PoA effects on Sichuan's forest coverage. We expect only a weak increase in forest coverage following the substitution of firewood by biogas because traditional fuel consists mainly of straw and stalks from shrubs and not of trees. Moreover, firewood is often collected from places other than forests but rather in the immediate surroundings and neighbourhoods of the farms. Still, a small positive effect might be achieved through biogas installations in certain villages with accessible forest areas. It is recommended to dedicate further research to the generation of specific evidence whether some "biogas villages" included in the PoA contribute to a cease in deforestation.

4.3 Use of Invasive Alien Species of plants as a prospective co-benefit

With the usage of invasive alien species of plants (IAS_p) as additional feedstock for biogas production, not only this resource could be efficiently used but also additional benefits for protecting the biodiversity in the area could be generated.

Alien species are defined as organisms that find a new habitat in a different geographic location than their origin. Many of these species reach the new location as an unintended result of human activities such as trade or agriculture. Others are purposely introduced for food cultivation or even in attempts of beneficial ecological intervention, but often resulting in opposite effects. Alien species could successfully flourish and reproduce in their new habitat, mainly because of the absence of natural predators and parasites that attack them. In consequence, the enemy-free habitat allows them to out-compete native species, appropriating a habitat formerly occupied by native species within their niches (Hogan, 2010b).

Invasive species act as the second major cause of species extinction worldwide after habitat destruction. The impacts that these kinds of species have are "immense, insidious, and usually irreversible", they cause significant damage in ecological, economic and health aspects (IUCN, n.d.).

4.4 Invasive Alien Species of Plants in China

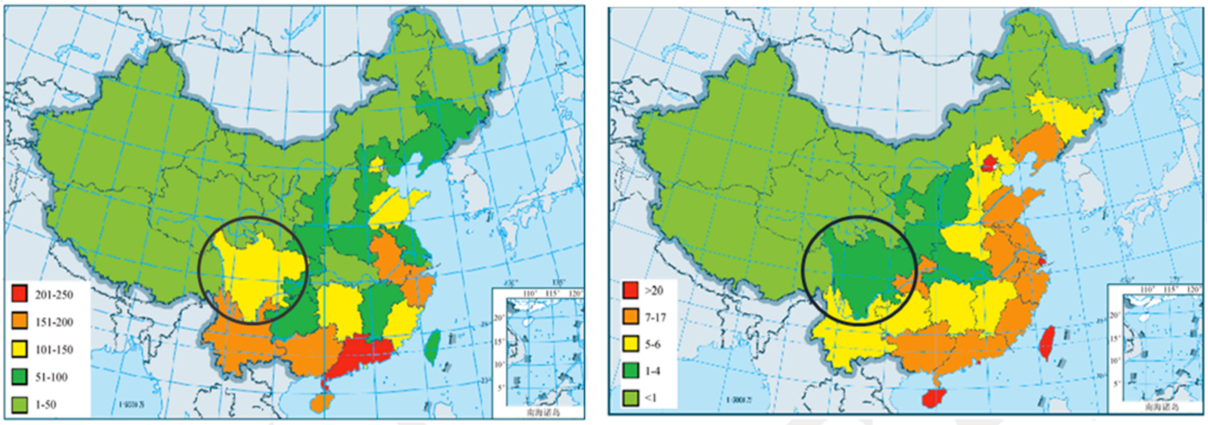
Weber et al. (2008) reported that IAS_P are present throughout China and particularly abundant in the Southeast. They identified 270 invasive plant species that correspond to 0.9% of the flora of the country, which were estimated to provoke economic losses that amount to US$ 15 billion annually (Xu et al., 2004, cited by Weber et al., 2008).

In 2012, Yan et al. stated that data about invasive species in China is far from complete; and that authorities, institutions and scientists have not yet properly noticed the ecological and economic impact caused by several IAS_P. Based on both literature review and fieldwork, “An Inventory of invasive alien species in China”, lists 488 IAS identified in China’s terrestrial habitats, inland waters and marine ecosystems. Invasive plants account for 51.6% of the total number of IAS. In terms of habitats, 64.3% of IAS_P are found on farmlands, 13.9% in forests, 8.4% in marine ecosystems, 7.3% in inland water bodies, and 6.1% grow in residential areas (Xu et al., 2012).

Pan et al. (2015) quotes a national survey of invasive species in China, published by Xu & Qiang in 2011, counting 265 IAS_P in the country, only a slight difference to the earlier reported 270 IAS_P identified by Weber et al. (2008).

Yan et al. (2012) provided an overview on the average number of IAS_p in every province of China. As displayed in Figure 5 (a) Yan et al. (2012) identified a range of 101-150 invasive alien plant species in Sichuan; while in Figure 5 (b) the number of IAS_P per square kilometre (km^2) is visible. With less than 4 IAS_P per km^2, Sichuan Province shows a low occurrence of IAS_p.

Figure 5: Numbers of invasive alien plants in Chinese provinces (a), and number of invasive alien plants per unit area in Chinese provinces (b).



(a) (b)

Source: X. Yan et al. (2012)

Based on literature, mainly using the data provided by the Chengdu Province Forestry and Landscape Authority (2013) on “China's First List of Invasive Species” created in 2003, and “An inventory of invasive alien species in China” by Xu et al. (2012), the study team compiled a list of IAS_P present in Sichuan Province – refer to Table 11. The presence of invasive alien plant species in the households’ fields was included in the present survey in order to determine their potential as feedstock for biogas production, because their removal and energetic use could also contribute to biodiversity conservation.

Table 11: List of IAS_P growing in Sichuan Province

Scientific name	Common names in English	Chinese name	Chinese synonyms
*Eupatorium adenophorum Spreng**	Eupatory, sticky snakeroot, crofton weed, Mexican devil	紫茎泽兰 Zǐ jīng zé lán	解放草 jiěfàng cǎo、破坏草 pòhuài cǎo
Galinsoga parviflora Cav.**	Small-flowered quickweed, quickweed	牛膝菊 Niú xī jú	辣子草 Làzǐ cǎo,珍珠草 zhēnzhū cǎo, 铜锤草 Tóng chuí cǎo
Galinsoga quadriradiata Ruiz & Pav.**	French weed, hairy galinsoga	粗毛牛膝菊 Cūmáo niú xī jú	粗毛小米菊 Cūmáo xiǎomǐ jú
Pennisetum purpureum Schumach.**	Elephant grass, Napier grass, Uganda grass	象草 Xiàng cǎo	狼尾草 Láng wěi cǎo
Raphanus raphanistrum L.**	Wild Radish	野萝卜 Yě luóbo	
*Sorghum halepense (L.) Pers.**	Johnson grass, Aleppo grass, Aleppo millet grass	假高粱 Jiă gāoliáng	石茅 Shí máo, 阿拉伯高粱 ālābó gāoliáng
Ulex europaeus L.**	Common gorse, European gorse, furze, golden gorse, gorse, Irish furze, whin	荆豆 Jīng dòu	欧洲的荆豆 ōuzhōu de jīng dòu

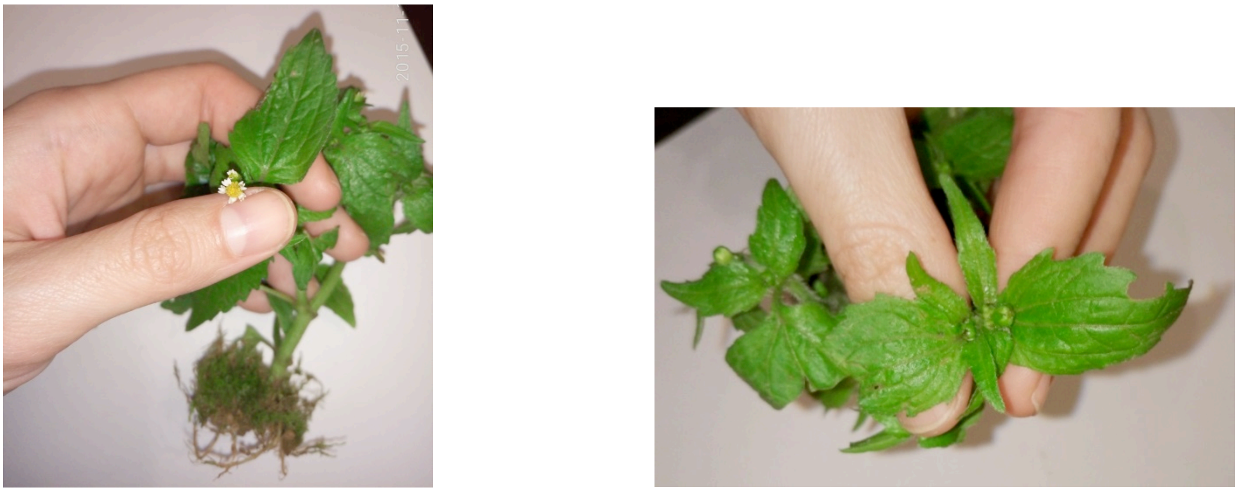
* China's First List of Invasive Species (2003); ** Xu et al. (2012)

All interviewed families addressed the presence of IAS_p with considerable uncertainty, when asked to determine their existence on the fields. Three farmers expressed a slight possibility of identifying *Pennisetum purpureum* Schumach, also known as Napier grass or elephant grass, or a plant with similar appearance. Two households answered similarly about *Galinsoga parviflora* Cavaniles, an herbaceous plant in the Asteraceae (daisy) family, and *Galinsoga quadriradiata* Ruiz & Pavón, another species of flowering plant in the daisy family. They all said that they would basically not be able to identify such plants in their fields. However, the study team collected a plant supposedly *Galinsoga* spp. and later identified it as a member of the aforementioned *Galinsoga* genus in the field of one of these households. Nonetheless it could not be determined whether it was the species *Galinsoga parviflora* or *Galinsoga quadriradiata*.

When inquired if IAS_P affect their crops, two families answered positively, adding that they are found in the fields. Five households were also asked whether they use any synthetic herbicides, but they negated it and explained that they just cut off or pulled out unwanted plants. Four of them put the plants below their fruit trees as fertilizer, while only one household stated to feed small amounts of IAS_P into their digester.

Overall, for the purpose of collecting IAS_p within the participant households of the PoA, further sampling and identification is advised considering a larger and more diversified sample.

Figure 6: Sample of Galinsoga spp. collected by CSES study team



4.5 Potential biogas generation from Invasive Alien Plants

Despite the fact that during the visits to the PoA households the orientation survey did not show significant results referring to the presence of IAS_P, it is worth to note that at least their occurrence could be confirmed even within the relatively small random sample size. The potential biogas production from IAS_P has been studied; their efficient use for biogas generation could strengthen the local biodiversity as a possible co-benefit of the PoA.

In fact, the use of leafy material for biogas production has been long tested.

- Raychaudhuri et al. (1999) tested the combination of *Acacia auriculiformis* leaves and cow dung in biodigesters: the leaves produced around 332 L biogas/kg DM, constituting 1.5 times the volume produced only from cow dung (220 L biogas/kg DM) under similar conditions. In parallel, a mixture of *A. auriculiformis* leaves and cow dung in equal weights (1:1) generated a maximum of 347 L biogas/kg DM containing 64% of methane while the biogas produced from only cow dung contained 59% of methane.
- According to the results of Mallick et al. (2009), leafy biomass and vegetable wastes are favourable for biogas generation.
- Biogas yields of tropical biomass were evaluated by using among other substrates of the *Albizia moluccana* tree. The albizia chips and leaves were used as feedstock in both wet and dry fermentation. Animal manure, sewage sludge, and food waste are normally treated using wet fermentation systems, while organic parts of municipal solid waste and ligno-cellulosic biomass such as crop residues and energy crops can be processed through dry fermentation (Li et al., 2011). Wet fermentation processes are applied in the household biogas digesters of the PoA, resulting in higher methane yields for albizia leaves and chips (161 and 113 L/kg VS, respectively) than dry fermentation (156.8 and 59.6 L/kg VS) (Ge et al., 2014).
- On a large scale, Napier grass (*Pennisetum purpureum*) as one of the IAS_P present in Sichuan (refer to Table 10) is evaluated to have both high biomass and biogas yield, according to a study conducted in Thailand. In this specific location, a local hybrid has been developed and named “*Pennisetum purpureum cv. Pakchong1*”, which consists in a cross breed able to cope with local environments. Napier grass shows similar compositions if compared to maize silage

with considerably higher methane yield per plantation area, as presented in Table 12. The highest methane production occurs at 45 days of anaerobic digestion with 190-270 m^3/t VS, and an annual range of 7,389-17,496 m^3/ha; while the whole crop of maize silage produces an annual range of 3,573-18,540 m^3/ha (Pruk, 2014).

Table 12: Methane yield of fresh Napier grass compared with maize

Methane yield	Napier grass at 45 days of AD	Napier grass at 60 days of AD	Maize (whole crop)
m^3/ton VS*	190-270	170-220	387-618
m^3/ha/year	7,389-17,496	7,012-16,500	3,573-18,540

Source: adapted from Pruk (2014)

- A study by Sawasdee & Pisutpaisal (2014) provides results that makes Napier grass' - due to its organic composition, an ideal feedstock for biogas generation. Its content of total carbohydrates amounts to 30.9%, proteins (27%), lipids (14.8%), total ash (18.2%) and fibre (9.1% of dry weight) and further substantiates this recommendation. The optimal condition for biogas production was encountered at 5% of solid concentration, where the methane content was 53%, the methane yield 122.4 L/kg of total volatile solids (TVS) remove and generation rate 0.0048 L/h at the optimum condition. The results suggest considering Napier grass as energy crop.

Other studies in China and beyond provide information about biogas generation from water hyacinths (*Eichhornia crassipes*) as feedstock. The Water hyacinth is a freshwater aquatic plant originally from South America, and considered as a noxious IAS_P in many parts of the world because of its rapid growth combined with significant oxygen and nutrient depletion from water bodies, harmfully affecting the local flora and fauna (Kunatsa & Mufundirwa, 2013).

- Almoustapha et al. (2008) investigated the possibility to produce biogas through co-fermentation of water hyacinths and fresh rumen residues to meet the energy needs of a medical facility in Niger, Africa. The use of water hyacinths as substrate for the production of biogas provides at the same time a strategy to fight the plant's invasion. The feedstock resource is available at any time, and renewable, as the growth of water hyacinths in the affected water bodies cannot be stopped entirely by their usage as feedstock for the digester. The facility's yield was reported to be 0.52 m^3/d/digester during the warm season and 0.29 m^3/d/digester during the cold season. The facility not only saves firewood (7.3 t/y) but also promotes the use of biogas as a contribution to the fight against desertification.
- Lu et al. (2010) carried out a study on a pig farm in China, proposing the co-fermentation of pig manure and water hyacinths. The experiment resulted in much higher biogas generation than pig manure alone; the highest biogas production was achieved when water hyacinths were added as 15% of the co-fermentation substrate.

4.6 Conclusions and recommendations

Most evaluated scientific studies agree on the benefits of replacing chemical fertilizer with digestate as an organic fertilizer. Using digestate on the fields is reported to increase crop productivity and to support soil remediation. Less applied synthetic fertilizer and pesticides by rural households participating in the PoA improves the quality of nearby aquatic and terrestrial ecosystems by avoiding eutrophication and accumulating pollution with harmful substances. The PoA is therefore highly instrumental to preserving and enhancing the existing fauna and flora and maintaining the natural balance of these ecosystems.

Reliable local statistical data on the forest coverage change before and after biogas digester implementation in PoA specific locations could not be found. Referring to FAO definitions only minor deforestation took place in the PoA area because coal has been the most important source of energy and traditional biomass fuel mainly consists of straw and stalks from shrubs. Firewood is often collected from places other than forests but rather in the immediate surroundings and neighbourhoods. Still, a small positive effect might be achieved through biogas installations in certain villages with accessible forest areas.

So far, most of the interviewed PoA farmers are not yet aware of the potential co-benefits of using Invasive Alien Plant Species (IAS_P) as an additional biogas digester feedstock. The utilization of the easily biodegradable plant parts of IAS_P as co-feedstock could create important further PoA co-benefits because this would simultaneously improve biogas yields and strengthen local biodiversity by enhancing the reduction or control of the spread of IAS_p. The IAS_P energy potential is similar to fresh vegetable leaves residues or green leaves. Therefore, 10 kg of IAS_P leaves roughly produce up to 1 m^3 of additional biogas per day.

We encourage UPM to carry through a more detailed assessment of the specific use and damage of chemical fertilizers and pesticides before and after the PoA.

The degree of PoA-induced pesticide savings and its positive effect on local biodiversity and surrounding natural habitats is still less clear than the better verifiable reductions of chemical fertilizer and will therefore need to be substantiated further by follow-up research.

UPM should also dedicate further research to obtaining robust evidence about whether, and to what extent, some “biogas villages” included in the PoA contribute to a slow-down or cease of deforestation in Sichuan.

Furthermore, it is recommended that UPM and its local cooperation partner Oasis begin to identify strategic partners who are interested in demonstrating and promoting the additional biogas production potential of IAS_P growing in the fields and surrounding areas of the PoA households’ farms.

5. PoA co-benefits for air quality

A wide range of scientific literature has been reviewed in order to analyse the effects on air quality caused by the installation of biogas digesters in the PoA region. A focus was put on impacts on Indoor Air Pollution (IAP) as these are considerable and already well investigated.

The study team also investigated the emissions of digestate during storage and after spreading, and a comparison to emissions occurred before digester installation.

5.1 Indoor Air Pollution

Indoor Air Pollution (IAP) is mainly caused by the combustion of solid fuels such as coal or firewood. Their incomplete combustion generates flue gases, which contain many dangerous pollutants as products of incomplete combustion (PICs). Kampa & Castanas (2008) grouped these pollutants in four categories:

1. Gaseous pollutants: *e.g. sulphur dioxide - SO_2; mono-nitrogen oxides, nitric oxide and nitrogen dioxide - summarized as NO_x; carbon monoxide - CO; ozone - O_3; and Volatile Organic Compounds - VOCs*
2. Persistent organic pollutants,
3. Heavy metals,
4. Particulate Matter (PM).

The study team investigated PM, CO, SO_2, VOCs and some heavy metals emitted by biogas stoves used in the surveyed household. IAP has been proven to be the cause of an estimated 4.3 million premature deaths worldwide per year (WHO, 2014); it plays a crucial role for human health – refer to Chapter 8.1 Improved indoor air quality, for further details.

The obligatory Gold Standard and CDM monitoring of the Sichuan Household Biogas PoA reflects the households' perception on smoke quantity in the kitchen during cooking. In the 2015 PoA Monitoring Report, housewives described a considerable reduction of indoor smoke since using biogas as cooking fuel. The smoke indicator came down from 2.65 to 0.63, where the maximum indicator of 3 means "a lot of smoke very often", while a minimum of 0 means "no smoke". Containing just a few larger hydrocarbons, burning biogas generates only negligible concentrations of harmful products of incomplete combustion (PICs); hence, it causes significantly less indoor air pollution compared to solid fuels.

The study team reviewed many studies comparing biogas and traditional stoves, although the underlying conditions are not always comparable to the PoA region.

- Zhang et al. (2000) created an exhaustive database on 28 traditional stove types and their respective emissions, including PICs, and concluded that during combustion of biomass or coal 10% to 38% of the fuel carbon is converted into PICs.
- As already indicated above (refer to Chapters 3 and 4) many biogas households still use their traditional stove, thus diminishing positive effects on indoor air quality (Wang & Li, 2005; van Groenendaal & Wang, 2010; Gosens et al., 2013).

Interviewed PoA households confirmed a significant decline in the use of solid fuels for cooking purposes from three times per day before the installation of a biogas plant to less than once a month (only one surveyed household stated that they use firewood more than once a month).

Concerning home heating, different studies report that biogas households still use traditional fuels for heating (Sinton et al., 2004; Jin et al., 2005). PoA households participating in the field survey described that they only heat their homes indirectly through residual heat from cooking; one household stated that they use biomass for heating. Beneficial impacts from the replacement of traditional stoves are nevertheless created during those months when no heating is required.

The two large-scale studies conducted by Sinton et al. (2004) and Jin et al. (2005) were following similar methodological approaches as the field survey presented here. However, these large-scale studies include many different kinds of fuels, stoves, climatic conditions and kitchen designs, thus impeding clear statistical evaluation due to a number of confounding co-factors. Although data is therefore differing referring to the above-mentioned parameters and are not quantitatively comparable, studies of different scales often result in similar conclusions and therefore give indications on the Sichuan PoA.

All reviewed studies confirm substantially reduced air pollutant emissions for liquid and gaseous fuels in general (Begum et al., 2009) and for biogas in particular (Wang et al., 2010; Zhang & Smith, 2007; China Agricultural University Beijing - Renewable Resource Laboratory, RRL, 2002) A number of studies only compare traditional fuels such as coal and biomass (Sinton et al., 2004; Jin et al., 2005) and can be used for assumptions on the air quality before implementation of the project.

RRL (2002) monitored indoor air pollution in three counties in Sichuan during the Sino-Dutch biogas project. In each county, CO, SO_2 and $PM_{2.5}$ were measured in 30 households before and after the implementation of a biogas digester. Before the installation, most households used traditional stoves burning mostly biomass (fuel wood, crop straw) or coal. The investigation showed considerable improvements on indoor air quality for each parameter. Table 13 displays the results for Nanbu county in order to give an impression on the general range of CO, SO_2 and $PM_{2.5}$ levels.

Table 13: Results of air quality monitoring in Nanbu county

Pollutant	Before installation	After installation	Improvement rate
CO [mg/m^3]	61.22±47.69	7.51±6.52	87.73 %
SO_2 [mg/m^3]	4.08±3.72	0.02±0.01	99.51 %
$PM_{2.5}$ [µg/m^3]	232.86±158.25	117.73±86.44	49.44 %

The calculation of the improvement rate (IR) is given in the cited article: $IR=\frac{C_i - C'_i}{C_i}\times 100$;

Where: C_i = level before installation; C'_i = level after installation

The above studies present CO reductions to values below the WHO standard of 10 ppm (= 12.3 mg/m^3 (Lenntech, 2016)) in all investigated regions, while SO_2 levels were at least around the recommended maximum level of 20 µg/m^3, showing improvement rates of more than 99% in two regions. Only PM values could not meet WHO requirements (50 µg/m^3 for PM_{10}), but still went below the Chinese standard of 150 µg/m^3 (see also in Table 14).

The Sino-Dutch project could prove that the introduction of biogas contributed considerably to both improved living conditions of household members (especially in terms of air quality) and environmental protection.

Wang et al. (2010) monitored household IAP for different villages in Guizhou province (China) where biogas, coal or wood was used as main fuel source. Two to three households were selected for each village and fuel type. As Guizhou is located next to Sichuan, similar climatic conditions could be assumed. Measured concentrations during fuel combustion are compared to indoor air without combustion and to outdoor air (background pollution). As expected, it was shown that the combustion of solid fuels resulted in much higher concentrations of both PM and VOCs than the combustion of biogas (refer to Table 14). VOCs included high amounts of BTEX (benzene, toluene, ethylbenzene, xylene) that are considered very detrimental to health. Values for biogas combustion were comparable to indoor concentrations without combustion, implying that biogas combustion only releases very small to negligible amounts of pollutants. The study does not provide information on heating habits of the participating households. Conducted in the month of March (heating season, Jin et al., 2005), heating might still have occurred if a separate heating stove was present.

Measurements during cooking could not be carried out while conducting the current field survey, but indoor $PM_{2.5}$ and PM_{10} measurements during biogas combustion (close to the flame) were possible, accounting to 63.88±11.08 μg/m^3 and 106.63±16.36 μg/m^3 respectively. $PM_{2.5}$ hereby represents fine particles of diameter smaller than 2.5 μm, while PM_{10} additionally includes coarse dust particles of diameter up to 10 μm. Values are found to be similar to those measured by Wang et al. (2010). VOC concentrations during biogas combustion varied largely between 0.037 and 116.0 mg/m^3 (median 2.83 mg/m^3). Follow-up measurements are strongly recommended.

Table 14: Mass concentrations of pollutants in indoor air during biogas combustion

Pollutant	Outdoor background* [μg/m^3]	Indoor without combustion* [μg/m^3]	Biogas (Guai Ji) [μg/m^3]	Coal (Qian Feng) [μg/m^3]	Wood (Guai Ji) [μg/m^3]
PM_{10}	66.58 ± 13.07	85.12 ± 30.93	104.0 ± 11.57	240.7 ± 12.14	354.5 ± 55.42
$PM_{2.5}$	59.36 ± 7.32	74.47 ± 29.04	89.00 ± 6.57	197.8 ± 8.91	295.6 ± 58.16
VOCs (sum)**	-	13.3 ± 6.5	34.4 ± 19.4	695.3 ± 354.5	466.7 ± 337.9

Adapted from Wang et al. (2010); *Data from Guai Ji village, as there was no coal mining nearby. Values for Qian Feng were slightly higher; **VOCs: mostly made up of BTEX

He et al. (2005), monitored PM_4, CO, SO_2, fluorine (F) and arsenic (As) concentrations in four households each in Guizhou and Shaanxi. Like the majority of rural households in this specific region, the households mainly used coal for cooking and heating. Raised values for PM_4 and SO_2 were found in both provinces (1944 and 204 μg/m^3 PM_4 and 0.4 and 0.3 ppm respectively for Guizhou and Shaanxi). Concentrations of CO, F and As ranged continuously in very low levels. Whereas Jin et al. (2005) also found low CO levels, and Sinton et al. (2004) measured elevated CO concentrations (see below).

In addition, He et al. (2005) found a considerable dispersion to the other rooms in the house, leading to living and sleeping rooms being affected to the same or even higher extents than the cooking area. Begum et al. (2009) measured high PM_{10} concentrations in living areas, too (104 – 332 μg/m^3, depending on house type), although kitchen PM_{10} concentrations exceeded those considerably (592–1177 µg/m^3, values for biomass combustion). Depending on room arrangements and ventilation, other rooms than the cooking area can be affected, which increases household members' exposure to polluted air.

Sinton et al. (2004) and Jin et al. (2005) included in their studies more than 400 households in different Chinese provinces. Fuels were categorised as "mostly coal", "mostly biomass" and as "electricity or LPG" (Liquefied Petroleum Gas) in the study from Sinton et al. (2004). PM_4 and CO emissions for the respective fuels have been investigated, and Jin et al. (2005) included SO_2 emissions in the analysis examinations.

PM_4 levels for coal combustion ranged between 187 and 361 µg/m^3 in both studies, exceeding the Chinese and WHO standards (150 and 50 µg/m^3 respectively for PM_{10}, Table 15). Emissions resulting from biomass combustion reached even higher concentrations of up to 719 µg/m^3. While Jin et al. (2005) encountered CO concentrations mostly lower than 10 ppm (WHO standard) for both coal and biomass, Sinton et al. (2004) partly found elevated values. Although monitoring took place during winter (heating season) and in summer and was evaluated separately, exact figures have not been published since. Values for summer might have given more accurate indications on the situation in Sichuan before biogas implementation, as households in Sichuan usually do not heat. Jin et al. (2005) pointed out that SO_2 concentrations of 0.18 – 1.44 ppm after coal combustion exceed air quality guidelines manifoldly (WHO guideline: 0.04 ppm, 24 h exposures).

As results from both studies (Sinton et al., 2004; Jin et al., 2005) include data from the heating season, it can be assumed that concentrations were generally higher than in Sichuan households who do not heat their homes by usage of a solid fuel stove (except in one household). However, particularly PM concentrations exceeded health guidelines to such an extent that even without heating, levels detrimental to health can be assumed for the time before using biogas as cooking fuel.

Further investigations on effects of biogas combustion show that indoor SO_2 levels are effectively reduced compared to traditional (solid) fuels (Hamburg, 1989; van Groenendaal & Wang, 2010). H_2S is usually converted to SO_2 during combustion and thus does not pose a great risk (Hamburg, 1989). The vast majority of studies therefore did not include H_2S into their investigations.

Table 15: International and Chinese health standards (period of exposure in parenthesis)

	Chinese standard*	**WHO****
PM_{10} [µg/m^3]	150 (24 h)	50 (24 h)
CO [ppm]	9 (1 h)	10 (8 h)
SO_2 [µg/m^3]	150 (24 h)	20 (24 h) = 0.04 ppm

* GB 3095-2012 (China ambient air quality standards)

** "WHO Air Quality Guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005" and "WHO Guidelines for Air Quality: Selected Pollutants" (2010)

As for monitoring methodology, Smith et al. (1994) argue that measuring exposure to pollutants instead of measuring emissions might be a more accurate way to examine health impacts by air pollutants. Furthermore, the aspect of neighbourhood pollution is pointed out. It implies that harmful smoke from households that did not replace fuels can still enter neighbouring houses. As the study was conducted in densely populated urban areas, it can be assumed that neighbourhood pollution does not occur to the same extent among rural households. However, to the study team's knowledge no study focusing on neighbourhood pollution in rural areas has been published to date.

Another source of pollutants impairing air quality are industrial emissions, regionally elevating air pollution levels within several hundred kilometres (Streets et al., 2007). Those outdoor air pollutants can easily enter indoor spaces. Health effects decrease less than linearly with emission reduction (Gosens et al., 2013), which means that reduction within high pollution levels cannot bring about the same health effects as the same reduction within lower levels could. As a result, population of rural areas situated close to industrial production will not profit to the same extent from improved private fuel usage. Background pollution would still impede health. For example, Staff Mestl et al. (2006) calculated theoretical background pollutions of 80 $\mu g/m^3$ PM_{10} in summer and 140 $\mu g/m^3$ in winter in case solid fuels were replaced completely. The model is based on values for Shanxi province. Estimations for outdoor air pollution in eastern Sichuan province are found in the same range (50 – 120 $\mu g/m^3$ PM_{10}, including seasonal changes; X. Liu et al., 2010). In the same study, western Sichuan showed negligible PM_{10} levels and furthermore is only very scarcely affected by background SO_2 and NO_2. Thus, depending on background (outdoor) pollution levels, beneficial effects of fuel substitution can differ.

5.2 Emissions from manure and digestate

Manure tends to emit several gases, among them methane (CH_4), ammonia (NH_3), nitrous oxide (N_2O) and odorous substances (e.g. Vitousek et al., 1997; FNR, 2012). *(Methane emissions are not covered by this report, as they are supposed to be considered in the calculation of the carbon dioxide emission reduction certificates.)*

N_2O is a very potent greenhouse gas, its global warming potential during the next hundred years after its release being considered 310 times bigger than that of CO_2 (Guinée et al., 2002). While NH_3 stays in the atmosphere only for a few days, its deposition has severe environmental consequences, which were summarized by Vitousek et al. (1997). On the one hand, when NH_3 is deposited onto water or non-agricultural land, the resulting nutrient enrichment causes eutrophication. Nitrogen availability poses a limiting factor to many ecosystems and nitrogen enrichment leads to decreased biodiversity. On the other hand, when ammonia (NH_3) is converted into ammonium (NH_4^+) in the atmosphere, the deposition of ammonium exacerbates acidification, which decreases biodiversity, too (see also LUBW, 2008). Eutrophication and acidification can occur together or independently. In fact, agriculture is the main source for global NH_3 emissions (Schlesinger & Hartley, 1992).

Nitrogen loss due to NH_3 volatilization is a serious problem of manure and digestate application, not only because of its environmental consequences but also because it significantly decreases the nutrient content of manure and digestate and thereby their fertilizing effects. Although NH_3 losses after application increase with temperature and viscosity of the fluid (FNR, 2012; Amon et al., 2006), already 25% of nitrogen contained in pig manure can volatize within 48 hours after being spread on fields - if it is not worked into the soil, and if temperature reaches 15°C (FNR, 2012). Yet, NH_3 losses could be reduced by application techniques, which minimize the contact between digestate and air, such as trailing shoes, trailing hoses or direct injection into soil (Al Seadi & Lukehurst, 2012; FNR, 2012; Wulf et al., 2002a).

The potential co-benefit of the PoA is the reduction of N_2O, NH_3 and odour emissions. Consequently, the following paragraphs compare the emissions from animal and human excreta to those of digestate as effluent from biogas digesters.

It is difficult to determine whether applying digestate instead of manure benefits the environment in terms of NH_3 and N_2O emissions. Digestate application causes higher or at least similar NH_3 emissions (Pain et al., 1990; Wulf et al., 2002b; Amon et al., 2006; Möller & Stinner, 2009; Ni et al., 2012; Höjgård & Wilhelmsson, 2012) but lower N_2O emissions than fresh manure application (Amon et al., 2006; Chantigny et al., 2007; Börjesson & Berglund, 2007; Collins et al., 2011; Höjgård & Wilhelmsson, 2012).

In other words, applying digestate instead of manure causes considerably lower greenhouse gas emissions (due N_2O reduction), but bear higher eutrophication and acidification risks (due to NH_3 increase). According to Höjgård & Wilhelmsson (2012), the increase of eutrophication risk due to increased NH_3 emissions is partly counteracted by decreased nitrogen leakage, which results from higher accessibility and uptake in plants of nitrogen contained in digestate. Nevertheless, the necessity to weigh the influence of the two kinds of emissions as well as the great variety of measurement results make a distinct statement of possible benefits difficult.

Comparison of digestate and synthetic fertilizer application even shows digestate application to be worse in terms of NH_3 and N_2O emissions. Many studies proved NH_3 emissions to be higher (Hou et al., 2007; Sunaga et al., 2009; Win et al., 2010) and N_2O emissions to be higher (Senbayram et al., 2009) or similar after application of digestate instead of synthetic fertilizer (Sawamoto et al., 2010; Win et al., 2010; Sasada et al., 2011; Collins et al., 2011).

In addition, different studies contain a wide range of measured N_2O emissions during storage of digestate, preventing any reliable comparison with the emissions from manure storage (FNR, 2012; Amon et al., 2006).

Nevertheless, the PoA is able to reduce NH_3 emissions during storage. Digestate not only emits less NH_3 during storage than undigested manure (Amon et al., 2006), but it is also stored in a different way. Before the digester installation, animal and human excreta in the participating households were stored in open pits. Now these excreta are fed into the digester and the digestate remains in the digester or the concrete covered outlet chamber until it is taken out for use as fertilizer. The moveable covers allow less air circulation than the former open storage pits for manure and excreta. Since covered storage is an effective way to prevent NH_3 emissions (Al Seadi & Lukehurst, 2012), covers made of plastic, tent canvas or concrete reduce NH_3 emissions by 90% compared to uncovered storage facilities (Döhler et al., 2001). Plus, reduced air circulation reduces odour and thereby improves living conditions in the neighbourhood considerably.

Another benefit from the PoA in terms of nitrogen emissions refers to the significant abatement of synthetic fertilizer use, because through the use of digestate the PoA closes the nutrient cycle and thus reduces the nitrogen input into the agricultural system. Abating the use of synthetic fertilizer also abates related nitrogen emissions. For example, IPCC (1996) estimates that the application of 1 kg of synthetic fertilizer nitrogen roughly causes emissions of 0.1 kg nitrogen via NH_3 and NO_x, and of 0.0125 kg nitrogen via N_2O.

5.3 Conclusions and recommendations

Indoor Air Pollution (IAP) is mainly caused by the combustion of solid fuels such as coal or firewood. Their incomplete combustion generates flue gases, which contain many dangerous pollutants. According to WHO, IAP has been proven to be the cause of an estimated 4.3 million premature deaths worldwide per year.

During the field survey for this study, concentrations exceeding Chinese and international health standards have been measured during combustion of solid fuels, especially concerning PM and, in case of coal burning, SO_2. In some cases, elevated CO levels have been found as well. Although the exact pollutant concentrations vary considerably depending on the fuels burned, the ventilation system and the climate, solid fuel combustion generally generated raised amounts of PICs in comparison to biogas combustion.

The obligatory Gold Standard and CDM monitoring of the Sichuan Household Biogas PoA reflects the households' perception on smoke quantity in the kitchen during cooking. In the 2015 PoA Monitoring Report (UPM & Oasis, 2015), housewives described a considerable reduction of indoor smoke since using biogas as cooking fuel. The smoke indicator came down from 2.65 to 0.63, where the maximum indicator of 3 means "a lot of smoke very often", while a minimum of 0 means "no smoke". Containing just a few larger hydrocarbons, burning biogas generates only negligible concentrations of harmful products of incomplete combustion (PICs); hence, it causes significantly less indoor air pollution compared to solid fuels.

Both our desk research of relevant scientific studies and our field survey interviews confirm these monitoring results as indoor cooking with a proper kitchen room is standard in the PoA region. The substitution of solid fuels by high quality biogas is a viable path to reduce health risks caused by indoor air pollution.

Manure tends to emit several gases, among them methane (CH_4), ammonia (NH_3), nitrous oxide (N_2O) and odorous substances. The potential co-benefit of the PoA is the reduction of N_2O, NH_3 and odour emissions. Methane emissions are not covered by this report, as they are already considered in the PoA's GHG emissions reduction calculations for the CDM. Consequently, the emissions from animal manure and human excreta and those of chemical fertilizer are compared to those of digestate as effluent from biogas digesters.

Over-application (usually defined by more than 170kgN/ha) of liquid digestate, which may cause nitrogen emissions similar as to high application of synthetic fertilizer could not be found at the surveyed PoA households. Thus, it can be assumed that the PoA contributes significantly to a reduction of total nutrient input in the agricultural system, which finally leads to less nutrient output in form of harmful emissions.

It can be further concluded that the PoA has both benefits and drawbacks in terms of N_2O and NH_3 emissions. The PoA leads probably to less NH_3 emissions during storage and less N_2O emissions after application of digestate instead of manure. However, surface applying digestate instead of manure causes higher NH_3 emissions and applying digestate as partial replacement of synthetic fertilizer causes higher NH_3 and N_2O emissions. Still, the latter is counteracted by the fact that reduced nitrogen input into a system (by means of reduced synthetic fertilizer use) offers less opportunities for nitrogen emissions, therefore, substitution of synthetic fertilizer by digestate could still reduce NH_3 and N_2O emissions.

As the PoA households now treat animal manure and human excreta in closed digester tanks instead of open pits, bad odours can now largely be avoided and this considerably improves the living conditions at the farmers' premises and in their neighbourhood.

In order to quantify the air quality impact achieved for PoA households more precisely, more frequent, seasonal and exact on-site measurements during cooking time are suggested.

In addition, we advise UPM to assess the applied amounts of digestate and compare it to the amounts of manure and synthetic fertilizer used before the installation of the household biogas digesters. This will result in an individual baseline per household, and would therefore be possible before any new biogas plant is constructed. During PoA CDM and GS monitoring such enhanced baseline would allow a much better pre-after-comparison of fertilizing practices and resulting co-benefits.

To further improve the air quality and ban bad odours in and around the farm buildings of the PoA households permanently, it is highly advisable to change the H_2S filters of installed biogas devices periodically according to the respective manuals. Thus, raising awareness among households and instructing them how to use and maintain H_2S filters properly should be put into action.

6. PoA co-benefits for water quality

6.1 Potential threats to water quality in rural China

FAO's "Guidelines to control agricultural water pollution in China" provides general information about impacts of crop growing, manure management and rural living on water quality (FAO, 2013), which all have a share in agricultural and rural non-point source pollution and contribute to water pollution of both surface waters like rivers, reservoirs or lakes and groundwater.

Crop growing often leads to runoff or seeping of nutrients, especially nitrogen (N) and phosphorous (P), when synthetic fertilizer or manure are applied in excess or in an ineffective way. A minor problem is pesticide runoff or seeping. Livestock raising and rural living can cause runoff and seeping of manure and excreta. In addition to nutrients, they contain pathogens and chemical contaminants derived for example from food additives or medicines.

Many studies cover nitrogen or phosphorous seeping or runoff from crop growing in China (e.g. Ju et al., 2006; Z. Yan et al., 2013; Xue et al., 2013). Other studies proved that agricultural and rural non-point source pollution pollute surface waters throughout China with nitrogen and phosphorus and that they are the main source of nitrogen in Chinese groundwater (FAO, 2013).

Nutrient enrichment (eutrophication) of surface water bodies has serious environmental consequences, because nitrogen and/or phosphorus are often limiting factors in aquatic ecosystems. They increase algae growth, which can significantly alter the composition of aquatic ecosystems and deplete dissolved oxygen (EPA, 2002). Jin (2003) discovered that of over 50 major Chinese lakes across the country, 44% were eutrophic and 22% were even hyper-eutrophic.

Contamination of surface and groundwater threatens human health. One of the most predominant contaminants is nitrate (NO^{3-}). According to WHO (2011), nitrate concentrations in drinking water should be below 50 mg/l (or 11 mg/l as nitrate-N) in order to prevent methaemo globinaemia, the so-called "blue-baby syndrome", a disease that reduces the blood's ability to transport oxygen. An additional threat poses indirect links between nitrate and human cancer, as nitrate is suspected to contribute to the forming carcinogenic substances in the human body. Several studies in China encountered nitrate concentrations above the Chinese Drinking Water Standard (FAO, 2013). Pathogens like bacteria, viruses, protozoa and helminths pose another widespread threat to human health. As a result, the WHO considers keeping drinking water free from faecal contamination as one of three key hygiene behaviours to prevent the spread of diseases (WHO, 1998). Other contaminants are chemical substances that derive for example from food additives or medicine and were excreted by either humans or animals.

6.2 Storage of human excreta and digestate

In rural China, households are rarely connected to sewage collection and treatment systems (The World Bank, 2011). In the absence of a public sewage system, excreta of humans are usually stored in open pits or septic tanks until they are either disposed of or used (WHO, n.d.-a). Such open pits were observed at non-PoA households during the field survey (refer to Figure 7).

Figure 7: A household not participating in the PoA collects manure in a pit (left picture); its content is discharged to the fields at the other side of the street (right picture)

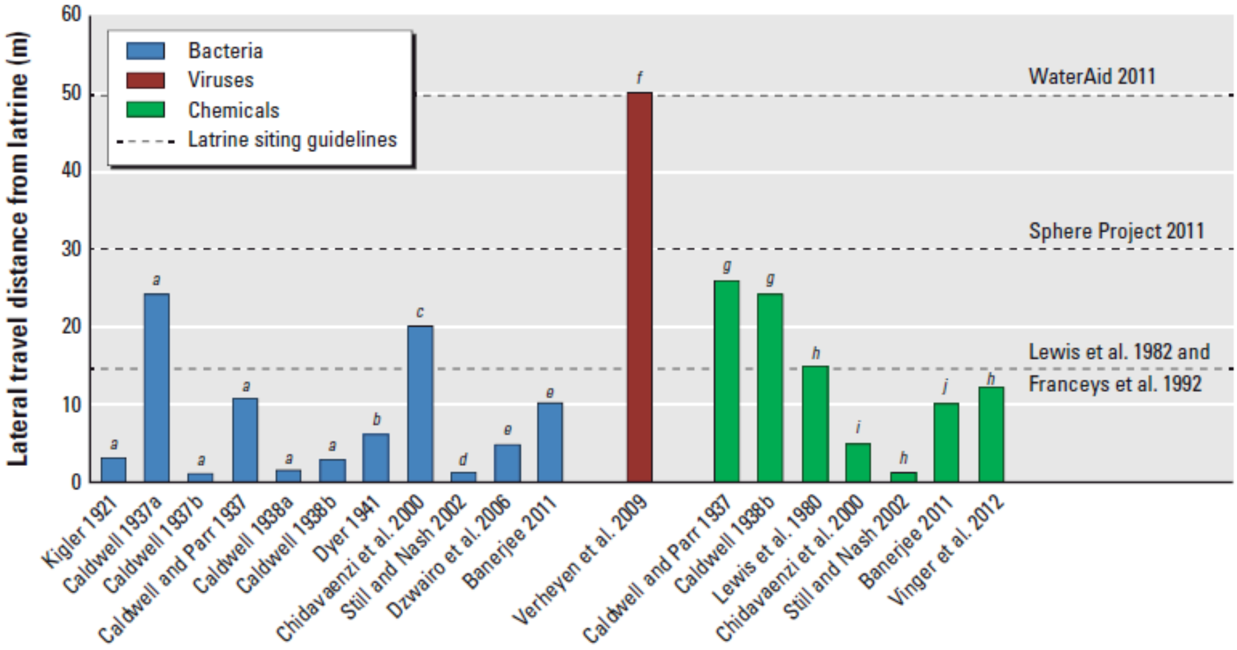
All surveyed households answered that before the installation of their biogas digester they applied all excreta, which are now fed into the digester, to their fields and did not discharge them to water bodies or leave them in closed pits. Since watertight excreta storage facilities require frequent emptying, and hence a lot of labour, non-watertight excreta storage can be assumed for the majority of rural households in Sichuan. Currently, more precise and reliable information about the storage and disposal of excreta by Sichuan households without biogas digesters is not available - such as the tightness of storage facilities, proportion of overflow and discharge, and fraction of excreta applied to fields.

It can be assumed that before the installation of biogas digesters, most of the liquids as well as dissolved solids of excreta disposed in pits infiltrated into the ground (WHO, 1998). If the distance between the excreta pit and the drinking water well is less than 30 m (the minimum recommendation of WHO is at least 30 m distance (WHO, n.d.-b; WHO, n.d.-d; WHO, n.d.-e)) this infiltration contaminates the well water on which rural households in general rely for drinking water supply.

A survey among 300 biogas plant owners in Bangladesh revealed an average distance of the biogas digester from the source of drinking water (tube well, well or pond) to be 17.6 m (IDCOL, 2011). Another survey among 66 Bangladeshi biogas households noted a distance below 10 m for 67% of the households (Ghimire, 2005). The required distance of a biogas plant to a water source is as well determined by the kind of soil and the direction of the water flow. In Bangladesh, construction of a biogas plant closer than 10m to the top sealed well water source is only accepted by the subsidized construction program if the plant is provided with liquid proof sealing of the entire part of the plant – not just the dome, and the bottom plate being designed as water proof through a minimum cement fraction of 350kg/m^3 concrete (KfW 2009).

Graham & Polizzotto (2013) reviewed scientific literature on the occurrence of contaminants from pit latrines and created the graph reproduced in Figure 8, showing at which distances from pit latrines biological or chemical contaminants were detected. The graph further displays the wide range of distances encountered, which is partly due to varying hydrogeological circumstances. This span is reflected in the variety of recommended distances between wells and pits for excreta storage (e.g. IGI, 2007; NMSU, n.d.; Lebeau et al., 2013).

Figure 8: Lateral travel distances of contaminants infiltrating from pit latrines



[a]*B. coli*; [b]total coliforms; [c]coliforms; [d]fecal coliforms; [e]total and fecal coliforms; [f]adenovirus and rotavirus; [g]chemical stream (nitrate, nitrite, and chloride); [h]nitrate; [i]nitrogen; [j]salt tracer.

Source: Graham & Polizzotto, 2013

To prevent contamination, FAO (2013) requests that manure storage facilities should be constructed in a way that minimizes seepage into groundwater; they should be big enough to store all manure produced in the period between seasonal applications of manure. These requirements are fulfilled by biogas digesters, which are constructed watertight as a matter of principle (e.g. Ullrich, 2008; Krossmann et al., n.d.). As a result, recommended minimum distances between digesters and water sources are shorter than for unsealed pits, for example 10m (A. B. Karki et al., 2005) in Bangladesh and Nepal.

It can be concluded that replacing non-watertight excreta storage pits with biogas digesters considerably lowers the risk of groundwater pollution and thus drinking water contamination.

6.3 Disposal and utilization of excreta and digestate

Most of the surveyed households apply the entire digestate to their nearby fields. One household does not use of the entire solid fraction of the digestate on their field; another household applies only the liquid fraction and buries the solid part.

Studies on the application of manure and /or digestate in other areas of China and beyond present different scenarios:

- S. Wu (2005) observed that Chinese households outside the dry North of China apply about 20% of pigs' solid excreta (or generally pig manure) to their fields during farmland fertilization season, whereas the rest of pigs' solid excreta and all of pigs' urine are discharged into nearby water bodies. Numbers were different for other animals, for example only 20% of chicken manure are discharged into water bodies in these regions.

- Of 610 Chinese households interviewed in 2009, only 77% used their digestate as fertilizer (Christiaensen & Heltberg, 2012).
- This is consistent with two studies from Bangladesh: 74.3% of the 300 households interviewed by IDCOL (2011) used digestate as fertilizer and 16.6% used it as fish feed, while 6.3% do not use it at all. In another study from Bangladesh, 23% of the 66 interviewed households did not use the digestate neither as fertilizer nor as fish feed; and of those, 78% drained it directly to water courses (Ghimire, 2005).
- Studies in Nepal and India found higher utilization rates of digestate from biogas system owning households: 94% of 102 households in Nepal stated that they use the digestate as fertilizer (MEG, 2013b); among 340 households in India 90% apply their digestate to fields (Planning Commission, 2002).
- Surveys in Vietnam revealed that a large portion of biogas households discharge digestate to water bodies. This might be partly due to the common practice to use digestate in fishponds to promote growth of plankton as fish feed (T. Vu et al., 2007). This seems to be positive (de Groot & Bogdanski, 2013).
- However, still in Vietnam a considerable portion of manure and digestate is discharged to the environment and the public sewage system, due to lacking knowledge on how to use it and due to the high dilution of the digestate (T. Vu et al., 2007; Q. D. Vu et al., 2012). Out of 340 Vietnamese households interviewed by EPRO (2014), only 40.3% used all their digestate and 5.9% used part of their digestate. 32.1% of the households stated to have no need or no cultivation land for which they could use the digestate; 17.1% explained that their fields were too far away to transport the liquid digestate.

In summary, while 100% of the PoA households make use of the digestate, reports from other biogas programs indicate digestate utilization by 77% up to 94% of participating households. The result from the present PoA survey corresponds to the findings of the PoA's Monitoring Report 2015, according to which also 100% of the surveyed households stated to apply the produced digestate to their fields (UPM & Oasis, 2015).

The consequences of applying a bigger amount of digestate as organic fertilizer are analyzed below:

1. There is a potential abatement of nutrient pollution. Contamination of surface water and groundwater with excess nitrogen and phosphorus from field application of manure or digestate is a major environmental concern. Since digestate is considered to be at least as rich in terms of nutrients as the respective raw excreta, its application can cause at least the same nutrient enrichment (Nkoa, 2014). The nitrogen concentration in drainage water from paddy fields is even about the same after application of digestate as it is after application of synthetic fertilizer (Sasada et al., 2011; Lu et al., 2012; Chen et al., 2013). Still, when comparing leaching of nutrients from non-watertight excreta storage facilities with leaching of nutrients after excessive application of digestate to fields, the second option is clearly preferable. Application of digestate to fields reduces nutrient contamination of water bodies, because a significant fraction of the nutrients are conveniently taken up by plants and thereby prevented from entering water bodies (Holm-Nielsen et al., 2009). As a consequence, field application of all

nutrients causes less nutrient pollution than if a large proportion of the nutrients already seep away during storage.

2. There is potential pollution with other chemical contaminants, such as heavy metals. Their presence in excreta and digestate are described in Chapter 7.2. To date, literature on the contamination of water bodies by heavy metals sourced from excreta is not available. Future research is necessary to compare human exposure to heavy metals (1) from leaking excreta storage facilities resulting in drinking water contamination and (2) from applying digestate to fields and subsequent uptake by crops, leaching and runoff. The discussion of soil and crop contamination in Chapter 7.2 is related to these issues.
3. Water pollution decreases as a direct result of the reduction of synthetic fertilizer and pesticide use, as elaborated in detail in Chapter 3.3. Less use of synthetic fertilizer means less nutrient input into the agricultural system and consequently less eutrophication of water bodies and contamination of drinking water (FAO, 2013). Less use of pesticides reduces pesticide concentration in surface runoff and percolation water (FAO, 2013). Pesticides in surface water bodies result in pesticide accumulation in aquatic creatures, which is the case for much seafood sold in China (e.g. Yang et al., 2006; Z. Liu et al., 2010). Uptake of pesticides via eating contaminated seafood or via drinking contaminated water can lead to serious health impacts.

6.4 Conclusions and recommendations

Unsustainable practices of crop growing, manure management and rural living can have severe negative effects on water quality because all of these contribute to point or non-point source pollution of both surface waters like rivers, reservoirs or lakes and groundwater with potentially severe consequences for the local environment and human health.

Crop growing often leads to runoff or seeping of nutrients, especially nitrogen (N) and phosphorous (P), when synthetic fertilizer or manure are applied in excess or in an ineffective way. Another problem is runoff or seeping of pesticides which can accumulate in aquatic creatures and humans. Livestock raising and rural living can cause runoff and seeping of manure and excreta. In addition to nutrients, they contain pathogens like bacteria, viruses, protozoa and helminths and chemical contaminants such as carcinogenic nitrate (NO^3).

Biogas digester systems and the correct utilization of digestate lead to several co-benefits for water quality. Due to the standardized tightness and appropriate volume of the waterproof and air tight biogas digester tanks as a hermetic storage facility for animal and human excreta, groundwater and drinking water resources are well protected against infiltration with harmful substances from leaking pits.

None of the households interviewed for the PoA's latest Monitoring Report (UPM & Oasis, 2015) mentioned that there is any manure flowing into nearby rivers or creeks. However, also digestate could have a harmful effect on aquatic ecosystems. But, in contrast to excessive nutrient supply from leaking manure and excreta storage devices, the nutrients contained in the digestate are taken up more easily and conveniently by the plants and are thereby prevented from entering nearby water bodies. As a consequence, washout and runoff effects of nutrients are significantly reduced, as is the risk of eutrophication of rivers and lakes.

As the availability and application of superior quality digestate by the PoA households reduces the utilization of synthetic fertilizer and pesticides, there is less nutrient input into the agricultural system and less concentration of pesticides in surface runoff and percolation water. Thus, the PoA also contributes to closing these sources of aquatic nutrient enrichment, water pollution and contamination of drinking water.

To increase the PoA's positive effects on water quality even more, it is advisable for UPM to brief the PoA households on the best time to apply the digestate in order to maximise nutrient uptake by plants and thus to minimise any potential water pollution. The correct time of application has a major impact on the proportion of nutrients absorbed by plants.

On the other hand, excreta and digestate can also be a potential source of pollution with other chemical contaminants, such as heavy metals. This risk has not been sufficiently explored and needs further investigation. To date, literature on the contamination of water bodies by heavy metals sourced from excreta is not available. Future research is necessary to compare human exposure to heavy metals (1) from leaking excreta storage facilities resulting in drinking water contamination, and (2) from applying digestate, respecting different appropriate application methods, to fields and subsequent uptake by crops, leaching and runoff.

7. PoA co-benefits for soil quality

7.1 Fertilizing and soil-improving effects

To determine PoA benefits on soil quality, it is necessary to know, how animal and human excreta were disposed off before biogas digester installation. The survey gave a a clear indication of former disposal practice: All surveyed households claimed to have applied to their fields the entire amount of animal and human excreta generated in their households before digester installation. Except in two cases, all surveyed households stated that nowadays they apply all their digestate to their fields. One household does apply only a certain fraction of the solids of the digestate, and another household does not apply but buries the solid fraction in its fields. According to the PoA Monitoring Report 2015, 100% of the then interviewed 200 households applied their entire digestate to fields (UPM & Oasis, 2015).

In Sichuan, excreta are traditionally stored in permeable and open pits to avoid that they fill up too fast. Nutrients contained in excreta leach out, causing contamination of groundwater, but also nutrient enrichment in the immediately surrounding soil. However, in these places, crops could hardly access the nutrients, which are essentially removed from the local nutrient cycle. Consequently, farmers depend on synthetic fertilizer for cultivation.

Another possible way of excreta disposal is their discharge into water bodies or the public sewage system. Although none of the households participating in the field survey mentioned to have ever acted like this, it might have taken place. This, too, would mean that nutrients are not reinserted into the local soils, and crops would need to be fertilized with synthetic fertilizer. Households, which might have used any of the two aforementioned disposal routes for human and animal excreta are enabled by the PoA to substitute synthetic fertilizer by digestate. Consequently, any benefits for soil quality derive from advantages of digestate over synthetic fertilizer.

Utilization of manure and excreta as ‘fertilizer’ closes the local nutrient cycle. If a biogas digester is installed in a household, which used this disposal route earlier, the digestate replaces both manure and excreta as fertilizer. Due to the watertight storage and treatment in the biogas digester, the quantity of nutrients provided by digestate is higher than the one provided by manure. Therefore, digestate not only replaces manure but also a considerable amount of synthetic fertilizer. In this way, the PoA benefits soil quality by advantages of digestate over manure and synthetic fertilizer. This last scenario is the most common one since all households interviewed during the field survey stated that before running a biogas plant they have applied their manure to their fields

Advantages of digestate over manure

Digested manure has a higher availability of plant nutrients than undigested one, because anaerobic digestion increases the amount of NH_4-N (ADAS & SAC, 2007; Smith et al., 2014). Consequently, the application of digestate usually leads to at least 10 % higher crop yields than undigested manure (Karki and Bhimsen, 1996; A. B. Karki et al., 2005; Möller et al., 2008; de Groot & Bogdanski, 2013; Nkoa, 2014).

Using anaerobic reactor effluent instead of industrial fertilizer increased a field‘s net economic yield by 30% . What‘s more, anaerobic effluent used in mushroom production increases yields by 30%, lifts up fish production by 6-12% and reduces the cost of breeding pigs (Li K., 2006). Biogas slurry is often used to make liquid fertilizer directly to improve crop yield and quality as its rich content of nutritive elements, and the most application way of slurry is used as foliar fertilizer. The winter wheat with biogas slurry spraying can not only increase the spikelet length and grain number, the thousand-grain weight and yield, but also can inhibit diseases and insects (Wang, J., 2008).

To soak seeds with biogas slurry can increase sprouting rate significantly because of the inhibitory effects on rice root rot, sheath blight, helminthosporium sigmoideum cavara, bakanae disease, anthracnose of cotton and the leaf spot of corn. Studies have shown that compared with the control group, the wheat seeds soaking treatment with 100% original slurry which have a better rotten degree and longer fermentation time bring about many positive effects: For instance, seed germination rate increased by 13%, the seedling stage occurred three days in advance, the leaf length increased by 1.70 cm, the leaf width increased by 0.09 cm, the seedlings dry weight increased by 0.71 g, the maturity stage shortened by two days, the wheat output increased by 25.3 kg per mu, and the rate of growth is 9.20% (Liang, J., 2007).

Advantages of digestate over synthetic fertilizer

The comparison between digestate and synthetic fertilizer is topic in a broad range of studies with varying findings. In some cases, digestate leads to higher yields, while in other cases the opposite is presented (K. B. Karki, 2001; Lu et al., 2012; de Groot & Bogdanski, 2013; Nkoa, 2014; Kumar et al., 2015). These differing results are probably caused by differences in experimental design such as composition of digestate, type of soil and requirement of respective crops (de Groot & Bogdanski, 2013). Many studies recommend a combination of digestate and synthetic fertilizer as the most productive mixture (A. B. Karki et al., 2005; FAO, 2013).

Nevertheless, there seems to be a strong scientific consensus on other advantages of digestate over synthetic fertilizer. In contrast to synthetic fertilizer, manure and digestate provide both nutrients and organic matter (ADAS & SAC, 2007; Lu et al., 2012) to increase soil organic matter content (Lu et al., 2012; FAO, 2013), a factor, which is quite relevant for crop yields (Pan et al., 2009). Soil organic matter improves aeration as well as water holding capacity of soil and reduces erosion and nutrient loss by leaching (Smith et al., 2014; Li et al., 2012; Gurung, 1997; FAO, 2013). In addition, it stimulates microbial activity (Odlare et al., 2008; Kadian et al., 2008).

7.2 Contamination

Manure tends to contain several kinds of heavy metals, especially in intensive swine farming. Consequently, manure application to fields can lead to heavy metal accumulation in soils and to the entry of heavy metals in the human food chain (de Groot & Bogdanski, 2013; Bian et al., 2015). Heavy metals require special attention, because the toxic levels of some heavy metals are just above natural background levels (Al Seadi & Lukehurst, 2012).

Among the heavy metals present in manure are zinc (Zn) and copper (Cu), which mostly derive from feed additives (Li et al., 2007; Dach & Starmans, 2005). They are classed as heavy metals while being micronutrients at the same time (FNR, 2012) and thus being added especially to pig feed in order to accelerate growth. However, they mostly end up in the livestock's excreta (Li et al., 2007; Dach & Starmans, 2005). Another example is arsenic (As), which is added to pig feed to control diseases, improve weight gain and redden the pork meat, as stated by EC (2003) and Li & Chen (2005). As is banned in the EU, but is still used in China and the USA.

Anaerobic Digestion (AD) has no beneficial effect on manure's amount of heavy metals, because the total amount of heavy metals does not change during digestion (Al Seadi & Lukehurst, 2012; FNR, 2012; de Groot & Bogdanski, 2013). Only the concentration of heavy metals tends to change during the AD process because of the gasification of organic matter and the addition of water (Duan et al., 2012). Yet, there is a lack of research on potential changes in chemical form or even valency of heavy metals during AD, which could modify their toxicity considerably (EC, 2003).

To reflect soil and crop conditions under the PoA as accurately as possible, only studies on heavy metal accumulation in Chinese soils and in Chinese crops such as rice, maize and vegetables are considered in this chapter.

According to the Statistical Bureau of Sichuan (2013), the shares of major farm crops were 35% rice, 16% maize, 16% garden fruits, 11% tubers and 5% rapeseed in the year 2012. The CSES survey team found different crops in the two surveyed PoA counties: In Fucheng county farmers mostly cultivate cereals like rice, maize and wheat as well as vegetables, whereas farmers in Dongpo county grow citrus fruit trees on over 90% of their farmland and some vegetables for own consumption on the remaining land. Many farmers don't apply fertilizer to rice, neither as digestate nor as synthetic fertilizer. No studies on citrus fruits were found, but since the results for the other crops were consistent, similar results can be assumed for citrus fruits.

- Zhao et al. (2012) applied pig slurry digestate (PSD) to maize fields in Sichuan. They discovered slightly increased amounts of cadmium (Cd), chromium (Cr) and mercury (Hg) in soil and slightly increased amounts of Cd, Cr and lead (Pb) in maize grain. Nonetheless, the heavy metal concentrations were below the threshold values of the Chinese Soil Environmental Quality Standards (GB 15618-1995) and the Chinese Food Safety Standard (GB 2762-2005), respectively.
- Lu et al. (2012) applied PSD to paddy fields in Jiaxing region of China for three times during one growing season. This did not lead to a significant difference of heavy metal content in soil as well as rice grain, which is not too surprising considering the short duration of the study.
- Duan et al. (2012) applied PSD to paddy fields in the same region for two years and on fields, which had already been fertilized with pig manure or PSD for at least eight years. This allowed a comparison between heavy metal concentrations in those two different years as well as a comparison with fields never fertilized with pig manure or pig slurry digestate. They found that PSD fertilization lead to As, Cd, Cu and Zn accumulation in paddy soil and rice straw as well as to increased Cd, Cu and Zn concentrations in polished rice grain. However, all heavy metal concentrations were below Chinese standards, that is Grade II of the Chinese Soil Environmental Quality Standard (GB 15618-1995), the Chinese Feed Hygienic Standard (GB13078-2001) and the Chinese Food Safety Standards (GB2762-2005).

While these studies report heavy metal accumulation in soils and crops to be below the limits of Chinese standards, they forecast an increment until heavy metal concentration will most likely exceed the limits, because heavy metals in soil are not easy to remove. This danger is confirmed by two studies from the Taihu Basin in Jiangsu province.

- Bian et al. (2014) discovered soils with nickel (Ni), Zn, Cd and Pb concentrations above the Chinese Soil Environmental Quality Standard (GB 15618-2008). Digestate with heavy metal concentrations above the Chinese Standard for Irrigation Water Quality (GB5084-2005) had been applied to those soils for several years and the vegetables growing on it contained Cr, Ni, Zn, Cd and Pb concentrations above Chinese standards.
- Bian et al. (2015) found Zn, Pb and Cd concentrations above Grade II of the Chinese Soil Environmental Quality Standard (GB 15618-2008) in soils amended with PSD. The Zn, Pb and

Cd concentrations of rice growing on those soils as well as the Pb and Cd concentrations of vegetables growing on those soils exceeded Chinese standards.

7.3 Conclusions and recommendations

Digested manure has a higher availability of plant nutrients than undigested one, because anaerobic digestion increases the amount of NH_4-N. The waste sludge produced at the bottom of reactor can be used as fertilizer after composted in the field. Using anaerobic reactor effluent instead of industrial fertilizer increased a field‘s net economic yield by 30%. Consequently, the application of digestate usually leads to at least 10% higher crop yields than undigested manure.

The PoA also benefits soil quality by the advantages of digestate application over the replaced synthetic fertilizer: high organic matter content increases soils’ organic matter content associated with favourable effects such as improved aeration, reduced erosion, higher water retention capacity, less nutrient loss by leaching, all of these resulting in increased crop yields.

Referring to the potential contamination of soils with heavy metals such as zinc (Zn), copper (Cu) and arsenic (As), PoA households are definitely not involved in intensive agro-industrial swine farming which is associated with some heavy metal containing feed additives for pigs. In general, PoA households feed their pigs with food left overs and cereal concentrate. The content declaration on the concentrate bags analysed during the field survey did not list any ingredients with heavy metals as micronutrients.

Recommendations to UPM mainly refer to increasing the awareness among the PoA households about the advantages of providing healthy, uncontaminated feed to the pigs that prevents the accumulation of heavy metals in the soils of their farmland and bans these dangerous substances from the human food chain.

These trainings could also demonstrate how recent findings on sustainable eco-farming practices could be applied successfully to traditional small-scale farming and animal husbandry of PoA households in rural Sichuan.

8. Co-benefits for human health

The installation of household biogas plants has various positive impacts on health. As sanitation measures come along with the system installation, sanitary improvements, etc., a reduced exposure to pathogens from human and animal excreta can be expected. In addition, a considerable improvement of indoor air quality is expected to contribute to health improvements especially for women and children.

8.1 Improved indoor air quality

The effects of the PoA implementation on Indoor Air Pollution (IAP) have been described in Chapter 5.1. It has been concluded that solid fuel usage, compared to clean fuels such as biogas, leads to substantially higher concentrations of pollutants in indoor environments. The present Chapter puts its focus on impacts of IAP on health, primarily assessing the effects of coal and biogas combustion (representing the mainly used fuels before and after the installation).

According to WHO (2007), dependence on solid fuels globally poses one of the ten most important health risks; annual deaths caused by indoor smoke are estimated to amount to more than four million (WHO, 2012; WHO, 2014). In 2015, UNICEF reported that 534,000 children aged younger than five (13%) are among these deaths; the report (UNICEF, 2015) emphasizes the importance of replacing harmful solid fuels by clean technologies.

- Large-scale surveys (MEG, 2013b; Christiaensen & Heltberg, 2012; 102 and 2,700 participants respectively) result in the conclusion that a reduction of solid fuel use or switching to cleaner fuels has positive effects on foremost the respiratory health status. Because the relation between solid fuel use and its health effects is not linear, the studies confirm that mere reduction of solid fuel use has a much smaller effect than its complete substitution, as suggested by Gosens et al. (2013). Christiaensen & Heltberg (2012) divided users only by those with high solid fuel use and those using lower amounts, but not directly by fuel type. It follows that they only found slight improvements, whereas MEG (2013b) observed far greater impacts.
- Since health risks are closely related to individual exposure to pollutants, reliable results for estimating health risks can only be obtained by measuring personal exposure (Baumgartner et al., 2011; WHO, 2004). For example, women as responsible persons for cooking and their accompanying children in general experience higher exposures to indoor smoke then male household members (Ezzati & Kammen, 2001; Smith et al., 1994; Baumgartner et al., 2011). However, as concluded in Chapter 6.1, higher emissions will lead to higher exposure and thus qualitative assumptions based on emissions can be made.
- Aside from individual behaviour and room ventilation, the used fuel type influences personal exposure levels. Depending on the fuel type, the composition of emitted smoke can vary. It follows that the respective smoke components (pollutants) affect health in different ways, which has been further analysed by Kampa & Castanas (2008). According to their studies, PM, CO and SO_2 can lead to both respiratory and cardiovascular diseases. The aforementioned pollutants all arise from coal combustion and therefore are essential for assessing health risks

in this context. Besides sulphur (S), coal can contain heavy metal contaminants such as lead (Pb) and mercury (Hg) (Zhang & Smith, 2007). Heavy metals accumulate in cellular organelles and thus can inhibit their functions (Kampa & Castanas, 2008). Primarily the respiratory and nervous system can be affected that way. The other air pollutants may cause degenerative diseases (such as chronic inflammatory diseases, cataract and cancer) by acting as free radical generators.

- Zhou et al. (1995) investigated the relation of respiratory disease symptoms to the usage of different solid fuel types, namely anthracite, smoky coal (soft coal) and firewood in a survey among 10,892 people in Sichuan's neighbouring province Yunnan. Lung cancer and other respiratory diseases were already widespread in that region during the survey conduction 20 years ago. Thus, causes needed to be scrutinized. Occurrence rates of panting, coughing and sputum were examined. Indoor smoke caused by coal burning, especially soft coal, was shown to be the highest risk factor for coughing and sputum (occurrence rates of 10.0% and 6.11%, respectively, for smoky coal during a time span less than three months). The highest incidence rate accounting to more than 10% was found to be panting for all three fuel types (12.32%, 11.44%, 11.80% for wood, smoky coal and anthracite respectively). In that context, SO_2 and TSP (total suspended particulate) were assumed to be the main pollutants, exceeding WHO guidelines by far for all tested fuels with exception to SO_2 during wood combustion. Thus, a relation between solid fuel combustion and respiratory health risks was strongly indicated and investigations followed during the next decades.
- WHO (2004) evaluated a broad number of studies to establish an improved estimation method concerning effects of IAP on human health. The publication's objective already indicates the need for more standardized research to provide scientific evidence, as methodological approaches in preceding studies differ significantly. Since many studies focused on investigating health risks for women and children, strong evidence could only be found for those groups. Diseases grouped in this category comprise ALRI (acute lower respiratory infection) in young children (< 5 years) and COPD (chronic obstructive pulmonary disease) and lung cancer in women. Moderate evidence was found for COPD and lung cancer for men. Lung cancer was only shown to result from coal smoke, but not from exposure to other solid fuels' smoke.
- A major literature review by Zhang & Smith (2007) drew similar conclusions, associating lung cancer with exposure to coal smoke and several respiratory diseases with solid fuel use in general. Further diseases linked with exposure to solid fuel combustion, although to a lower extent include asthma, cataracts and tuberculosis (WHO, 2004; Zhang & Smith, 2007). Especially the combination of various kinds of pollutants found in solid fuel smoke increases health risks considerably (Kampa & Castanas, 2008).

In summary, it is evident that burning solid fuels poses a serious health risk. Especially respiratory diseases and lung cancer are of major concern. Only their complete substitution by clean energy could improve health conditions substantially. However, it has to be considered that outdoor air pollution can still exceed WHO guideline levels and can thus affect human health negatively (refer to Chapter 5.1).

94% of the interviewed PoA households decreased their solid fuel use substantially to less than once a month; considerable health benefits due to improved indoor air can be expected. These findings are in line with the 2015 CDM and GS monitoring conducted for the Sichuan Household

Biogas PoA (UPM & Oasis, 2015), in which the interviewed households reported improved health: the indicator for "frequency of illness" sank from 1.69 to 0.42 (3 = very often; 0 = never).

8.2 Sanitary situation

Wastewater as well as human and animal excreta are known to contain large amounts of pathogens (disease-transmitting biological agents) and rising amounts of chemicals and antibiotics (WHO, 2006b). Especially rural areas without proper sewage management are exposed to various pathogens. Improper storage and disposal of human and animal excreta endangers not only farm workers and their families, but also neighbours via drinking water and consumers of plants that were fertilized with these excreta. In addition, if manure is spread on the fields without further treatment, serious health risks arise, particularly if applied on food crops. Besides intestinal worms which, according to WHO (2006b), are found predominantly in rural areas, diarrhoea and other infectious diseases (such as typhoid, cholera) pose notable risks. Incidence rates of parasitic protozoa and viruses should not be neglected neither.

In this chapter, potential pathogen removal due to anaerobic digestion will be described (focusing on bacteria and parasitic worms), the situation in the investigated Sichuan Household Biogas PoA will be analysed and links to further sanitary conditions will be drawn.

Treatment of human and animal manure by anaerobic digestion is known to reduce the number of pathogens (Remais et al., 2009; Horan et al., 2004). Nevertheless, the extent of reduction is largely influenced by individual process parameters. The majority of human pathogens are mesophile (thermal optimum between 20 and 45°C, close to human body temperature), but exhibit varying characteristics concerning optimum conditions. According to Avery et al. (2014), hydraulic retention time and temperature are the two main factors influencing pathogen die-off. Increased temperatures (creating thermophilic conditions of >40°C) reduce both the retention time (due to improved conditions for methanogenic bacteria) and the time needed for a certain pathogen reduction (adverse conditions for most pathogens). Furthermore, feedstock composition, competitive microbial interactions, pH, presence / build-up of toxic materials, reactor type and stability of the process are central influencing factors (Avery et al., 2014; Smith et al., 2005).

To date, only a few studies concerning pathogen die-off in household scale biogas digesters (temperatures around 20-25°C) have been conducted. Substantially more literature is available on pathogen die-off during industrial AD processes.

- Horan et al. (2004), for example, found considerable reductions of bacterial pathogens (*E.coli, Listeria monocytogenes, Salmonella senftenberg*) at 35±3°C (mesophilic conditions) for retention times of 12-22 days.
- Smith et al. (2005) observed that *E.coli* and *Salmonella* spp. are not impaired by mesophilic temperatures but show a significant die-off under thermophilic conditions (>40°C; investigation conducted at 55°C). They conclude that in case of mesophilic conditions, pathogen die-off is not induced by temperature but rather by microbial competition and substrate limitation. This might also explain dissenting results by Horan et al. (2004), which are potentially caused by different microbial environments and substrate provisions. Therefore, although thermophilic conditions provide the most effective way to inactivate pathogens, maximized stabilization rates, minimized by-pass flow and adequate retention time can enhance die-off in case of

moderate (mesophilic) temperatures. Thus optimized, a 2-log pathogen reduction can still be achieved in mesophilic environments (Smith et al., 2005).

- A study by Remais et al. (2009) focused on the removal of ova of *Schistosoma japonica,* a parasitic worm and representative of a frequently encountered health risk (as described by WHO, 2006b). The study investigated household biogas digesters in rural Sichuan and is therefore well suited for comparisons to the PoA, both in terms of digestion process and prevalent pathogen species. Biochemical inactivation and sedimentation of pathogens in biogas digesters led to an estimated 3-log reduction of the investigated pathogens.
- In addition, treatment in a closed system such as a biogas digester reduces the number of insects and vectors, hence reduces the risk of disease transmission (van Groenendaal & Wang, 2010).

During the survey, relatively similar digester temperatures ranging between 19.1°C and 20.7°C (mesophilic conditions) were measured in PoA digesters. The underground installation of the systems contributes to constant temperatures inside the digesters. However, measurements throughout an entire year are required in order to investigate temperature stability. Hydraulic retention time as one of the central parameters is mainly influenced by pig manure input and thus by the number of pigs (human excreta contributing smaller and more stable amounts and temperatures presumed to be stable, as well). Some households informed about significantly fluctuating numbers of pigs while others maintain a constant number of animals. In case of stable pig numbers, retention time is presumed to stay at a relatively constant level. As the digester volume is bigger than the volume of the manure pits used before the project, longer retention times can be found for PoA manure treatment. In the PoA Monitoring Report by UPM & Oasis (2015) retention times of several months are stated, allowing for high pathogen die-off rates.

A drawback regarding pathogen elimination is that household biogas digesters implemented in China are always semi-continuous reactors, which risk to developing short circuit flows. These could impede pathogen die-off due to shortened retention times (Avery et al., 2014). The present PoA survey revealed that prior to biogas digester installation, manure and excreta were stored in open pits and spread on the fields when the pits were full. It is questionable whether all excreta and manure had been stored for two years before application to the fields as suggested by WHO (n.d.-c) to ensure pathogen die-off. In case manure had not been retained for two years, the AD process compared to untreated manure and excreta application has a positive effect by generally reducing the number of pathogens (Remais et al., 2009).

In order to assess possible co-benefits concerning health by means of improved sanitation, aspects as listed in Table 16 and Table 17 have to be considered.

Supported by government subsidies, sanitary conditions have been improved in the course of biogas digester installation (Table 16). Hence, barriers to pathogen sources (animal barn, manure pit, toilet) have been created. In this respect, the 2015 PoA Monitoring Report UPM & Oasis, 2015) finds that for each sampled household the sanitation conditions of toilet and pig pen have improved after project implementation. Nevertheless, observations during the field survey indicate further potential for improving toilets by modernization measures (refer to Figure 9). Albeit most alterations are beneficial to reducing exposure to pathogens and other health-damaging (chemical) sources, PoA households are still affected by unchanged disposal patterns of neighbouring households.

Table 16: Sanitary conditions before and after project implementation

Before digester installation	After digester installation
Toilets partly without roof	Toilets with new floor and roof
Soil or stone floor in the barn	Concrete floor in the barn
Sometimes the only entrance to homes passed the animal barn	Entering homes without passing the animal barn is possible
Manure is partly stored in open pits and at times directly applied to fields	Animal and human excreta are stored in a closed tank (biogas digester)
No treatment of excreta (except for retention/ storage)	Treatment of excreta by anaerobic digestion
Potential leakages during storage in pits	Tight storage during treatment in digester

Table 17: Assessment of sanitary changes

Improvement	Possible drawbacks
Improved sanitary conditions within household; less pathogens	Still affected by neighbouring households and contaminated food (WHO, 2006b)
Contributes to reduction of environmental pollution (reduced over-fertilization, less ammonia emissions) [Holm-Nielsen et al., 2009]	
Nutrient recycling → saves resources (e.g. P) [Holm-Nielsen et al., 2009]	If not composted, risk of distribution of pathogens. Also contains heavy metals and chemicals [WHO, 2006b; Holm-Nielsen, 2009]

Figure 9: Toilets of individual PoA households

Even though pathogens from unsealed pits maintained by neighbouring households might still affect soil and water quality, and contaminated food products might be consumed by PoA households, Liang et al. (2005) found in a simulation that infection intensity reduction is nearly proportional to reduction in parasitic ova. Consequently, each additional PoA participating household would contribute to overall pathogen reduction within the village, so that even a small number of PoA households contribute to improved sanitary conditions in the village.

All in all, sanitary conditions in project households improved, reducing exposure to pathogens and consequently abating the risk of disease transmission. Regarding manure treatment, benefits for health conditions are found to be depending on the prior manure management. In the rare cases of proper handling and storage in closed tank for two years, no major change would occur. However, in most cases of rural households in Sichuan province, manure is not properly stored; therefore the PoA contributes to relevant levels of pathogen removal during anaerobic digestion.

8.3 Pesticide reduction

As described in Chapter 3.3, digestate can substitute pesticides. Depending on application habits before and after biogas digester installation, notable benefits for human health can be achieved.

- Most pesticides are not only toxic to pests. A number of human diseases, such as eye infections, headaches, skin irritation, impaired liver function, kidney problems, and neurological problems could be linked to pesticide exposure (Huang et al., 2000).
- WHO (2006a) estimated approximately 17,000 annual deaths in China caused by improper pesticide applications. Farmers are directly exposed to pesticides in two ways while applying them to their fields. Both skin contact and inhalation are detrimental to health and pose a direct risk, especially if improperly sprayed (no adequate safety measures, e.g. in terms of clothing). An even larger part of the population can be affected indirectly due to contaminated food, as pesticide run-off leads to polluted water.
- Particularly organochlorine pesticides were found to accumulate in fish and thus enter the food chain (Yang et al., 2006; Z. Liu et al., 2010).
- FAO (2013) points out that pesticides could severely affect human health, and even more so in case of improper application, which is frequently reported. Hence, seafood (such as fish, shellfish) can be contaminated and thus affect consumers' health negatively (FAO, 2013). Besides, people are easily affected by the consumption of pesticide treated fruit and vegetables. Another way for pesticides to enter the environment and thereby affecting human exposure can be found in improper storage and disposal, since pesticides should always be kept sealed, stored securely and not be disposed of near wells and other water sources (FAO, 2013).
- Hu et al. (2015) discovered impacts on blood cells, liver and the peripheral nervous system.

For a more detailed assessment of the health impact of lower pesticide use for PoA households more field research is necessary at the farmers premises.

8.4 Conclusions and recommendations

Switching from solid fuels to biogas improves indoor air quality and leads to substantial benefits on health. Recent publications by WHO (2014) and UNICEF (2015) emphasize the importance of improved indoor air quality to avoid millions of premature deaths caused by exposure to indoor smoke.

As mentioned above, 94% of the interviewed PoA households reduced their use of solid fuels to less than once per month. In effect, this leads to substantially lower concentrations of incomplete combustion pollutants in the PoA household's homes and considerable health benefits due to improved indoor air quality. It can therefore be assumed that especially respiratory diseases such as asthma, cataracts and tuberculosis, as well as lung cancer will decrease significantly because of the PoA with its currently almost 400,000 participating households. Since women, as responsible persons for cooking, and their accompanying children in general experience higher exposures to indoor smoke then male household members they will experience the highest health benefit. These findings are in line with the 2015 CDM and GS monitoring conducted for the Sichuan Household Biogas PoA, in which the interviewed households reported improved health: the indicator for "frequency of illness" sank from 1.69 to 0.42 (3 = very often; 0 = never).

However, a precise quantification of the PoA's positive health effects in terms of reliable figures on avoided respiratory diseases and premature deaths because of less indoor air pollution, will require further in-depth research.

Many hygienic and sanitary amendments in the course of the PoA implementation such as the modernization of toilets and the storage of animal and human excreta in closed biogas digester tanks, as well as the treatment of excreta by anaerobic digestion further enhance the health benefits for PoA households and their local communities through verified reduction of pathogens and abatement of disease transmissions. In this respect, the 2015 PoA Monitoring Report finds that for each sampled household the sanitation conditions of toilet and pig pen have improved after project implementation.

However, it should be taken into account that not every PoA household carried through sanitary measures to the same extent. Moreover, complete pathogen removal cannot be achieved at low to medium reactor temperatures (20-25°C) in those one-step-digesters mostly in use by PoA households. But, it could be completed for such small household systems by post-composting the digestate together with garden and fruit orchard waste.

As improper handling of pesticides is still very common in China and in Sichuan, the PoA will help to bring down relevantly the number of pesticide-related human diseases such as eye inflammations, headaches, skin irritation, impaired liver function, kidney problems, and neurological symptoms in its target areas. Again, an exact quantification of these PoA-related health improvements has not been possible yet.

Although there are several large-scale scientific surveys on the health risks of indoor air pollution and the beneficial effects of a switch from solid fuels to clean energy, a more representative, precise and complete assessment of the positive PoA health impacts needs to consider the individual household behaviour and the specific room situation with and without PoA influence in sufficient cases. Such research will also have to isolate the interfering effects of outdoor air pollution that can still exceed WHO guideline levels and might affect the target group's health negatively.

UPM, Oasis and the SREO should incentivise the full implementation of sanitary measures to maximise the positive effects on the PoA household's health. They should further promote post-composting within the PoA households and involve the local agricultural extension service in the information campaign to reach as many qualifying households as possible.

A more detailed assessment of sanitary improvements and of manure storage and treatment habits before and after PoA participation could give a better estimate of the size of actual and potential benefits. This research should be complemented by new empirical studies about pathogen die-off in typical household-scale biogas digesters.

Depending on pesticide application habits before and after biogas digester installation, already achieved and potentially achievable health benefits should be further investigated in the PoA counties. Ideally such research project should make use of the local knowledge of Sichuan’s Public Agricultural Extension Service (PAES). The PAES supports small-scale farmers in particular with best-available agricultural practises and expertise, as well as with commercial sales services and has thus contributed greatly to China’s agricultural production growth since the 1980s.

9. PoA co-benefits for local economic development

Subsidies provided by the Chinese government for household biogas plants aim primarily at the economic development in rural areas (Domanski et al., 2005). In addition, potential financial benefits are a major motivation for households to install a biogas digester (Remais et al., 2009).

Economic benefits can be categorized as either direct or indirect benefits (Wang & Li, 2005). Direct economic benefits arise for example from new or additional job and income generation opportunities created by the PoA, whereas indirect economic benefits for the PoA households mainly originate from saved expenditures.

9.1 Direct economic gains

Employment and income generation for biogas technicians and construction workers

The PoA creates many opportunities for employment and income generation for local biogas technicians and construction workers and provides professional training on how to build and maintain biogas digesters.

According to SREO officials, in total approximately 10,550 permanent and temporary jobs related to digester construction and maintenance were created directly by this PoA in its Sichuan target areas. Thereof, about 2,000 people, most of them farmers and bricklayers before the PoA, have been trained as biogas technicians to build the PoA biogas plants and have been employed on a permanent basis by SREO. SREO estimates the required construction time for one PoA biogas plant to be about five working days for a technician and ten working days for an unskilled worker to support him on-site. Seven more working days are necessary, if toilet, kitchen and stable are to be renovated in conjunction with the installation of the biogas plant.

Considering that, according to UPM, from the start of this PoA by the end of 2010 until the end of 2015 about 400,000 biogas plants have been installed under the PoA with ten expert working days on average, this sums up to at least 5.4 years of paid working time for each of the 2,000 trained biogas technicians, alone. With around 500 CNY paid to them per digester, their aggregated income since this PoA was launched amounts to 200 million CNY. This represents a relevant financial input in the local economy, even if unskilled labour would be provided by the PoA households during construction to save costs, and even more so, as the maintenance of operating biogas digesters has not been taken into account yet.

The PoA's 2015 Monitoring Report provides further evidence by finding that all biogas technicians employed for digester construction have received due payment.

Substitution of traditional fuel

The replacement of traditional fuels by biogas represents an obvious monetary gain caused by the biogas digester. Substitution of commercial fuels such as coal brings about a greater or rather more direct benefit than replacing biomass such as collected fuel wood or harvest residues.

Available studies mostly analysed cases of fuel wood substitution rather than coal replacement (e.g. Wang et al., 2007; IDCOL, 2011). However, two Chinese studies analysing replacement of mostly coal both report coal reductions of more than 60% (Remais et al., 2009; van Groenendaal &

Wang, 2010). During a survey among 142 households in Sichuan, Van Groenendaal & Wang (2010) noted cost savings of 141 CNY/y or 63.8% (221 CNY/y spent by non-users compared to 80 CNY/y by biogas users).

The present PoA survey results confirm the 2015 PoA Monitoring Report (UPM & Oasis, 2015) stating a decrease in coal expenditures. Even if exceptionally high saving amounts were excluded, the survey still reveals monthly savings of 70.1±40.0 CNY (arithmetic mean) or 50.3 CNY (median). Thus, annual savings of 841.2 or 603.6 CNY respectively were calculated based on the answers of the surveyed households. These results imply considerable economic benefits, although they deviate substantially from earlier studies (for example by van Groenendaal & Wang, 2010). Future investigations should take into account external factors such as fluctuating coal prices, and varying amounts of fuel required in correlation to local annual weather conditions (strong winter, etc.), as well as purposes of biogas and coal utilization for either cooking or heating.

Substitution of electricity and natural gas as cooking fuel

Besides replacing traditional solid fuels, biogas can partly be used instead of electricity mainly for rice cookers, and natural gas for cooking.

An electrical rice cooker of 500-900 W has a monthly energy consumption of 30.5-54.9 kWh, if calculated for an estimated daily use during 2h and 30.5 days per month on average. Considering current electricity prices ranging between 0.4624 and 0.6224 CNY/kWh (955sd.com, 2015), potential savings between 14.10 and 34.17 CNY/month (≙ 169.20-410.04 CNY/year) could thus be achieved if replaced by biogas, as displayed in Table 18.

The PoA's 2015 Monitoring Report (UPM & Oasis, 2015) supports these projections on electricity replacement as all sampled households stated that their consumption of electricity is now lower than without a biogas digester.

The recent introduction of natural gas as clean cooking energy in some villages in the PoA region will further support the positive impacts of biogas on the environment and indoor air. PoA households connected to the natural gas grid in Meishan (Fucheng county) explained that biogas helped them to get acquainted with using gas as cooking fuel. Housewives told the study team that they would continue to use 'their' biogas, and only in case biogas would not be enough for cooking they would switch to temporarily use natural gas, which they have to pay for. Biogas has been a 'door-opener' for natural gas; but while biogas is a low- to no-cost fuel for most of the PoA households, natural gas consumption must be paid for and thus is only the second-best option.

Table 18: Monthly potential savings depending on type of rice cooker and electricity consumption rate [CNY]

		Rice cooker	
		Low (500 W)	**High (900 W)**
Electricity consumption	**Low (<60 kWh/month)**	14.10 CNY	25.39 CNY
	High (>150 kWh/month)	18.98 CNY	34.17 CNY

*Calculation: $P_{rice\ cooker}$*t_{usage}*costs; P: electric power [kW]; t: time of usage [h/month]; costs in [CNY/kWh]

Additional income from sales of the PoA's carbon credits

UPM and Oasis share a considerable portion of their annual PoA carbon credit sales revenues with the PoA households as an additional incentive for biogas technology investments, and with the SREO for the provision of free digester maintenance services by trained SREO experts. Although major volumes of the PoA's issued GS CERs could be sold successfully to public or private sector carbon offsetters, emissions trading revenues have been lower than expected due to fallen carbon credit prices both in mandatory and voluntary carbon markets. This means that, so far, the extra household income generated by carbon finance is only minor. However, this source of income should not be neglected as it might become much more important as soon as the carbon markets recover to healthy price levels. In this context, it is to be expected that the historic Paris Agreement on climate change mitigation and adaptation, which has been adopted by all UNFCCC member states in December 2015, will revitalize the world's carbon markets as from 2020 onwards.

Income from digestate sale

Two studies carried out in Bangladesh assessed potential gains from sales of the digestate (IDCOL, 2011; de Groot & Bogdanski, 2013). According to de Groot & Bogdanski (2013), 10 USD can be earned per tonne of digestate. However, during the field survey the majority of the PoA households (89%) reported to apply all of their digestate to their own fields. No household declared to sell any digestate.

If the production of high-quality digestate could be increased further and the PoA farmers were more aware of the potentially achievable income from digestate sales, those amounts not needed by the households for their own purposes could be sold to create an additional income which is directly related to the introduction of biogas digesters. The establishment of such new digestate markets could eventually be supported by the SREO and relevant agricultural authorities in Sichuan with complementary information and promotion activities.

9.2 Indirect economic gains

Expenditure savings from the substitution of synthetic fertilizer

Since synthetic fertilizers require a lot of energy for production, their prices vary and increase with the prices for fossil fuels. In addition, phosphate rock is becoming scarcer and thereby more expensive (de Groot & Bogdanski, 2013). Consequently, prices for synthetic fertilizers are constantly increasing, and are predicted to continue doing so over the years (Basak, n.d.).

As digestate is known to contain favourable fertilizing properties, monetary benefits can arise from substitution of synthetic fertilizer and were confirmed to varying extents in several studies. IDCOL (2011) recorded considerable annual savings of 5,467 Bangladesh Taka (BDT) for 4.8 m^3 digesters in Bangladesh, equalling approximately 480 CNY (2011 exchange rate; fx-rate.net, 2015).

Surveys conducted in China present diverse findings, with annual savings ranging between 35.87 CNY (in 2003, Wang et al., 2007) and 285 CNY (Gosens et al., 2013). One study even encountered households spending more on fertilizer if in possession of a biogas digester, which was attributed to a lacking awareness of the digestate's fertilizing properties (van Groenendaal & Wang, 2010).

In the present survey, PoA participants stated to use less synthetic fertilizer than before, accounting to a saved amount of 251±113 kg/year on average. Containing an average 20% N and 13% P_2O_5, approximate fertilizer values can be calculated using data by FAO (2013) that suggest prices of 4 CNY/kg for N and 4.5 CNY/kg for P_2O_5. Using these numbers, monetary savings per household accounted to 348±156 CNY/year. The calculation formula applied is:

∑ Saved fertilizer amount [kg/year] * nutrient costs [CNY/kg] * percentage of nutrient

Resulting in:

251 kg/a * 4 CNY/kg * 0.2 + 251 kg/a * 4.5 CNY/kg * 0.13 = 347.64 CNY/a (likewise for standard deviation)

Compared to literature findings, the calculated cost savings appear reasonable.

Substitution of pesticides

Besides serving as fertilizer, digestate can also replace pesticides, as described in Chapter 8.3. Minor savings of 12 to 81 CNY/year are mentioned in relevant studies (Wang et al., 2007; Gosens et al., 2013). For PoA households, no significant savings due to reduced pesticide use were identified.

Reduction of medical expenses

Since the digester installation has positive effects on the household's health as described in Chapter 8, **medical expenses** are assumed to decrease.

Based on interviews with 2,700 households, Christiaensen & Heltberg (2012), concluded that households using less solid fuels consistently showed lower rates of disease (decrease by 5-8%). In addition, presumably they exhibited a less serious degree of illness, as the doctor was visited in fewer cases (23.7% compared to 35.9%) and expenses per visit were considerably lower (432 instead of 614 CNY).

Decreased medical costs are also presented by Wang et al. (2007), but at a much lower level: biogas households in Jiangsu and Anhui province saved annually 13.4 and 41.1 CNY, respectively.

In contrast, a study among more than 1,000 biogas households in the four Chinese provinces Gansu, Guangxi, Hubei and Shandong did not find a significant reduction for medical costs (Gosens et al., 2013).

These differing results reinforce the impression that in order to find reliable results concerning impacts on health and thereby medical expenses, long-term studies over at least ten years are necessary, as concluded by van Groenendaal & Wang (2010).

As mentioned above, in the 2015 CDM and GS PoA Report (UPM & Oasis, 2015), the representative sample of interviewed PoA households revealed that, after biogas digester installation, the frequency of suffered diseases such as cough, headache and eye infection dropped remarkably. Since the digester installation obviously has distinct positive effects on the PoA household's health, their medical expenses are assumed to decrease considerably, especially in the long run. However, the field survey undertaken for this study has not yet been able to substantiate or measure these cost savings with sufficient reliability and precision.

9.3 Economic gains from alternative use of saved time

The PoA can also benefit local economic development by reducing the time people need to spend on cooking and collecting firewood. This time can be used for income generating activities or for education, which ultimately leads to economic development as well.

Reduction of cooking time

Many surveys inquired the reduction of cooking time after the installation of a biogas stove. A survey among 610 households in five South Eastern provinces of China revealed that 98% of them save time for cooking, namely 1.7 hours per day. However, women stated that they save about 1.2 hours (Christiaensen & Heltberg, 2012). In contrast, a study conducted in Sichuan among 142 households (127 of which possessed a biogas digester) showed savings of merely 20 minutes per day (van Groenendaal & Wang, 2010).

Ghimire (2005) reported a cooking time reduction of 40 minutes per day on average after having interviewed 66 biogas households in Bangladesh. According to another survey among 300 households in Bangladesh, biogas users spend 3.8 instead of 4.7 hours per day on cooking, which corresponds to 0.9 hours (54 minutes) saved. In addition, women reported that cooking with biogas instead of firewood needs less attention, so they actually saved even more time by not staying in the kitchen during the entire cooking time (IDCOL, 2011).

In 102 biogas households in Nepal, women save 35 minutes per day for cooking on average. Women also save 20 minutes for washing dishes, because there is less soot attached to them. Rana et al. (2014) interviewed 150 Nepalese households: 49% of them stated that they save 1.5 – 2 hours per day for cooking and 80% of them stated that they even save an additional 0.5 – 1 hour per day for washing cooking utensils.

Study findings in Bangladesh and Nepal have to be considered under gender specific aspects, as male researchers in both countries usually interview mainly male biogas users, who due to clear gender roles are not responsible for cooking and cleaning. In addition, different studies showing highly varying results on saved cooking time indicate that statements on reduced cooking time depend largely on cooking patterns, different food preparation methods, and personal and gender specific perceptions.

The CSES field survey results in a median time reduction for cooking of 1.5 hours per day. The median seems more reliable in this case than the average of 1.9 hours with a standard deviation of 1.1 hours, because of three very high estimations of up to 4.5 hours saved. This is not very different from Christiaensen & Heltberg (2012) findings for Chinese biogas programs. Since the result of Christiaensen & Heltberg (2012) is higher than that of most of the other aforementioned studies, the reduction of cooking time in PoA households can be assumed as 1.7 hours per day and household, which were reported by them.

Reduction of time for firewood collection

Time savings due to decreased need of firewood collection are another benefit created on account of biogas digester installation. Most studies found time savings of less than one hour per day, accounting to roughly two days per month (Christiaensen & Heltberg, 2012; IDCOL, 2011; MEG, 2013b). These studies covered households, which replaced mainly firewood and agricultural residues by biogas (>88%, except for Christiaensen & Heltberg, 2012). A survey among 239 households in the Chinese provinces Gansu and Sichuan could not prove statistically significant time savings regarding firewood collection. Nevertheless, biogas users spent on average 16.9

days/year (≙ 1.4 days/ month) less than non-users in a village primarily relying on wood as fuel. Savings in primarily coal burning areas were much smaller, only 3.2 days/year in Hua Niu in Sichuan (van Groenendaal & Wang, 2010). Consequently, there are only slight time savings on account of reduced firewood collection and these are even less relevant in areas where coal is the primary cooking fuel.

According to the PoA's baseline survey (SREO, 2012), the latest PoA monitoring report (UPM & Oasis, 2015) and a recent SREO report on the situation of energy usage in the countryside of Sichuan (SREO, 2015), households in rural Sichuan traditionally rely on coal for cooking. The time spent on firewood collection is therefore low and decreases only by a small amount after the installation of a biogas stove. The field survey confirmed this, as only 7 out of 18 households felt that they spent less time on wood collection since the installation of their biogas digester. Three of them responded that they saved on average 18 minutes per day, while the other four saved even too little time to quantify it.

Use of saved time

In order to enhance local economic development by the means of time savings, surplus time should be used for income generating activities. In a survey among biogas users in Bangladesh, the time saved after digester installation by less time for cooking and firewood collection was spent on the following purposes: 38% for income generation, 20% for recreation, and 18% for education (IDCOL, 2011).

According to Christiaensen & Heltberg (2012), three quarters of the survey participants reported to use their additional time for other household chores and for income generation; only the remaining 25% used it for leisure. Similar results are given by MEG (2013b) with a majority of saved time being used in financially favourable ways such as agricultural, social and household work or direct income generating activities.

Our observations in Sichuan biogas villages confirm that time saved during fuel collection or cooking is not necessarily used for direct income generation, but for improved living conditions such as cleaning the house, handicraft production, and social life (more time with the family).

9.4 Conclusions and recommendations

Literature consistently reveals positive effects of biogas programmes for household income. These indications are substantiated by this study.

To summarize the findings on the PoA's economic co-benefits, this study rated the most important PoA effects on local economic development and income generation by classifying them into three groups of potential economic impact. For an assumed average annual household income in rural Sichuan of about 6,000 CNY (Remais et al., 2009) the rating "major potential" was chosen starting from possible monetary savings or income increases of more than 5% thereof (300 CNY). The category "minor potential" was selected below this share of income or if available quantitative data are weak and a direct monetary assessment is difficult. The third category "no noticeable potential" is applied for factors without measurable influence or even negative economic effects.

However it should be considered that the average annual income of rural households in the cited study varied largely between 1,500 and 7,500 CNY. A study conducted in provinces other than Sichuan even described a span of average annual incomes from 10,000 CNY to 24,000 CNY (Gosens et al., 2013).

Table 19 displays the PoA's economic potential as elaborated in detail above. New biogas technician jobs due to the PoA, as well as reduced fuel and fertilizer costs appeared to be the most promising income generating and expense saving opportunities. Some other aspects (reduced medical costs, additional carbon credit income, saved cooking time) were categorized as having "minor potential" (+), because available quantitative data are weak and a direct monetary assessment is difficult among farmers.

Table 19: Overview and rating of the Sichuan Household Biogas PoA's economic potential

Economic PoA Potential	Rating
Jobs and income for biogas technicians	++
Reduced fuel costs	++
Reduced fertilizer costs	++
Saved electricity and natural gas costs	+
Additional income from carbon credit sales	+
Saved digester maintenance costs	+
Reduced health/medical costs	+
Saved cooking time	+
Reduced pesticide costs	+
Saved time for firewood collection	/
Sales of surplus digestate	/

++ = major potential (>300 RMB/year); + = minor potential (<300 RMB/year); / = no noticeable potential; (- = negative effect)

During our on-site inquiry, all surveyed PoA households perceived improved financial conditions, mainly from reduced or even eliminated fuel and fertilizer costs and additional income through sales of PoA carbon credits.

Consequently, it can be assumed that economic benefits of PoA households are higher than in other international biogas programs. In Bangladesh, only 66% of biogas households count with better finances (IDCOL, 2011) and economic impacts turned out to be smaller than expected (van Groenendaal & Wang, 2010; Gosens et al., 2013; Sinton et al., 2004). Reasons for smaller effects were for example lacking awareness of the fertilizing effects of digestate (van Groenendaal & Wang, 2010) or a replacement of non-commercial fuels such as free firewood (Gosens et al., 2013).

Future investigations on expenditure savings for energy supply should take into account external factors such as fluctuating coal prices, and varying amounts of fuel required in correlation to local annual weather conditions (strong winter, etc.), as well as purposes of biogas and coal utilization for either cooking or heating.

If the production of high-quality digestate could still be increased further and the PoA farmers also were more aware of the potentially achievable income from digestate sales, those amounts not needed by the households for their own purposes could be sold to create an additional income which would be directly related to the introduction of biogas digesters. The establishment of such new digestate markets could eventually be supported by the SREO and relevant agricultural authorities in Sichuan, such as the PAES, with complementary information and promotion activities.

The results of this study suggest that the PoA households could eventually increase expenditure savings beyond current levels if they replace even more synthetic fertilizers by their own digestate. UPM, Oasis and the SREO should highlight this potential economic co-benefit in their PoA information campaigns. To which extent the use of the organic fertilizer will reduce the application of pesticide and the corresponding costs has to be evaluated by further research.

The wide range of estimates by available scientific studies on the potential monetary value of medical expenditure savings due to the introduction of household biogas, reinforce the impression that in order to find reliable results concerning the PoA's impacts on health and thereby medical expenses, long-term studies over at least ten years are necessary.

UPM, Oasis and the SREO should use these findings on the large economic co-benefits of biogas digesters and cook stoves to popularize state-of-the art household biogas technology in even greater numbers because the potential for the introduction and dissemination of such technology in Sichuan is far from being fully exploited.

10. PoA co-benefits for energy self-reliance

This chapter deals with the PoA's influence on how much of their energy needs households could produce by themselves. Two important means of increasing energy self-reliance are energy efficiency and producing renewable energy on-site (Firestine et al., 2007). While producing renewable energy obviously includes self-produced biogas used for cooking, burning biomass like firewood or crop residues is often forgotten as a means of energy self-reliance.

Evidence available about the PoA reveals that the installed biogas digesters are mostly fed with excreta of humans and livestock produced on-site. They are a prime example for improving energy self-reliance. The produced biogas is only used for cooking, which means it can only replace fuels serving that purpose. As described in Chapter 3.2, the program mainly leads to a reduction of coal use. According to the PoA Monitoring Report 2015, the annual coal consumption per household dropped from 970 kg to 27 kg after the digester installation (UPM & Oasis, 2015). The households also tend to use some firewood and crop residues like straw for cooking and told the survey team to use less since participating in the PoA (UPM & Oasis, 2015). During the recent CSES field survey, electric rice cookers were noticed in some households, but at the same time the survey conducted for the PoA Monitoring Report 2015 found a decrease of electricity use (UPM & Oasis, 2015). It can be concluded that the PoA increased energy self-reliance, as large amounts of coal and possibly also some electricity are substituted by biogas. As mentioned above, firewood and crop residues are sources of renewable energy, so replacing them with another renewable energy has no direct effect on energy self-reliance.

To assess the impact of the PoA on energy self-reliance, it is useful to estimate the percentage of a household's energy consumption for cooking, as this is the maximum percentage that can be converted from coal and electricity to biogas use. The field survey findings already indicated a high proportion of energy used for cooking, because the majority of the interviewed households do not heat their homes, which leaves mainly lighting, cooking and water boiling as purposes for energy use (Wang & Li, 2005; Wang et al., 2007).

According to Wang et al. (2007), biogas-using families in Jiangsu province spent on average 62% of their energy on cooking and 10% on boiling water, while biogas-using families from Anhui province spent 79% of their energy on cooking and 3% on boiling water. These results are consistent with interviews by Wang & Li (2005), which revealed that other biogas-using families in Jiangsu province used 60% of their energy for cooking and 11% for boiling water. Those percentages were calculated using the total supplied energy and not the effective energy.

While effective energy consumption for cooking means the fraction of fuel energy going into the cooking device (e.g. pot) (Smith et al., 2000), the supplied energy consumed for cooking covers the energy contained in primary energy like coal and biomass and in secondary energy like electricity. Since burning biogas is about 2-3 times more efficient than burning firewood, and even about 3-6 times more efficient than burning crop residues (Smith et al., 2000), its share, and therefore the share of cooking within the overall energy consumption, appears considerably smaller when supplied energy is examined than when effective energy is examined. For this reason, the percentage of effective energy spent on cooking and boiling water can be assumed as being even larger than the abovementioned percentages, if no room heating happens, as was the case in the studies of Wang et al. (2007) and Wang & Li (2005).

Therefore, it cannot be concluded that the portion of energy consumption provided by biogas instead of coal or electricity exactly corresponds to the PoA induced benefit on energy self-reliance. Gosens et al. (2013) elaborate on this relation:

> *[…] studies typically assume that (1) biogas will not add to the household energy balance, but replaces an equal amount of useful energy as previously supplied by other fuel types, and (2) that it will be coal and/or traditional biomass that are replaced ([…]). This assumption is often not sustained by empirical data, and is likely to be overly optimistic, for two reasons. First, the rural poor not only desire better quality fuels but also higher consumption levels of energy ([…]). Second, low income households continue to have a strong incentive to minimize fuel expense and reduce the consumption of costlier, high quality fuels rather than that of less costly low quality fuels (Smith et al., 1994).*

10.1 Energy Ladder

It needs to be analysed to which degree the two reasons mentioned by Gosens et al. (2013) address and limit the PoA intended benefit on energy self-reliance.

1) Researchers witnessed that households don't replace all fuels they could replace with biogas, but instead used biogas additionally in order to increase their energy consumption (e.g. Hiemstra-van der Horst & Hovorka, 2008). Gosens et al. (2013) supported this statement only with studies from regions where biogas replaced mainly biomass and not coal; hence, the statement might not be applicable to the situation in PoA households.

Wang et al. (2007) reported results contrary to an increase of energy consumption after interviewing 356 households in Jiangsu province and 340 households in Anhui province. Biogas households consumed 101.5% and 96.5% of the effective energy consumed by those without digesters in Jiangsu and Anhui province, respectively. No increase in effective energy consumption due to the installation of a digester and eventual suppressed demand was detected.

At the same time, the ratio of supplied energy consumed by households with digesters over the supplied energy consumed by households without digesters was 58,9% (5578.2 $MJ \times a^{-1} \times capita^{-1}$ / 9467.7 $MJ \times a^{-1} \times capita^{-1}$) in Jiangsu province and 58,7% (6469.3 $MJ \times a^{-1} \times capita^{-1}$ / 11018.8 $MJ \times a^{-1} \times capita^{-1}$) in Anhui province. The difference between the ratios for effective energy and for supplied energy resulted from the high heat value of biogas and the low efficiency of cooking with firewood, stalk and straw, which were the fuels mainly replaced by biogas (Wang et al., 2007). Thus, Wang et al. (2007) found no change in effective energy use but a big reduction of supplied energy use.

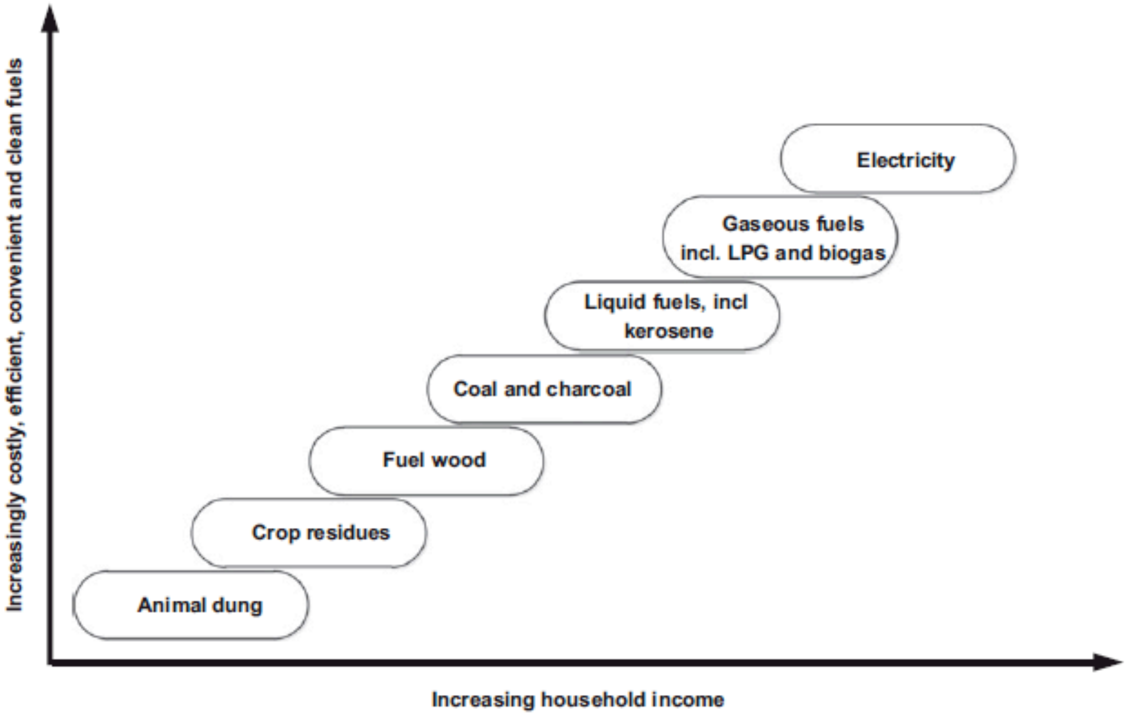
Wang & Li (2005) already encountered a similar situation, when interviewing 312 households in Jiangsu province. Biogas users consumed 101.5% of the effective energy and only 74.7% of the supplied energy consumed by households without biogas plants.

Wang et al. (2007) as well as Wang & Li (2005) conducted their surveys in regions of China where biogas mainly substituted biomass and not coal, so their findings might again not be applicable to the circumstances in the PoA area.

2) Gosens et al. (2013) mention that poor households tend to replace costly fuels instead of cheap traditional fuels. According to the "energy ladder" in Figure 10, costly fuels include electricity, kerosene and gaseous fuels like LPG and natural gas. The energy ladder illustrates further that with growing affluence, households prefer more expensive fuels, because these fuels are cleaner

and more convenient. Gosens et al. (2013) point out that biogas households might share these preferences but still be so poor that they favour cost-saving over comfortable fuels and thus substitute also electricity and LPG by biogas instead of only biomass and coal. Observation in the PoA area confirms that biogas producing households prefer to use their own biogas before paying for LPG or natural gas. For lighting and in some cases for pressure-cooking, electricity is the preferred energy form.

Figure 10: The energy ladder



Source: Gosens et al., 2013

LPG can be used for cooking and therefore be exchanged with biogas by PoA households. Table 20 displays results of several surveys, which all discovered considerably less LPG consumption by Chinese households with biogas digesters than without. Even though differences in fuel consumption levels between biogas users and non-users are not necessarily only due to the use of biogas, e.g. increased income can lead to use of fuels that rank higher on the energy ladder, and education promotes the use of cleaner fuels, this uniform tendency indicates a correlation between biogas use and reduced LPG use. Considering biogas as being almost the perfect substitute for LPG (Gosens et al., 2013), some households probably replace LPG with biogas. Except for the villages surveyed in Guanxi and Hubei province, LPG made up less than 5% of the energy available to rural households without biogas digesters, so its potential substitution is generally insignificant.

No PoA household interviewed during the CSES field survey mentioned to use currently or in former days kerosene, so it is excluded from the analysis of changes in energy consumption.

Similarly, no surveyed PoA household stated to use LPG for cooking, neither currently nor before biogas digester installation; however, its use as cooking energy could not be left out from the present analysis, as LPG is available in the PoA area. A natural gas grid had recently been installed in one of the PoA villages, and while several households started using natural gas in addition to biogas, they expressed a strong preference for biogas for the reason of it being much cheaper than natural gas now that their biogas digesters are already operating.

Table 20: Differences in annual LPG consumption per household between households without and with biogas digesters in kgce

County (Chinese Province)	Number of interviewed households	LPG consumption by households without digester [kgce]	LPG consumption by households with digester [kgce]	Difference in LPG consumption
Guichi [b] **(Anhui)**	340	13.08	8.91	- 32%
(Gansu) [a]	127 without, 150 with digester	4.1	1.7	- 60%
(Guangxi) [a]	69 without, 183 with digester	166.2	12.6	- 92%
(Hubei) [a]	53 without, 195 with digester	15.7	4.4	- 73%
Lianshui [c] **(Jiangsu)**	312	6.99	5.83	- 16%
Lianshui [b] **(Jiangsu)**	356	5.29	1.48	- 63%
(Shandong) [a]	84 without, 204 with digester	70.3	16.0	- 77%

[a] Data from Gosens et al. (2013), conversion of 1 GJ into 34.1208 kgce as stated by www.extraconversion.com/energy; [b] Data from Wang et al. (2007); [c] Data from Wang & Li (2005)

All visited PoA households use electricity for lighting and some of them also had electric rice cookers, air-conditioning or electric heaters. This is partly consistent with Wang et al. (2007) and Wang & Li (2005), whose studies in the provinces Anhui and Jiangsu do not mention air-conditioning or heating but describe electricity use mainly for lighting and to a certain degree for cooking, too. In fact, almost all villages in rural China have access to electricity (van Groenendaal & Wang, 2010).

Some households interviewed during the field survey used biogas for cooking rice and - as secondary effect - for room heating; participation in the PoA enables households to use biogas instead of electricity for rice cooking, too.

The compilation of findings from several surveys in Table 21 presents clear differences in electricity consumption between Chinese biogas users and non-users; this does not allow a comprehensive conclusion whether electricity is partly replaced with biogas or not. The only survey conducted in Sichuan about the replacement of electricity by biogas documented higher electricity consumption by biogas users than non-users. This confirms that only in few cases (rice cookers) biogas substitutes electricity, due to the fact that both forms of energy complement each other for the well-being of the household. On the other hand, the PoA's most recent monitoring report (UPM

& Oasis, 2015) provided statistically representative evidence not only for a reduction of coal and firewood by households equipped with biogas digesters but also for less electricity consumption.

Table 21: Differences in annual electricity consumption per household in kgce between households without and with biogas digesters

Village or County (Chinese Province)	Number of interviewed households	Electricity consumption by households without digester [kgce]	Electricity consumption by households with digester [kgce]	Difference in electricity consumption
Guichi [b] **(Anhui)**	340	46.6	35.6	- 23%
Dong Yuan [a] **(Gansu)**	14 without, 27 with digester	79.6	80.0	+ 0.5%
Xia Ping [a] **(Gansu)**	27 without, 29 with digester	125.8	141.5	+ 12%
(Gansu) [d]	127 without, 150 with digester	68.5	75.2	+ 10%
(Guangxi) [d]	69 without, 183 with digester	188.3	170.4	- 10%
(Hubei) [d]	53 without, 195 with digester	70.4	68.8	- 2%
Lianshui [c] **(Jiangsu)**	312	13.1	10.4	- 21%
Lianshui [b] **(Jiangsu)**	356	31.2	36.2	+ 16%
(Shandong) [d]	84 without, 204 with digester	52.8	36.1	- 32%
Hua Niu [a] **(Sichuan)**	15 without, 127 with digester	91.7	122.7	+ 34%

[a] Data from van Groenendaal & Wang (2010); [b] Data from Wang et al. (2007); [c] Data from Wang & Li (2005); [d] Data from Gosens et al. (2013)

10.2 Conclusions and recommendations

Higher electricity consumption by biogas users does not prove that they consume more effective energy than non-users, as is verified by comparison of the results for Lianshui county by Wang et al. (2007) and Wang & Li (2005).

Households participating in the PoA replace coal, firewood and crop residues by biogas as their own generated energy carrier. As has been shown above, the PoA’s third CDM and GS monitoring results proved for a representative amount of inquired households that their consumption of coal, firewood and electricity, as a percentage share of total energy requirements, decreased significantly.

This does not necessarily mean that biogas now covers the same percentage of PoA households' energy consumption as was provided by the replaced fuels, because there might be a potential increase in the overall effective energy consumption due to previously suppressed demand and possible substitution of non-traditional fuels such as LPG (Liquefied Petroleum Gas), natural gas and electricity. However, the PoA's monitoring report and accessible Chinese scientific studies evaluated for this report do not confirm an increase in overall effective energy consumption in biogas households. And although LPG is now available in the PoA area as well, the interviewed households expressed a strong preference for their own biogas as it is much cheaper than natural gas now that their biogas digesters are already operating. The high level of biogas acceptance might also be due to the fact that all of the monitored households have received the required training on proper handling of biogas digesters and cook stoves. Therefore, their use of renewable biogas is not expected to decline notably in the future.

The verified strong increase of energy self-reliance due to the availability of clean, convenient and inexpensive biogas out of own production is a very important PoA co-benefit which is highly appreciated by the participating farmer households. This fact could support UPM, Oasis and the SREO to market the biogas digesters also to other needy rural households in Sichuan, eventually not yet convinced of the PoA.

11. PoA co-benefits for gender equality and women empowerment

11.1 Promoting gender equality and women empowerment

This chapter is dedicated to the PoA's benefits on gender equality and women empowerment as one of the eight Millennium Development Goals of the United Nations (UN, 2001) that also has been included in the successor catalogue of 17 UN Sustainable Development Goals rolled out in September 2015 (UN, 2015). Besides economic profits from which the entire household benefits, a number of the previously described benefits especially improve working and living conditions of female household members.

More than 85% of surveyed biogas users in both Bangladesh and Vietnam reported that women profited most from the digester installation (Nguyen, 2011; IDCOL, 2011). As female household members are responsible for cooking and other household chores, such as for gathering fuel wood, many positive impacts of a biogas system affect them more directly than male household members (Gosens et al., 2013). Main issues are sanitary and health improvements, and time savings. Linkages to women's dignity, self-esteem and their involvement in decision-making and in PoA implementation were therefore investigated.

Many investigations (e.g. WHO, 2004; Begum et al., 2009) prove that women and children are exposed to high health risks through indoor air pollution due to the use of solid fuels for cooking. This is based on the fact that women spend more time inside the kitchen, as they are in general responsible for preparing food. Younger children spend most of their time close to their mothers and thus are equally affected by indoor air pollution. However, a study assessing exposure of gender and age categories did not find substantial evidence of elevated risks for women and children (Staff Mestl et al., 2006): since men spend more time in the living area heated by solid fuels, exposure levels turned out to be balanced. Yet, if no heating by means of solid fuels occurs, higher exposure of women and children prior to the digester installation can be expected, as shown by Ezzati & Kammen (2001). Personal exposure levels of the different genders therefore mainly depend on individual, although socially determined behaviour patterns.

In 94% of the surveyed PoA households no room heating with solid fuel is practiced; hence, women have probably experienced higher exposure to indoor air pollution than men and therefore benefit more from solid fuel substitution through biogas.

Being commonly responsible for cooking, women can save more time than male household members after the installation of the biogas digester (e.g. Christiaensen & Heltberg, 2012; MEG, 2013b; Gosens et al., 2013), like already shown in Chapter 9 (economic development). However, since most PoA households did not actively collect firewood but burnt coal, time savings from unnecessary wood collection are negligible. Thus, women's workload is reduced regarding the time spent for cooking and cleaning dishes. It is even not increased by their responsibility to clean the animal shed and feed the biogas digester, as these have been their responsibilities before. Moreover, the digester is placed deep in the ground and can be fed using gravity, whereas many ground-level manure pits had to be filled with buckets.

Warnars & Oppenoorth (2014) suggest that the above-mentioned benefits on health and workload (cooking time) and improved cleanliness due to decreased soot and cleaner air enhance women's self-esteem and dignity. They further conclude that biogas installations can foster the involvement of women and other disadvantaged groups' in local decision-making.

In contrast, surveys from Vietnam and Bangladesh showed that in most cases (85.5%, Nguyen, 2011), male heads of households decided alone on the digester installation and also surpassed women's knowledge concerning management and maintenance of the plant (IDCOL, 2011). IDCOL (2011) therefore argues that gender-based power structures cannot be altered by one single intervention. In this context it should be kept in mind that gender based roles and decision power in Bangladesh and Vietnam differ significantly from those in rural China.

11.2 Conclusions and recommendations

On-site visits in the PoA area confirm that women should be actively involved in energy programmes as they are the major energy users in a rural household, e.g. fuel use during cooking (IRADe & ENERGIA, 2009).

Because of traditional socially determined behaviour patterns, women in Sichuan rural households are almost solely responsible for cooking and collecting firewood. Hence, women and their young children have experienced a higher exposure to indoor air pollution than men and therefore benefit more from solid fuel substitution through biogas. The modern and easy-to-use biogas stoves do also significantly reduce their workload and time for cooking, whereas their time savings for firewood collection remain negligible.

According to SREO figures, up to 10 % of all jobs created by the PoA in conjunction with the introduction and dissemination of biogas digesters and cook stoves (construction, maintenance and trainings) have been occupied by women. This shows that there is still much room for improvement of this PoA's performance with respect to gender equality and women empowerment related to income generation and decision-making in Sichuan rural households and local communities.

Although the PoA already focuses much of its biogas information and promotion campaign on women as the major biogas users in Sichuan rural households, the SREO should further strengthen its efforts to convince especially those women not yet reached by the programme of the specific PoA advantages for female family members, such as the improvement of indoor air quality, time savings and monetary advantages. Only if these women really understand and support the programme, it can be conducted and scaled up as intended and will be able to fully meet the national and provincial government's targets for rural biogas promotion and climate protection the PoA shall help to achieve. Otherwise, many women in remote Sichuan counties may continue using traditional fuels and the PoA's enormous potential co-benefits will not be made accessible to as many low-income Sichuan rural households as possible.

It is also recommended that women are better included in job creation, for example in trainings for biogas technicians, as up to now, mostly male technicians have been employed within the framework of this PoA.

12. New PoA co-benefit: Improvement of animal welfare

While conducting the PoA survey, animal welfare emerged as a topic closely related to biogas projects. Animal welfare is the physical and physiological state of an animal. The manner in which animals are treated has significant consequences on their well-being, but also on environmental sustainability, food security and the economic conditions of farmers (HSI, n.d.).

The “Animal welfare guidelines for smallholder livestock programs” (HSI, n.d.) was compiled as follow-up to biogas projects in Vietnam. The projects aim to mitigate climate change and provide an affordable source of energy for rural families, but fail to take into consideration animal welfare: in order to simplify manure collection, pigs underwent a lifelong confinement in crowded, barren concrete enclosures that did not offer enough freedom of movement. The guidelines list five kinds of freedom that livestock animals must be granted as adequate living conditions:

1. Freedom from hunger and thirst by access to fresh water and an adequate diet to maintain full health and vigour.
2. Freedom from discomfort by providing an appropriate environment including shelter and a comfortable resting area.

   Facilities where animals are kept usually have concrete floors to facilitate the manure management. Nonetheless, concrete is not the most suitable walking and resting surface, several studies showing that lameness in cattle and pigs is associated with hard floors (Kilbride et al., 2008; Haskell et al., 2006) and that access to bedded parts and softer soil in outdoor grass or range land can improve leg and foot health (Vanegas et al., 2006; Bergsten, 2013). According to Kilbride et al. (2009) “Floors in pig housing can impact on the health and welfare of pigs by affecting an animal's opportunity to engage in normal behaviour and increasing the risk of infectious disease and physical damage due to contact with the floor”.

3. Freedom from pain, injury or disease by prevention or rapid diagnosis and treatment.

   Veterinary care is an important factor in the welfare of animals. Pigs natural behaviour consist in digging, grazing and, when they are piglets also chewing. If these activities are limited the animals may chew their pen mate’s tales or ears causing long-lasting and painful injuries. To prevent these aggressive behaviours, it is common to cut off piglet’s tails shortly after birth.

4. Freedom to express normal behaviour by providing sufficient space, proper facilities and company of the animal’s own kind.

   “Low levels of environmental stimulation in barren surroundings, the lack of opportunity to express key natural behaviour, such as rooting, wallowing, exploring, and nesting, and the inability to separate into natural social groups may lead to boredom, frustration, and aggression. Behavioural abnormalities and health problems are common, and pigs may not receive the individualized care they need” (HSI, 2014).

5. Freedom from fear and distress by ensuring conditions and treatment, which avoid mental suffering.

Referring to these guidelines, the CSES field survey covered the potential changes in the living conditions of pigs after the installation of a biogas digester in the PoA. The obtained results show that 22.2% of the households increased the number of pigs in the barn, thus also creating an additional economic co-benefit; none of the households reduced it. Regarding the size of the barn, 77.8% respondents said that they had made their barns bigger, and the majority of households (88.9%) mentioned that the barn's floor has been changed from stone or soil before the biogas unit was installed, to concrete at present time. During the evaluation of this aspect, though, we observed in some visited households that the concrete surface was wet or at some extent covered with manure causing pigs to repeatedly slip.

When asked whether the pigs spent more time in the barn than before, all households reported that the pigs have always spent all their time inside the barn, thus no change has taken place. Five households (25%) indicated to have more manure in the barn than before and seven households (28%) indicated there is less manure than before. According to three households, the reason why there is now less manure in the barn than before is due to the more frequent cleaning of the pigsty, while before, the manure ran down towards the pit by gravity if it was accumulating, and urine was infiltrating into the ground. One third of the households stated that they use fewer medicines or antibiotics than before.

12.1 Temperature, ventilation and air quality

Species-appropriate conditions for pig husbandry are quoted from the Code of Practice for the Care and Handling of Pigs of the Canadian Pork Council and the National Farm Animal Care Council (2014). They indicate the currently best and easiest way to respect animal welfare even in farm households with only a little number of pigs.

a) maintain air circulation, dust levels, temperature, relative humidity, and gas concentrations in such a way that is beneficial for the health and welfare of pigs
b) protect pigs from wide or abrupt temperature fluctuations
c) monitor pig behaviour frequently during extreme weather for indicators of thermal discomfort
d) aim to provide the optimal temperatures appropriate for the size/production phase of pigs.
e) ensure that separate temperature needs of lactating sows and piglets are met:
   - aim for a temperature range of 18°C (64°F) to 20°C (68°F) post-farrowing in the farrowing room as a whole. Higher temperatures may be appropriate during farrowing to ensure that newborn piglets are not chilled and maintain body heat
   - provide supplemental heat of up to 34°C (93°F) in creep areas for piglets
f) increase the effective temperature for the first 4-5 days post-weaning.
g) maintain adequate air quality and ventilation at all times (ammonia levels < 25 ppm). Take corrective action immediately to reduce ammonia levels if they exceed 25 ppm at pig level develop protocols that allow manure to be drained with a minimum release of noxious gases.

Recommended practices for lighting

a) match the intensity/location of the lighting to the purpose of the area that the lighting affects
b) provide lighting in a range of 150-250 lux in handling facilities.

Recommended practices for flooring and bedding management

a) ensure that gap widths for slatted floors are appropriate for the sizes of pigs and that the slat widths maximize the contact area with the soles of pigs' feet
b) slope solid floors to promote drainage
c) incorporate skid-resistant grooves for ramps that slope more than 10% and for concrete breeding floors and other floors to prevent slipping and falling
d) finish concrete floors on which pigs walk with texture to provide traction when wet

e) keep the lying area dry. Where bedding is used, provide sufficient amounts of bedding and top up as needed
f) remove soiled and wet bedding frequently in order to provide a clean living space to pigs check the source of sawdust and wood shavings to ensure that it does not come from wood that has been chemically treated (e.g. pentachlorophenol).

12.2 Conclusions and recommendations

All in all, it could be noted that living conditions for the pigs improved since the implementation of the PoA.

The reduced application of medicines claimed by the interviewed PoA households during the field survey indicates a positive effect of biogas digester installation and corresponding sanitary measures on pigs' health. If concrete floors are categorized as unfit for pig husbandry, this might make reference to a completely smooth surface, which was never found in PoA households. Since having concrete-built floors in the shed, manure is cleaned out more often into the digester facilitating a clean environment with less proliferation of pathogens and undesired microorganisms. Concrete floor also allows pigs to keep a cool temperature during summer.

The study team recommends to UPM, Oasis and the SREO to include such animal welfare considerations into the PoA systematically and comprehensively according to international best practice and find strategic partners among veterinaries and agricultural technicians to help promoting the many advantages of sustainable animal farming.

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