



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

*Short version of the
Field Survey & Desk Study Report*

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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 short version of the CSES field survey and the complementary desk study report about the co-benefits of UPM's Sichuan Household Biogas PoA. It summarizes the main findings and recommendations of the underlying study.



A. Rationale 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.

This climate protection programme has been developed and implemented by UPM, Chengdu Oasis Science & Technology Co., Ltd. (Oasis) and the Sichuan Rural Energy Office (SREO) as a Programme of Activities (PoA) under the Clean Development Mechanism (CDM) and the Gold Standard (CDM PoA 2898, GS 1239).

The PoA 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 that large amounts of methane emissions from animal husbandry are being released into the atmosphere and produce clean, renewable and free biogas to be used conveniently by participating households for cooking, heating, and lighting.

By avoiding both methane emissions originating from the widely used animal manure storage pits and carbon dioxide emissions from extensive household use of coal, the PoA shall save up to 20 million tCO₂e (tonnes of carbon dioxide equivalent) over the entire programme lifetime of 28 years (from 10.12.2010 to 09.12.2038).

To date, the Sichuan Household Biogas PoA and its 87 included CPAs (Component Project Activities) have reached 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 tCO₂e per year.

The present 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) and with what potential for improvements?

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](#), in

the [Gold Standard Sustainable Development Indicator Guidance](#) and the currently prepared [Gold Standard 3.0](#), and are also highly relevant for the new [UN Sustainable Development Goals \(SDGs\)](#) that were adopted in September 2015.

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, and elaborates on similarities and differences, mainly due to deviating climatic, environmental, economic and cultural circumstances.

The primary purpose of this mainly explorative PoA co-benefits analysis is to build the basis for future in-depth investigations of the programme's sustainability. The study does not claim to be representative or deliver statistically significant results. It also cannot provide an exact quantitative pre-after-assessment for all of the selected sustainability indicators and parameters nor does it intent a precise monetarization of accomplished or potential PoA co-benefits. And, as the UN SDGs and its indicator sets have not been available at the start of work for this study and the new Gold Standard 3.0 has not even been officially rolled out yet, the results of the present PoA co-benefits study will of course still have to be adapted to these new sustainability assessment standards. All of these highly complex tasks need to be left for more comprehensive follow-up research in the coming years.

Nonetheless, the present study provides robust evidence for the PoA's many advantages for the participating poor rural households in Sichuan and delivers preliminary calculations to quantify the extent of the PoA's contribution to 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.

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B. Main Findings and Recommendations

1. The PoA does have high co-benefits for natural resources efficiency.

- The PoA substantially reduces the household's use of coal and firewood.

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 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.

- The PoA households successfully replace major quantities of synthetic fertilizer by digestate.

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.

- On average, the surveyed farmers apply 13.9 m³ of bio-slurry annually in gardening, fruit and grain production.

The average annual 13.9 m³ effluent calculated based on local household data is considerably lower than the theoretically possible average annual substrate volume of 19.3 m³. 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.

The amount of N, P and K in the (diluted) digestate from PoA biogas digesters is relatively small in comparison with the amount provided by the saved chemical fertilizer, a fact, which can be interpreted in several ways:

- This effect could result from a severe use of synthetic fertilizer before digester installation.
- Ammonium 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.
- General information from agricultural statistics stresses that Chinese farmers tend to fertilize their agricultural land with chemical fertilizers (nitrogen), in excesses this could lead to ground- and surface water pollution and contaminated food products (*nitrogen run-off, phosphate in surface water (excess of algae), nitrate in drinking water*).

Recommendations:

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.

2. The PoA does have moderate co-benefits for biodiversity and habitat protection.

- The reduction of chemical fertilizer and pesticides by the PoA contributes to preventing the degradation of local ecosystems and preserves biodiversity.

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.

- So far, the PoA only contributes slightly to a decrease in firewood consumption and slower deforestation in Sichuan.

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 collected often 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.

- The intentional removal of Invasive Alien Plant Species from the land surrounding the farms and its use as an additional feedstock for biogas digesters could strongly improve resource efficiency, biodiversity and the preservation of natural habitats.

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 m³ of additional biogas per day.

Recommendations:

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.

3. The PoA does have high co-benefits for air quality by avoiding or reducing large amounts of harmful emissions.

- The PoA’s smoke-free biogas cook stoves have a major impact on reducing Indoor Air Pollution (IAP) and effectively mitigate IAP-related respiratory diseases and eye ailments.

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.

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.

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.

- The PoA brings about a significant decrease of total nutrient input in the agricultural system, which, in consequence, also reduces nutrient output in form of harmful emissions.

Manure tends to emit several gases, among them methane (CH₄), ammonia (NH₃), nitrous oxide (N₂O) and odorous substances. The potential co-benefit of the PoA is the reduction of N₂O, NH₃ 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 N₂O and NH₃ emissions. The PoA leads probably to less NH₃ emissions during storage and less N₂O emissions after application of digestate instead of manure. However, surface applying digestate instead of manure causes higher NH₃ emissions and applying digestate as partial replacement of synthetic fertilizer causes higher NH₃ and N₂O 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 NH₃ and N₂O emissions.

- The proper handling of animal manure and human excreta in the PoA's closed biogas digesters instead of formerly common open-air pits successfully abates bad H₂S or Ammonium odours.

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.

Recommendations:

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 H₂S filters of installed biogas devices periodically according to the respective manuals. Thus, raising awareness among households and instructing them how to use and maintain H₂S filters properly should be put into action.

4. The PoA does have high co-benefits for water quality and the availability of clean drinking water.

- The PoA's biogas digesters and the proper use of digestate strongly improve groundwater and drinking water quality.

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 (NO₃).

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.

- The PoA helps to avoid nutrient enrichment and prevents potential damage and losses by oxygen depletion of aquatic ecosystems.

None of the households interviewed for the PoA's latest Monitoring Report 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.

- The PoA households replace chemical fertilizer and pesticides by digestate which is far less detrimental to water quality.

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.

Recommendations:

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 some 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.

5. The PoA does have high co-benefits for soil quality.

- In contrast to manure and chemical fertilizer, digestate produced in the new biogas reactors has large fertilizing and soil-improving effects.

Digested manure has a higher availability of plant nutrients than undigested one, because anaerobic digestion increases the amount of $\text{NH}_4\text{-N}$. The waste sludge produced at the bottom of reactor can be used as fertilizer after composting 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 result in increased crop yields.

- Low-income rural households supported by the PoA do only possess a few pigs which they do not feed with heavy metal containing and soil contaminating feed additives.

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:

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.

6. The PoA does have high co-benefits for living conditions and human health.

- The PoA induced switch from solid fuels to biogas massively improves indoor air quality and leads to substantial benefits for the health of PoA households.

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 than 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.

- Much better hygienic and sanitary conditions after PoA participation of rural households contribute to relevant levels of pathogen removal and large health benefits.

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.

- There are clear indications that the use of digestate by the PoA households reduces the need to apply potentially dangerous pesticides.

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.

Recommendations:

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 estimation 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.

7. The PoA does have high co-benefits for household income as well as local economic development and employment.

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

- The PoA creates many opportunities for employment and income generation for local biogas technicians and construction workers (major potential).

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.

- The substitution of traditional fuels, in particular of expensive and dirty coal, by clean and renewable biogas out of own production allows major expenditure savings (major potential).

The present PoA survey results confirm the 2015 PoA Monitoring Report which stated a distinct decrease in coal expenditures. Even if exceptionally high outlier 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 CNY, or 603.6 CNY respectively, were calculated based on the answers of the surveyed households. In contrast, the financial benefit of replacing biomass such as collected firewood or harvest residues is much lower.

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- There are additional energy expenditure savings for the PoA households due to the substitution of electricity and natural gas by biogas (minor potential).

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, potential savings between 14.10 and 34.17 CNY/month (\cong 169.20-410.04 CNY/year) could thus be achieved if replaced by biogas. The PoA's 2015 Monitoring Report 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 situation is similar for natural gas: Biogas has been a 'door-opener' for natural gas; but while biogas is a convenient 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.

- Minor monetary benefits for the PoA households originate from reimbursed PoA carbon credit sales revenue for biogas digester investments and free biogas digester maintenance services.

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.

- There was no notable financial gain for the PoA households from sales of excess amounts of self-produced digestate.

PoA households could eventually achieve an additional income by selling those amounts of digestate from their own production which are not needed as a fertilizer for their own farmland. 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.

- PoA farmers obtain relevant economic gains from the substitution of synthetic fertilizer by their own inexpensive digestate but so far no significant savings due to reduced pesticide use.

Several scientific studies suggest that major expenditure savings are possible if farmers substituted costly synthetic fertilizer by their own inexpensive and superior quality digestate.

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% P₂O₅, 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 P₂O₅. Using these numbers, monetary savings per household accounted to 348 ± 156 CNY/year.

Minor cost savings might also be possible because of reduced pesticide use. However, the field survey of this study has not been able to confirm such effect for the interviewed PoA households.

- Lower medical costs after the switch from unhealthy solid fuels to clean biogas are very likely for this PoA but need further scientific evidence for a more precise quantification.

As mentioned above, in the 2015 CDM and GS PoA Monitoring Report, 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.

- While the positive income effect of saved cooking time due to the new biogas stoves is quite high, it is almost not noticeable for saved time for firewood collection.

The evaluated scientific publications indicate that the PoA might have further economic co-benefits in its target areas by reducing the time people need to spend on cooking and collecting firewood. This saved time can be used for income generating activities or for education, which ultimately leads to improved local economic development in rural Sichuan.

The present CSES field survey results show a median time reduction for cooking of an impressive 1.5 hours per day. In comparison, the time spent on firewood collection only decreases to a small extent after the installation of a biogas stove because, already before PoA participation, the households did not invest much time in firewood supply.

In order to enhance local economic development by means of time savings, surplus time should be used for income generating activities. Our observations in Sichuan biogas villages confirm though that the PoA households do not necessarily use the time saved during fuel collection or cooking for direct income generation but prefer to invest it in activities improving their quality of life and living conditions such as cleaning the house, handicraft production, and social life (more time with the family).

Recommendations:

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.

8. The PoA does have high co-benefits for the household's energy self-reliance.

- The PoA considerably increases the energy self-reliance of the participating poor rural households.

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 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.

Recommendations:

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.

9. The PoA does have moderate co-benefits for gender equality and women empowerment.

- In terms of improved health and reduced workload, women benefit significantly more than men from biogas digester and cook stove installation.

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.

- The PoA's positive effects on job creation for women and women empowerment are still relatively low but could be lifted substantially.

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.

Recommendations:

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.

10. The PoA does have a widely neglected new co-benefit: it improves animal welfare.

While conducting the PoA survey, animal welfare emerged as a topic closely related to household 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.

- Living conditions for the pigs improved since the implementation of the PoA.

The reduced application of medicines 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.

Recommendations:

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.

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

Table 1: Overview of 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	•		
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		•	

C. Addendum – The PoA’s Contribution to the Achievement of the UN Sustainable Development Goals

As pointed out above, the UN SDGs and its set of specific targets and indicators have not been fully available at the start of work for this 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 recently adopted sustainable development goals although this attempted alignment, of course, needs to be further substantiated and quantified by additional scientific research (see Table 2).

Table 2: The contribution of the Sichuan Household Biogas PoA to the achievement of the UN SDGs

UN Sustainable Development Goals					
SD Goal No.	Sustainable Development Goal (SDG)	Assessment of PoA contribution to the achievement of SDGs			
		Low	Moderate	High	N/A
1	End poverty in all its forms everywhere			•	
2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture			•	
3	Ensure healthy lives and promote well-being for all at all ages			•	
4	Ensure inclusive and quality education for all and promote lifelong learning		•		
5	Achieve gender equality and empower all women and girls		•		
6	Ensure access to water and sanitation for all			•	
7	Ensure access to affordable, reliable, sustainable and modern energy for all			•	
8	Promote inclusive and sustainable economic growth, employment and decent work for all			•	
9	Build resilient infrastructure, promote sustainable industrialization and foster innovation		•		
10	Reduce inequality within and among countries		•		
11	Make cities inclusive, safe, resilient and sustainable				•
12	Ensure sustainable consumption and production patterns		•		
13	Take urgent action to combat climate change and its impacts			•	
14	Conserve and sustainably use the oceans, seas and marine resources				•
15	Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss		•		
16	Promote just, peaceful and inclusive societies				•
17	Revitalize the global partnership for sustainable development			•	

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.



D. Study Contacts

UPM Umwelt-Projekt-Management GmbH (UPM), established in 1991 and headquartered in Munich (Germany), is a leading company in the international carbon markets. UPM develops, implements and manages premium quality climate change mitigation, adaptation and sustainable development projects all around the globe with a particular focus on highly innovative Programmes of Activities (PoAs). UPM disposes of a diversified portfolio of more than 20 registered CDM and Gold Standard projects. Altogether, these projects will not only save more than 25 million tonnes of greenhouse gas but will also substantially improve the lives of millions of people.

For more information about the Sichuan Rural Poor-Household Biogas Development Programme, this study or to order this study's full length version, please contact

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The **Center for Sustainable Environmental Sanitation (CSES)**, affiliated to the University of Science and Technology Beijing (USTB), 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, German CSES Guest Professor and Dipl.-Ing. Heinz-Peter Mang, ecological sanitation and bioenergy expert, and the two Junior Professors and lecturers Lei Zhang and Shikun Cheng, both PhDs.

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