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A Social Cost-Benefit Analysis of Biogas Technologies using Rice Straw and Water Hyacinths as Feedstock

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Abstract – *In many developing countries, the use of small-scale biogas digesters based on animal manure as feedstock is a well-known alternative to using firewood and fossil fuels. The present paper presents the results for a biogas research project in Vietnam where rice straw and water hyacinths have been added as supplementary feedstock. The project proves that the use of alternative feedstock can be practiced with success and the analysis presents the welfare gains of the technology. The investigation is performed as a social cost-benefit analysis trying to monetize all relevant economic and environmental effects obtained when shifting to climate-friendly biogas produced from a biomass feedstock. The conclusion from the cost-benefit analysis shows the technology to be very attractive in terms of both private and social welfare gains. The net benefits are primarily due to the fuel cost savings (LPG and firewood) and time gains when reducing the usage of firewood.*

Keywords – *biogas, climate-friendly energy, cost-benefit analysis, rice straw, water hyacinths.*

1. INTRODUCTION

The use of biogas from feedstock like pig or cattle manure has been a well-known and commonly used technology for a very long time in many developing countries. It is a cheap and stable source of energy supply for especially household cooking purposes. Biogas can be produced with a relatively simple, low-cost technology and, when displacing fossil fuels or firewood, it becomes very attractive in many ways - both in relation to economic and environmental effects. Developing countries are also assumed to engage more and more in the reduction of carbon emissions by relying on sustainable energy sources instead using fossil fuels and in this context, biogas might become useful. Although the potential for biogas is huge in many developing countries, there seems to be various barriers for the further expansion of biogas technologies [1], [2]. Biogas is often used at a very small scale, meaning farmhouses with just of few pigs or cows, and therefore the supply of biogas is very sensitive to the fluctuation in the stock of animals. In South East Asian countries like Vietnam farmers will tend to sell off pigs when prices are high and thereby have shorter periods of missing feedstock (*i.e.* pig manure) and similarly pig diseases will give feedstock supply problems. All of this will reduce the farmer's incentives to invest in biogas equipment unless there are options with access to alternative feedstock. A solution to the latter issue might be to use supplementary biomass feedstock like rice straw and water hyacinths, which has been investigated in a research project financed by the Danish Development Agency (DANIDA) in the Mekong Delta during the last four years and with very promising results. Technically, the use of these biomasses are working very well, *i.e.* can substitute for pig manure in the production of biogas. Therefore, it is important to analyze to what degree this biogas technology will be attractive from an economic point of view. This is also the purpose of this article, which will combine data and knowledge from the before-mentioned project with other relevant information from the existing literature on the topic. Thereby, with reliable data from a specific project at a relatively detailed level, the methodology will be to apply standard cost-benefit analysis to the available data in order to evaluate the net social benefits of biogas investments. Additionally, it is important to document the biomass solution to the problem of fluctuating pig manure in the production of biogas, which may help expand the use of renewable energy sources in developing countries. There is a vast amount of literature on the use of biogas, although not much knowledge of the exact social costs and benefits of biogas, but section 2 shortly addresses the topic. Thereafter, the next sections – parts 3 to 8 - systematically present data for the economic factors involved in a social evaluation of biogas, using the empirical data and information obtained from the research project in Vietnam. Then, part 9 presents the social welfare impacts of the biogas in the form of net present values. The latter includes monetization of difficult issues like time saving, environmental and health effects related to the shift from traditional fuels to biogas usage. The conclusion is in part 10.

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2. LITERATURE REVIEW

The literature on the application of biogas in developing countries deals with both economic and bioscience or technology topics, although most of the studies are in relation to the last-mentioned science issues. The potential benefits from applying this clean and cheap renewable energy source are evident – as the energy source is both cheap and climate friendly [3], [4]. The studies [5], [6] present the gains from biogas applications with low-cost digesters giving economic, environmental and health benefits. Many developing countries have the climatic conditions for investing in biogas technologies, but many factors may slow down the process of biogas usage like the low opportunity costs of the replaced energy sources, *e.g.* firewood in the case of Ethiopia [7]. Iqbal *et al.* [8] investigates factors influencing biogas adoption in Pakistan and finds a range of factors influencing the decision to invest in biogas, and thereby complicate the further expansion of biogas usage. A questionnaire with one hundred respondents was carried out and approximately half of the respondents were non-biogas users. The findings are that the age and education of the household head, the size of land and the number of cattle positively influence on the decision to invest in biogas. The rather slow introduction of biogas in developing countries is also a well-known issue. Schmidt and Dabur [2] analyze the diffusion of biogas in India from doing interviews with experts from various positions in the value chain, and find that technological and financial support are among the best instruments for advancing the introduction of biogas. Christiansen and Heltberg [1] analyze data from China obtained from a very large survey of households from 2009 with users and non-users of biogas. The study reports positive impacts on women's time use, economic welfare and health effects from shifting from firewood fuels to biogas. Despite all the benefits from the usage of biogas there may also be potential drawbacks due to the leakage of methane from the digesters if they are not properly installed and maintained [9]. This is a serious issue for the further promotion of biogas as the methane gas is among one of the more harmful carbon emissions. Despite of this, the net environmental effect is positive as the biogas may crowd out fossil fuels like coal and liquefied petroleum gas (LPG) [10], [11].

3. DATA

To perform a cost-benefit analysis of the present type, two kinds of data are needed. First, the costs of investment, maintenance and other direct expenses where data information has been made available from the project as around thirty biogas digesters have been installed at farmhouses in the Mekong area. Secondly, survey interviews have been performed in order to obtain information on topics related to the benefits, *i.e.* energy and time usage along other issues when switching to biogas from traditional fuels. These data come from two sets of surveys in the Mekong Delta undertaken in 2012/13 and 2015, respectively. Both surveys are extensive questionnaires among small farmers and households in rural districts and include questions of both technical and socio-economic content. The first questionnaire was performed in the districts Tien Giang and Vinh Long and involved around two hundred respondents, almost equally divided into users and non-users of biogas. The second one was performed in the district Soc Trang with two hundred and twenty respondents, involving only non-users of biogas. The structure and questions in both surveys were designed in accordance with the former experience acquired at the Can Tho University (CTU) from surveys on similar topics. Furthermore, to secure valid data and a high rate of response, in both cases students from the CTU collected the data by visiting all farms and households for up to one hour per visit carrying out the interview. The students were informed about the content of the questionnaire and the biogas technology on beforehand, and they were also instructed to obtain valid and objective answers when interviewing the respondents. In addition to these surveys, a large survey was carried out in the Hau Giang district in 2016 including the same type of topics. All surveys have a relatively large part of technical questions about farming and biogas, but also a whole range of social and economic topics like age, gender, income and other family characteristics along questions of behavior and attitudes related to the energy usage. Due to these efforts invested in getting data of reasonable quality, the results in the following analysis can be considered relatively reliable where the information is used for the quantification of the costs and benefits in the following parts 4 to 8.

4. THE BIOGAS DIGESTER INVESTMENT

Various kinds of household digesters are available at a relatively low cost of investment. The least expensive type is made from relatively thin, fragile polyethylene materials, a so-called low-density digester. It is easy to install, but with larger risks of leakage and breakdown within a shorter time span. At the other extreme is the relatively large dome digester made from concrete and bricks which is more expensive, but not fully suitable for places with high levels of groundwater like the Mekong Delta. The experiences obtained from the SubProM activities have shown that a high-density polyethylene digester (HDPE) is an efficient solution as it is still relatively cheap, will last at least for a decade and the methane leakage from the high-density material is minimal. This will most likely be the optimal solution for the southern part of Vietnam and probably also for many other places in South East Asia with similar conditions.

The HDPE will hold a guarantee for a period of ten years and is expected to last for at least fifteen years when properly maintained. For a digester size of 7.6 m3, suitable for small farms and households, the price of installation will be around 400 USD. This will cover a turnkey installation and the cost can be reduced slightly when the owner does part of the work in the form of preparing the area, *i.e.* removing soil, installing the HDPE and connecting pipelines to the house. The cost components are summarised in Table 1.

With a lifetime of fifteen years, there will be some maintenance costs. Experience from former biogas installations in Vietnam indicates a level of 5% of the investment as maintenance costs and with a small annual increase in these costs [12]. Setting the maintenance costs to a fixed 5% of the initial investment means an annual cost of 20 USD (in 2017 prices) throughout the lifetime of the digester. With a 10-year guarantee on the

HDPE equipment the actual costs to the farmer may be less as any problems under the guarantee will be covered by the supplier. From a social point of view, all costs will be included no matter who bears the risk of technical problems that need repair or maintenance.

Biogas is mainly for cooking purposes and in nearly all cases a substitute for bottled gas (LPG). This means that a stove and other equipment in the kitchen will be in place for either the biogas or the LPG alternatives, and therefore additional costs will be incurred for a stove suited for the use of biogas (not identical to the one used with LPG). In the case with only firewood as energy source, there will be similar extra costs for kitchen equipment when switching to biogas.

Table 1. Investment costs of a high-quality biogas digester (USD, 2017 price level).

Digester (HDPE)	200
Inlet/outlet tubes, connections	129
Technical assistance, transport	47
Kitchen equipment	37
Total investment	413

Notes: HDPE is a high-density polyethylene digester with a lifetime of 15 years. All numbers stem from the experiences obtained from the SubProM project where more than thirty HDPE digesters have been installed. Technical assistance includes local transport, and a kitchen stove adapted to biogas. The size of the digester is 6.8 m3 (liquid mass) and total volume 7.6 m^3.

5. ENERGY SOURCES AND FUEL SAVING

The HDPE digester is assumed to be installed at small farmhouses with a limited number of pigs and will therefore use both pig manure and rice straw as feedstock for the biogas production. The SubProM, initiated in 2012, is the first project formally analyzing and demonstrating how to apply the rice straw as a feedstock for methane production. Rice straw will be used as a supplement to pig manure, but can also be used as a stand-alone feedstock for the biogas digester where the use of rice straw is a sustainable method of biogas production [11]. Water hyacinths are also an optional feedstock, a perfect substitute for rice straw and freely supplied in the canals and rivers where they are found in large amounts and detrimental to the water systems and the shipping activities. In the present analysis only rice straw is mentioned, as the water hyacinths will be a very similar feedstock so there is no need to differentiate in the calculations as both types of feedstock are applied with similar costs of collection/feeding to the digester.

The amount of pig manure from three pigs will not be fully sufficient to produce biogas for the daily needs of energy for cooking purposes unless rice straw is added regularly to the digester. The results from the SubProM program show that adding 3-5 kg of rice straw every third day will enhance the biogas production to more methane than needed in most cases for the daily cooking. Thus, on an annual basis, at least 400 kg of rice straw is used for biogas production. In most cases, the straw will be collected at no cost apart from the time usage of handling and digester feeding. Recently, rice straw has been used for cattle feeding purposes north of the Mekong region, and in that case straw in rolls of 14 kg has been sold for 18-20 thousand VND (less than 1 USD). There will be work involved with this alternative use of rice straw, and the net surplus for the farmer is assumed close to zero from selling off the straw after harvest. Therefore, no cost is assigned to the use of straw as a biogas feedstock. This also means that enough biogas for cooking will always be available as more rice straw can be added to the digester at no cost.

When evaluating the use of energy in the rural district with no use of biogas digesters, the main fuels will be LPG and firewood. As evidenced from the conducted surveys among farmers, there is no simple concept of an ‘average farmhouse’ to use when assessing the amounts of energy saved when shifting to the biogas digester alternative. From the information collected in the SubProM surveys and [13] a best or likely estimate of the fuel saving will be made. The use of LPG in households seems to be around 0.1 kg of LPG per day (or 3 kg per month) which is indicated by households in both of the before-mentioned surveys. A recent survey in the Soc Trang district, see Table 2, reports a somewhat larger level of LPG as the average from 220 households is 4.8 kg per month. These numbers correspond to a consumption of 3 to 5 bottles of LPG annually, as the standard size is 12 kg.

Table 2. Energy usage for cooking purposes, biogas non-users (survey data).

District	Tien Giang/Vinh Long	Soc Trang	Hau Giang
Time of survey	2012/13	2015	2016
Number of obs	97	221	140
	--------	Consumption per month --------	
Firewood (kg)	82.50	138	126
LPG (kg)	2.40	4.78	3.93
Electricity (kwh)	28.20	27.40	34.60

Notes: The 2012/13 survey data are computed from daily consumption data. Data for firewood, 2015 and 2016, are reported in volume levels (in the local firewood-metre ‘ster’) and converted to weight units. Other fuels are also used for cooking purposes (especially charcoal, rice husk and kerosene).

The data in Table 2 reveal some regional variation in the consumption levels due to several factors, especially the farm size, local availability of firewood etc. The survey data show that for households having shifted to digester biogas there is still a modest use of LPG, less than a bottle annually, but some households report that plenty of energy is produced by the digester and therefore there is no more use of bottled gas. To summarize on this issue, it is assumed that 3.5 bottles of LPG is saved annually, which should be a conservative estimate. At the present price level of approximate 440 thousand VND per bottle, the saving will be around 68 USD.

In addition to LPG, some households also have usage of firewood that may be for both regular cooking purposes as well as for cooking animal food or using firewood at special occasions. Part of this firewood must be expected to disappear when investing in biogas. For households with no biogas, the surveys, cf. Table 2, show a consumption level around 2-4 kg/day of firewood. For the SubProM 2012-13 survey, which also included biogas users, the latter still use 1.7 kg/day of firewood. The monitoring report [13] has values of 5.26 kg/day for non-biogas households and this drops to 0.76 kg/day for biogas users.

When the households are using LPG and firewood, the decrease in firewood must be in the lower range of the indicated numbers and therefore it is assumed – as an average approximation taking all aspects into consideration – the use of firewood is reduced by 1-2 kg/day. Thus, the reduction is assumed to be slightly more than 1 kg/day and corresponding to 450 kg annually. The monetary value of the saved firewood – if bought from outside sources – will be around 55 USD annually. The calculation is based on 0.3 m3 of good quality firewood costing 500 thousand VND, and assuming a 0.6 density of firewood. Part of the firewood will be collected at no monetary cost in the garden and local surroundings and, therefore, the final value is assumed to be the mean value of the two options, *i.e.* 25 USD annually.

In total, it is assumed for the 'average biogas user' that the annual savings are 3.5 bottles of LPG and 450 kg of firewood. This is a stylized fact assumption due to the very heterogeneous patterns of fuel usage and somewhat uncertain information on actual energy usage. Some farmers rely mostly on LPG and power, and others have a larger share of firewood combined with using also some quantities of LPG and power. The values here for saved fuels are probably conservative and thus not inflating the economic benefits of the digester option too much. Finally, it is assumed that the power consumption is more or less the same after shifting to biogas, and therefore not included in the evaluation.

6. THE VALUE OF TIME SAVING

When switching to the use of biogas from LPG and other traditional fuels, there will be some mixed influences on the usage of time. The use of LPG is easy and clean with respect to the indoor climate where the use of firewood involves smoke and health problems as well as time usage for collecting the firewood. Biogas is just as easy and fast to use as LPG, but will involve some time allocated to the handling of the digester. The feedstock for the biogas digester will be pig manure, rice straw and water hyacinths.

Pig manure will have to be treated in all cases and there will be some efforts in connection with collecting the rice straw, keeping it dry in the rainy season and on a regularly basis feeding it to the digester. There will be a similar collecting process for the water hyacinths, but not with the same need for storing and drying, and they can be used directly when picked form the rivers. The access to both rice straw and water hyacinths is assumed easy and free of costs. From the experiments in the SubProM project the feeding with rice straw soaked in water will take place every third day and it may take between half an hour and one hour. In total, collecting, handling and feeding the straw to the digester might have an average daily time usage of less than half an hour, but to set the time usage on the safe side, 180 hours annually are used for the handling of the supplementary biomass. There will be time usage for handling the pig manure and this is assumed to be of the same magnitude whether or not there is a digester.

It is a common practise to use firewood as a supplement to LPG and in relatively large amounts.

Using firewood is a time consuming activity, *i.e.* both to collect the fuel, a slower process when cooking (maintaining the fire) and finally more cleaning of equipment in the kitchen afterwards. There are varying numbers for the time usage of firewood in households and it will depend on the local conditions also, *i.e.* whether just to collect the wood freely in nearby surroundings or whether to buy it from outside. A former survey from districts in the Mekong (Hau Giang) indicates high levels of time usage – some two hours daily for collection, cooking and cleaning. The survey from Tien Giang/Vinh Long indicates somewhat lower time usage with a quarter of an hour per day for firewood collection. Additional time must be used for cutting, drying and storing the firewood, which means an hour will be a realistic estimate of the daily time usage. The latter is only for preparing the firewood and therefore the time for cooking and cleaning (dishwashing) must also be included with around two hours per day, which will be the magnitude for households relying on firewood for cooking.

According to the 'Biogas Program for the Animal Husbandry Sector in Vietnam' managed by the Dutch development agency (SNV) and the Ministry of Agriculture and Development (MARD), there is a similar saving of 14 hours per week when not using time on firewood collection, maintaining the fire during cooking time, cleaning of kitchen equipment and no transport of LPG bottles. Khan and Martin [14] refers to a report on 300 biogas users where the average time saving was approximately 1.5 workdays per week, which is a high number, but in accordance with the before-mentioned MARD data.

A large survey carried out in China reports an average of 9.9 hours per month for firewood collection, but when time for collecting other fuels is included the time saving is larger [1]. The study indicates time saving of more than an hour per day in relation to cooking and cleaning when using biogas as a substitute for firewood. Thus, if relying fully on firewood for household cooking up to two hours per day might be a likely estimate and this is in accordance with the survey from Hau Giang in 2016, where the average time usage was reported to be up to two hours daily for all work involved in the firewood usage. In the present case where the households are assumed also to reduce the LPG usage, there will be less firewood involved in the total mixture of fuels for cooking purposes, and therefore a reasonable time saving will be up to an hour per day.

Assuming an average level is a saving of around one hour per day for the firewood, and adding the before-mentioned 180 hours annually for handling the biomass for the digester, the total result will be a net saving of 185 hours annually. The latter is only relevant when using relatively large amounts of firewood, but if saving 4 bottles of LPG (when switching to biogas) is also assumed, some households will have a much lower level of time savings. Therefore, a lower level like 100 hours will be more appropriate as an approximate value. The time saving effects are summarized in Table 3.

Table 3. Summary results of time saving amounts and values.

Time usage:	
Handling of rice straw:	½-1 hour every third day
Collecting firewood, slow cooking/cleaning:	1 hour per day
Net time saving when using biogas:	
Firewood main source:	180 hours annually
LPG main source:	No major time saving
Monetary value of time saving, annually:	
Range depending on main fuel source:	0 – 180 USD
Value used in the cost-benefit calculation:	50 USD

Note: The monetary value based on a daily salary of eight USD as the opportunity cost (more farm work done instead of using time on firewood).

With a daily salary of 8 USD, the time saving in the form of more labour hours will allow for increases in more work, and the value added activities might have a value around 100 USD. Alternatively, there might be an option for more leisure time and this will usually be assumed of smaller value than working hours. Thus, the monetization of the time effects will be in the range between a value close to zero and an upper limit of at least 100 USD. Again, applying the rule of a half, the final estimate will be 50 USD as the annual, net gain from the major time effects, and with the critical assumption that the use of especially firewood is reduced. Otherwise, when the households rely mainly on the LPG as cooking fuel, the time effects will be minor.

7. QUANTIFYING THE ENVIRONMENTAL EFFECTS

The major environmental effect is the CO_2 savings from less use of fossil fuels like LPG, but also emission effects from other fuels as well as methane leakage from the biogas production are involved when estimating total emissions [9]. Biogas will partly replace other fuels like LPG, charcoal, firewood, kerosene and a few other sources of energy. There will be net positive effects from using clean fuels, reduced de-forestation and chemical fertilizers might be replaced by digester effluent [15]. However, the methane production will involve some leakage risk with detrimental emission effects [1]. The combined environmental effects from using biogas digesters are positive [16]. For the present analysis of biogas in the Mekong Delta the major effect will be a positive CO_2 effect from using less LPG which is assumed to be a reasonable estimate of the major or net environmental effect.

There are several estimates of the CO_2 effects from using biogas. The before-mentioned project 'Biogas Program for the Animal Husbandry Sector in Vietnam' (SNV-MARD) has been involved in more than 100,000 biogas digesters in Vietnam and reports a reduction of 5 tonnes of CO_2 per digester annually. This is a high level of savings and related to the use of a relatively large brick dome digester as well as including effects of better handling of manure along with reducing the usage of CO_2 intensive solid fuels for cooking. For the Mekong the main effect comes from less usage of LPG, and a low estimate of the CO_2 saving will be assuming a reduction of 3.5 bottles of LPG when switching from this fuel to biogas. This corresponds to 42 kg of LPG with an approximate content of 127.3 kg of CO_2. There will be reductions in the usage of other fuels like charcoal and kerosene, and therefore this amount of CO_2 is clearly too low a value to assign as emission benefit for the biogas digester. Izumi *et al*. [16] estimates the total CO_2 effects from switching to biogas in the Mekong Delta – and thereby a highly relevant data source – to be 468 tonnes of CO_2 reduction annually from a project involving 961 households. This will be 487 kg of CO_2 per household. From these data, the most likely level of CO_2 savings will be in the range between 127 kg and 487 kg annually, and applying the rule of half results in a value of 307 kg CO_2 as a reasonable estimate. With a 15 years lifetime for the digester, the CO_2 savings will be 4.6 tonnes in accumulated quantities.

The monetary value of emissions is much harder to evaluate as the damages from global warming are not easily, if at all, estimable. Turning to the cap-and-trade system, *i.e.* the taxing of carbon emissions might be an indicator of how to monetize the effects, the span ranges from 3 USD to more than 100 USD per tonne of CO_2. Singapore is the first South East Asian country to launch a carbon tax in 2019 and the level is expected to be 10-20 USD per tonne of CO_2. In Vietnam, there is an environmental tax component as part of the taxation of gasoline and the level is 1000 VND per litre. This corresponds to 418 thousand VND (18 USD) per tonne of CO_2 calculated from the carbon content of gasoline. This price level is comparable to the prices of carbon credit in the EU's Emission Trading System (ETS) during the recent years, where prices of CO_2 credits have been relatively low.

Another complication with regard to the value of monetizing the emission effects is whether to apply discounting as done for the traditional cost-benefit effects in project evaluation. Carbon emission will accumulate over time and the damage is not related to a specific time period which is why a usual, annual discounting procedure is not an obvious methodology to apply. A simple solution will be to avoid any discounting and thus just set the gain as a present value of the total quantity (4.6 tonnes) times the price of 18 USD, *i.e.* the total contribution to benefits will be 83 USD.

There are also positive environmental effects from using biogas in relation to avoiding smell problems, and less smoke will decrease respiratory problems and eye diseases because no firewood is used in the kitchen. These issues are documented in a number of studies, but it is not easy to monetize such benefits [1], [7], [17], [18]. One option is to apply the information from studies of willingness to pay for reduced health risks. There are two studies trying to assess the value of a statistical life related to Vietnam [19], [20], and the information from these empirical studies are combined to obtain an estimate of the willingness to pay for reduced mortality risk [12]. The result is a lower bound of 18 USD annually for the value of the health benefits due to the clean biogas, which will be included in the benefit computations. The upper bound is 63 USD in the study, and therefore there is no reason to assume a more conservative or lower value of the health impacts than the 18 USD.

8. BIOGAS EFFLUENT AS A FERTILIZER

The residual, or effluent, from the digester will have a high value as a non-chemical fertilizer and can replace the traditional fertilizers in the rice fields. The effluent (biogas-slurry) can be collected from the digester as a liquid, 'high-volume' product compared to the traditional chemical fertilizer, where the latter is less demanding in handling and working hours and also easy to bring to the rice fields. It is not easy to quantify this effect of using the effluent as it involves additional time usage for the farmer and it is difficult to assess how much slurry – or how large an area of the rice field - will be involved by the optional use of the biogas-slurry. The empirical evidence is sparse on this topic, but Mengistu *et al*. [15] reports considerable effects from using the bio-slurry from a survey among biogas users in Ethiopia where one-third of the respondents reported using biogas effluents to reduce some amounts of chemical fertilizers. Likewise, it is important to use slurry as a fertilizer in order to make a successful biogas program [21]. The same applies for Indonesia where Haryanto *et al*. [10] reports data for smaller household digesters based on cow dung, and with a value of 32 USD annually for the effluent when substituting for chemical fertilizers. The use of effluent from the digester is better than direct usage of the pig manure and the use of less chemical fertilizers will have positive environmental and cost-reducing effects [15].

In the present case of biogas in the Mekong Delta, there is no widespread usage of effluent as fertilizer due to both the problems of bringing bio-slurry to the fields and the perception of a more safe harvest secured when traditional fertilizers are brought into use. In order to quantify the positive economic effects at a realistic level for the use of effluents, only a modest contribution will be assumed. Most of the farmhouses will have a kitchen garden of a size of around 150-200 m^2 and as they are usually situated near the digester, the effluent can contribute with fertilizer amounts for this purpose. From the data for the use of chemical fertilizers in the traditional rice fields, the amount of reduced chemical fertilizer in the garden can be calculated - assuming the same intensity of fertilizer usage. Finally, from the price of chemical fertilizers the economic gain can be estimated.

For the rice fields the use of chemical fertilizers (NPK) is around 3-5 bags, each 50 kg, per hectare for every harvest season. With three harvest cycles annually this amounts to some 450-750 kg of fertilizer per hectare. The fertilizer price will be around 12-15,000 VND/kg and, therefore, the total cost for a hectare of agricultural land will easily be some millions of VND per year. From the mean values of the before-mentioned data, the annual saving will be around 140,000 VND (approx. 6 USD). There will be some costs in the form of time usage for bringing the effluent to the garden, but this might be a minor effect and is therefore not included. The alternative usage will be floating the effluent to a fishpond, which might have a small economic value, but if the local canals are the outlet for effluents, the kitchen garden solution is much to be preferred. In total, a net gain of 6 USD annually is assumed when the effluent is used in a sustainable manner in kitchen gardens. From a social point of view the effects are positive and, additionally, the chemical fertilizer is an imported good (marginally) and will thus have impact on the use of scarce foreign exchange. The benefits of shifting into the environmentally more friendly slurry usage will be added to the social benefits of the biogas.

9. THE TOTAL WELFARE EFFECTS FROM USING BIOGAS

The assumptions and estimates of the social costs and benefits as presented in parts 4-8 are summarized in Table 4.

The values as exhibited in Table 4 are assumed to be representative of the correct welfare economic costs and benefits and, therefore, further adjustments are not necessarily needed prior to being handled with various project evaluation criteria. With the values as the best available estimates of the respective effects, the standard decision criteria will be the net present value calculated with a relevant social discount rate. There are alternative methodologies in social cost-benefit analysis to the simple net present value calculation. One standard approach will be to shadow price the investment cost, [22], as the resources for investment goods will be an alternative private investment, often assumed to have a rate of return larger than the social discount rate or the time preference rate for private consumption. There are further alternative evaluation methodologies like the World Bank, [23], or applying Mishan's alternative concept of compounded terminal values, [24], instead of a NPV approach. The final calculations show in most cases a considerable positive net social surplus from the NPV calculations. Alternative criteria will only influence the overall conclusion slightly and are, therefore, not included.

Table 4. Social costs and benefits of the HDPE biogas digester (USD, 2017-prices).

Costs		*Benefits*	
Investment:	413*	LPG:	68
Maintenance:	20	Firewood:	25
		Time:	50
		Effluent:	6
		Health:	18
		Environment:	83*

Note: * indicates a present value, other values as annual costs/benefits. The benefits are the net effects from the respective categories and fully explained in the main text. The environmental benefit (less CO_2) is the present undiscounted value of the gains in the lifetime of the digester.

Table 5. Social welfare effects of the biogas technology (NPV, 2017 USD).

	10 years		15 years	
SDR	3.5%	7%	3.5%	7%
		--------------- NPV ---------------		
All effects	893	703	1363	1009
All effects, SPC	764	579	1239	885
Time & fuel saving	610	451	1004	707
Fuel saving	194	100	428	252

Notes: The 'All effects' includes the variables from Table 4, and the SPC indicates that the investment costs have been adjusted by a shadow price of 1.3 (less relevant for the case of a 7% discount rate). The last two cases include only time and fuel savings, and all other effects are excluded from the NPV calculations.

The social discount rate is usually assumed relatively high in developing countries, cf. the guidelines from the Asian Development Bank, with a range of 10-12% as the level is decided from applying an opportunity cost of capital (SOC) approach [25]. The World Development Indicator database from the World Bank homepage reports a real interest rate of some 5-7% in Vietnam for the period 2010-16, which is the level for the inflation-corrected interest rate in the financial sector. The Bank for Social Policies in Vietnam has some lending interest rates depending on household incomes and purposes in relation to the credit in question. Lending to poor households is presently 6.6% annually, and with a close to 3% inflation for 2017, the real interest rate will be 3.5%. There are many more deposit and lending rates in the Vietnamese economy but for a social evaluation, the time preference rate is assumed to be 3.5% and to be used as the social discount rate in real terms. The social opportunity cost of capital (SOC) is assumed to be 7% in real terms, *i.e.* lower than appearing in the Asian Development Bank guidelines, and to be used as an alternative to the lower social discount rate of 3.5%.

For the case with the social discount rate of 3.5% the NPV is also calculated when doing shadow pricing of the investment, *i.e.* estimating the conversion factor for a shadow price adjustment as found in the cost-benefit literature [22]. In the present case, half of the investment cost is assumed to represent resources with an alternative investment application and the shadow pricing is done with a 1.3 conversion factor. This will raise the investment cost and lower the net gains. The results are exhibited in Table 5.

The NPV for the cases with 'All effects' are all the cost and benefit components from Table 4, and with a version including the shadow price adjustment of investment costs (SPC). The results are calculated for the two discount rates (SDR) and the alternative time spans, ten years and fifteen years. Similar computations are exhibited for the 'Time and fuel saving', which will only include the first three benefits from Table 4, and the last one, 'Fuel saving', only includes LPG and firewood.

Shadow pricing of investment goods is mostly relevant when using the lower social discount rate reflecting time preferences for consumption (3.5%), but also reported for the higher discount rate. For the varying time spans and discount rates all cases show up with a positive NPV and are, therefore, worthwhile from a social welfare point of view. The absolute values in Table 5 must be evaluated in relation to a 400 USD investment in a small-scale digester, *i.e.* a very efficient investment even in cases including only a part of the benefits. Additionally, all the numerical estimates have been kept in a conservative direction in order not to exaggerate the net gains in the project and, therefore, the values in Table 5 may be interpreted as the lower bounds on social profitability. Even from a narrow private perspective where only the saving of LPG and firewood – and some value on time saving and more healthy indoor conditions – is included, the annual benefit will be more than 100 USD and is thus still a profitable investment.

10. CONCLUSION

The use of biogas digesters in developing countries can be expanded to include organic feedstock like rice straw and water hyacinths along the traditional substrates like animal manure. The results from the project mentioned in the introduction show that these feedstock are very good substitutes in relation to replacing the traditional use of manure, and that the biogas production can be done with the sole use of these local sources. The present project is designed for small-scale households with a simple and robust technology based on a high-density polyethylene (HDPE) digester bag which is relatively cheap, *i.e.* around 400 USD, and expected to last more than a decade. The main economic advantages from using the biogas is the saving of traditional fuels like firewood and LPG, considerable time savings and also positive environmental effects. An important gain is related to better indoor conditions when not using firewood for cooking purposes, *i.e.* positive health effects, and at the global level GHG emissions are reduced from less or no usage of fossil fuels like LPG. Adding the monetary estimates of the benefits, cf. Table 4, will be a gain of more than 150 USD annually, and relatively much compared to the investment. According to all usual decision criteria from social cost benefit analysis, the project economics is doing fine with a huge surplus, for example when measured in net present values as exhibited in Table 5. The household biogas installation will require an upfront investment of the before-mentioned approximately 400 USD, which is a barrier for the further dissemination of the technology in rural low-income areas. There is a financial constraint as low-income households cannot pay the investment costs upfront and may not be able to obtain loans from banks or financial institutions. This is a serious challenge to an otherwise socially desirable solution to energy and climate problems in developing countries. Government subsidies are often used as instruments to expand specific activities or projects, and this has also been the case for Vietnam where smaller subsidies until recently has been an option. By now, the national biogas program is a transformation away from subsidies towards a market-driven private biogas sector. As mentioned in part 9 on the total economic effects, the biogas investment is profitable form a private point of view, but reality reveals that most of the biogas digesters in Vietnam has received some government support or partly subsidised by foreign development agencies [13]. Thus, although the biogas technology is privately and socially desirable, it is important that also the behavioural and financial constraints are taken seriously into consideration when official authorities and other institutions are developing new energy policy initiatives.

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