Resilience Development Initiative

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# Working Paper Series

No. 8 | August 2015

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**WP No** : 8

**Date** : August, 2015

Resilience Development Initiative

Resilience Development Initiative (RDI) is a think tank initiative based in Bandung, Indonesia that focuses on environmental change and sustainable development. RDI contributes to the body of knowledge on development and disaster research studies in Indonesia and South East Asian Region.

RDI Working Paper Series is published electronically by RDI.



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# Analysing the economic benefits of rural biogas adoption in Selo District, Boyolali


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## Abstract

*Selo, a small agricultural-based village in Boyolali, West-Java, Indonesia has initiated small-scale rural biogas adoption as it presumably reduces the consumption of LPG, firewood, chemical fertilizer and (women's) overall workload. As global warming from fossil fuel consumption, gender empowerment and self-sufficiency are becoming more pressing, it is useful to analyse the benefits of biogas as an alternative renewable energy technology (RET) provision in rural areas. This paper aims to assess the benefits of rural biogas adoption from an economic perspective, through calculating the direct and indirect benefits obtained from biogas adoption in Selo. For this, a field survey was carried out in Selo to ask questions to biogas users (N=21) and non-users (N=5) on their energy and fertilizer consumption, as well as emissions reductions resulting from biogas adoption. Based on the analysis, on average, a household with biogas saves 490 kWh month$^{-1}$, 20,000 IDR month$^{-1}$,185 kg $CO_2$e month$^{-1}$.Chemical fertilizer consumption remains remarkably high, which may due to a lack of awareness on the potential of digester slurry by the farmers. The biogas quality of one household has also been determined by comparing its heating value to that of methane; the methane percentage (MP) was approximately 31%. The quality is considerably lower than expected from the literature (i.e. around 60%), which may be due to the farmers neither mixing nor supplying water to the dung. Trainings providing methods for improving digester overall effectiveness to particularly the women-folk may enhance digester management and thus biogas production, as they form the main primary operatives. Despite the room for improvement, the existing results clearly show that biogas adoption significantly reduces greenhouse gas (GHG) emissions, household energy costs, workload, improves environmental conditions and generates income through carbon credit exchange. Therefore, under the notions of sustainable development, environmental preservation and self-sufficiency, policy makers and NGOs should expedite their support in biogas development, e.g. by providing subsidies and awareness raising.*



**Keywords: benefits; biogas; energy; renewable; Selo**


## 1. Introduction

As the Food and Agriculture Organization (FAO) in reported that almost 75% of Indonesia's total food consumption and 85 million tons in agricultural and wood is wasted yearly, waste management in Indonesia has become problematic (Aprilia, 2013, Rawlins et al., 2014). Public health and the environment can suffer from severe damage as a result of uncontrolled waste disposal; over two-thirds of the solid waste is disposed in open landfill sites, of which the remainder is mainly buried, burned, composted or simply unmanaged (Rawlins et al., 2014). Improper management may cause eutrophication of waterways and attract rodents, insects and parasites, which may considerably impede crop production and precipitate the spread of diseases (IAEA, 2008). Furthermore, as stored manure bring about methane ($CH_4$) emissions, a greenhouse gas (GHG) twenty-five as strong as $CO_2$,

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it also contributes to environmental pollution on larger scales. Proper agricultural waste management is therefore vital.

In Selo, an agriculture-based village to the north of Mt. Merapi and to the south of Mt. Merbabu in Central Java, similar problems exist regarding waste management, as livestock keeping and crop production are wide-spread. Further, trees on the slopes of the two mountains have been chopped extensively and have mainly been used to provide for the local energy needs, resulting in a deforestation rate of over 90% (SLI, 2015). The deforestation in this area causes land degradation and potential disasters (e.g. landslides). It is worth to mention that this area is located at the slopes of a very active volcano of Mt. Merapi. The last eruption in 2010 caused huge economical damage to the surroundings of Mt. Merapi (Wimbardana and Sagala, 2014),although Selo was among the areas that experienced less harm. In this area too, environmental preservation, resilience and sustainability is crucial, and waste management combined with sustainable energy production could be used as a means for this development.

The NGO *Sahabat Lahan Indonesia* (SLI) has therefore set the objective to develop almost 130 biogas installations by June 2015 (Mack, 2013) in Selo as part of the Merapi Landcare Project, in order to replace the energy resources the villagers use now, namely LPG and firewood, and to act as a means for improving rural waste management. This goal has not been met entirely, as only around forty digesters were contructed (SLI, 2015). Nevertheless, biogas has been recognized as a technology with numerous environmental and socio-economic benefits, for it is proven to, among other things, reduce $CO_2$ and $CH_4$ emissions from reduced fossil energy consumption, generate income by capturing slurry and provide energy less costly. As it also reduces time used for firewood collection and cooking, biogas usage seriously contributes to gender empowerment as well (Christiaensen and Heltberg, 2012), despite the fact that most of the household's decisions are generally done by the male members of the household (SNV, 2011).

This paper begins with a brief description of rural biogas adoption for farmers in different parts of Asia, in which the benefits of adoption in terms of health, environment and economy are discussed. Also, foreign policy for biogas adoption is also briefly mentioned, followed by analysis of problems encountered during the development process. Then, a transitory paragraph on general information of Selo is presented, after which the methods, results and conclusions of this research are given. The aim of this paper is to assess the economic benefits and its greater potentials from installing household-size biogas digesters by using a case study performed in Selo, Boyolali.

## 2. Biogas Adoption in Rural Communities

Many have seen the benefits of biogas adaptation in the rural communities, as the amount of constructed plants are in the increase, especially in times of environmental awareness and financial constraint. Previously conducted case studies on introducing biogas installations in rural areas in Bangladesh (Biswas et al., 2001), Taktse (Tibet) (Liu et al., 2008), and other parts of China (Chen et al., 2010, Feng et al., 2012, Li et al., 2005, Zhang et al., 2009) provide preliminary information on rural energy and organic fertilizer development, environmental protection and health improvement.

In Taktse, energy consumption using conventional energy resources (i.e. biomass) has led to serious health impairments as a result of discharged smoke when burning biomass directly for cooking (Liu et al., 2008). Also, entirely eliminating biomass from the crop fields had led to land degradation, soil erosion and desertification, which can be avoided by making use of biogas plants, as digester slurry will ensure the minerals inhabit the land again (ibid.). Furthermore, biogas usage will not bring about smoke production, thus eliminating health hazards biomass-burners would generally experience. Comparable to the situation in Selo, Taktse has also experienced severe deforestation due to firewood being the primary source of energy, which, in Taktse, resulted in desertification and soil erosion (ibid.). In 2001, similar studies were conducted in Bangladesh, which introduced renewable energy technologies (RETs) as a means for reducing said environmental problems. Biswas et al. (2001) suggest that RETs may also serve as tools for income-generation by selling fertilizer. Fertilizer factories in Bangladesh would use up as much as 34.5% of Bangladesh's total natural gas

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consumption (Biswas et al., 2001), though two more recent studies present this ratio decreased considerably, as they showed numbers of around 10% (Rahman et al., 2013, Gomes, 2013). In Indonesia, the fertilizer industry also consumed a significant portion of as much as 11%[2] of Indonesia's total natural gas consumption in 2009 (Yasmin, 2013, Salami et al., 2010, Rachman and Sudaryanto, 2010, Munawar et al., 2003, Gellings and Parmenter, 2004, CIA, 2015, Bhat et al., 1994), indicating considerable opportunities for reduction in $CO_2$ emissions.. As biogas installations also provide organic fertilizer in the form of slurry, farmers could significantly reduce and even nullify the amount of synthetic fertilizer they would have to purchase and thus also reduce greenhouse emissions emitted from the industry.

China has administered many projects in favour of biogas energy adoption since the 1970s and made these household-scale plants affordable by subsidizing it momentously (Chen et al., 2010, Feng et al., 2012, Li et al., 2005, Liu et al., 2008, Zhang et al., 2009). In Yunnan, both provincial and local county governments together accounted for 50% of the costs, due to which a Chinese farmer would be able to redeem his personal investments in less than two years (Li et al., 2005). In many other areas, farmers made use of subsidies and bond funds (Zhang et al., 2009). The Chinese government's great efforts to popularize biogas resulted in an exponential growth of plants between 1978 and 2007, wherein over 25 million plants were built by the end of 2007 (ibid.). Farmers themselves built these digesters as "under the principle of self-building, self-managing and self-using", after having received subsidies and training (ibid.). Thus, "under policy encouragement and legal protection", biogas in China provides $1.54x10^8$ MWh annually (Feng et al., 2012).

Despite China's effort, the industry faces poor management, lack of materials, skilled labour, technical personnel and policy support (ibid.). As both "the majority of biogas users have not received technical training" and biogas literate staff were limited, only 60% of the plants still worked by 2007 (Chen et al., 2010). Also, a study in Yunnan (Li et al., 2005) showed that farmers would still use firewood as an energy resource due to low income. Indonesian Center for Agricultural Engineering Research and Development (ICAERD) research project on biogas also identified a lack of technical expertise by the staff, user-unfriendliness of the plant and high production costs (Widodo and Hendriadi, 2005). In fact, the local government of Boyolali carried out a biogas project in the 1990s, although unsuccessful due to slow progress and high costs (SLI, 2015). SLI, however, already planned to reduce aforementioned problems from occurring by designing cost-friendly plants, arranging quarterly bulletins, radio talk shows, field training on biogas development and training on slurry processing, over the course of 18 months (SLI, 2015). Albeit on a smaller scale than in China, farmers in Selo receive subsidized prices of the plants as well and may also receive additional funding using a community managed revolving credit scheme (ibid.).

## 3. Background information of Selo

As of 2013, Selo counts 27,198 citizens (BPS, 2014), of which most are occupied in agriculture—predominantly cabbage, carrot, cauliflower and mustard—and has to cope with land degradation, land slide formation and difficulties in disaster risk reduction, which all are in relation with Mt. Merapi's active volcanic activity. (Sagala et al., 2009) Next to cow dung , crop residues may also be used in biogas digesters—most farmers own livestock; predominantly in the form of cows (SLI, 2015, Idat G. Permana, 2012).

Assuming one bundle of firewood amounts to approximately 15 kg, having a calorific value of about 15.5 MJ $kg^{-1}$ (Centre, 2010) at a moisture content of a little less than 19% (Sinaga, 1994), around 1.5 GJ of firewood is burnt by a household in Selo per month, adding up to a total of about 2 GJ per month when accounting for LPG as well (SLI, 2015). Then, if one plant produces around 10.3 kWh $day^{-1}$ (36.9 MJ $day^{-1}$), 1.1 GJ in energy could be saved monthly (Feng et al., 2012).

Various entities influence the development of sustainable biogas development. Farmers form the main group of stakeholders, as they will have to purchase, implement and maintain the biogas plants.

[2] The energy costs for ZA (Ammonium Sulfate) were estimated at 11 MJ $kg^{-1}$; deviations hardly influence the result.

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Further, the local government is a stakeholder as well and forms the executive branch of governance, making their core responsibility policy implementation (Cahyat, 2011). The Bappeda (i.e. the local government's regional development planning agency) plays a major role in project budget allocation and so has the most influence in local governance (ibid.). Dinas, the local government's external service provider, could aid in enhancing education services and public infrastructure and thus behaves as a key player as well (ibid.). The national government is of less direct influence, yet remains important as it could, for instance, allocate more funds into rural energy development and thus has the power to enhance biogas production momentously—the case of China clearly displays this. Furthermore, SLI acts as the primary initiator and organizer of the biogas project in Selo, and provides the villagers—in collaboration with Mt. Merapi National Park—funding, micro-education (trainings), raises awareness, monitors and evaluates the development process. As various stakeholders play a part in the development process, it may be wise to develop a multi-stakeholder platform on the basis of public-private partnership, as suggested by SNV in order to ensure ownership, accountability and transparency during all stages of the development process (Ghimire, 2013).

## 4. Methods

*4.1 Data collection tools*

In order to gather direct information on the acquired benefits from biogas adoption of farmers in Boyolali, questionnaires have been set up. The questionnaires included questions on basic information on the farmer's household, energy consumption and costs of both biogas users and non-users. The survey also included questions on the benefits and costs adopters have experienced themselves. See the Appendix for an elaborate overview of the questionnaire.

*4.2 Data collection method*

As the data originated from specific entities only, i.e. farmers who do not use biogas (N=5) and farmers who do (N=21), the collection method is performed in the form of homogeneous, purposive sampling. A 'Merapi Landcare' biogas facilitator provided the names of the farmers who had digesters installed. Then, ten non-biogas users were interviewed and twenty biogas users of which the digesters ranged from 4 $m^3$ to 12 $m^3$ in size were interviewed in a span of three days. The interviews were semi-structured, in that the interviewee could provide more information if needed. Further, the interviews were held directly, in private, and inside their own households, in order to ensure all questions are properly understood and to minimize non-response (Dialsingh, 2008). Lastly, an experiments for determining the heating value of biogas were also performed, of which the tools are explained in further detail in section 4.3.

*4.3 Data analysis*

Biogas usage is compared by scrutinizing both biogas-households' current situations—these are in terms of energy consumption, GHG emissions and financial costs—and that of non-user households. The total costs and energy consumption of a farmer were determined according Eqs. 1 and 2 respectively. $C_{plant}$ is the purchasing cost for the biogas plant, $C_{run}$ the running costs of the plant per unit time, $c_i$ the specific costs of a product $i$ per unit time per unit mass or volume, with $i$ = 1,2,3,4 which are LPG, wood, fertilizer and biogas respectively. The same is done for determining the energy consumption in Eq. 3, where $e_i$ is the heat of combustion ($\Delta H_c$) of a fuel or, in the case of fertilizer, the production energy needed per mass. $E_{el}$ is the amount of energy consumed from electricity.

$$C_{tot}(t) = C_{plant} + \left( C_{run} + \sum_{i}^{N=3} m_{eq,i} c_i \right) \cdot t \quad \text{(Eq. 1)}$$

$$E_{tot}(t) = \left( E_{el} + \sum_{i}^{N=4} m_{eq,i} e_i \right) \cdot t \quad \text{(Eq. 2)}$$

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The heat of combustion for biogas can be estimated at around 20– 40 MJ m$^{-3}$ though it would be more accurate to determine it experimentally, which can be done by heating water with a known amount of volume with biogas. See Eq. 3 for the expression of the formula used for this experiment: $\rho$ is the density, $c$ the specific heat capacity, $T_p$ the temperature at time-point $p$ and $\eta_{stove}$ an estimated efficiency of the stove. The heating value for wood is also determined using Eq. 3.

$$\Delta H_{c,i} = \frac{1}{V_i}[V\rho c(T_1 - T_0)]_{H_2O} \cdot \frac{1}{\eta_{stove,i}} \quad \text{(Eq.3)}$$

The amount of biogas $V_{bgas}$ used is determined by multiplying the average volumetric flow rate with which biogas flows through the stove $\dot{V}$ times the amount of time $t_{heat}$ needed to heat the water—see Eq. 4. The average flow rate $\dot{V}$ is determined from the survey.

$$V_{biogas} = \dot{V} t_{heat} \quad \text{(Eq. 4)}$$

Further, to estimate the volume-percentage of methane (MP) Eq. 5 is used.

$$MP = \frac{\Delta H_{c,bgas}}{\Delta H_{c,CH_4}} \times 100 \quad \text{(Eq. 5)}$$

Biogas adoption of households will also have an impact on GHG, and will thus also be calculated. Solely the differences in $CO_2$-emissions will be determined, for these make up for the greatest share of emissions from LPG and wood. Note that, for simplification, only emissions from burning the fuels are taking into account, meaning no other sources of $CO_2$ emissions such as those from production or transportation are accounted for. Biogas combustion is carbon neutral, and thus will neither contribute to the emission rates, also using the previous assumption. Burning wood is considered not carbon neutral, as the trees cut are not reforested. See Eq. 6.

$$EM(t) = \left( \sum_{i}^{N=3} \sum_{j}^{M=2} E_i q_{i,j}\, GWP_j \right) \cdot t \quad \text{(Eq. 6)}$$

The energy usage $E_i$ is in MJ month$^{-1}$ and $q_{i,j}$ is the specific carbon dioxide ($j$ = 1) emission in kg $CO_2$ MJ$^{-1}$ or methane emission ($j$ = 2) in kg $CH_4$ MJ$^{-1}$ and GWP the Global Warming Potential.

Finally, Table 1 lists the values and units of the quantities used in the calculations (Quaschning, 2013, Chemicals, 1999, Francescato et al., 2008, Shrestha, 2001, Pathak et al., 2009).

**Table 1 Parameters used in the model**

| Quantity | Value | Unit |
|---|---|---|
| $e_f$ | 11.26 | MJ kg$^{-1}$ |
| $\Delta H_{c,LPG}$ | 46 | MJ kg$^{-1}$ |
| $\Delta H_{c,wood}$ | 18.9 | MJ kg$^{-1}$ |
| $\Delta H_{c,bgas}$ | 16 | MJ kg$^{-1}$ |
| $\Delta H_{c,CH_4}$ | 50 | MJ kg$^{-1}$ |
| $q_{LPG,CO_2}$ | 2.94 | kg $CO_2$ kg$^{-1}$ |
| $q_{wood,CO_2}$ | 1.83 | kg $CO_2$ kg$^{-1}$ |
| $q_{wood,CH_4}$ | 3.9 | g $CO_2$ kg$^{-1}$ |
| $q_{ngas,CO_2}$ | 0.051 | kg $CO_2$ MJ$^{-1}$ |
| $GWP_{CO_2}$ | 1 | kg $CO_2$ eq. kg$^{-1}$ |
| $GWP_{CH_4}$ | 25 | kg $CO_2$ eq. kg$^{-1}$ |
| $\rho_{water}$ | 998 | kg m$^{-3}$ |
| $c_{water}$ | 419 | J kg$^{-1}$ K$^{-1}$ |
| $\eta_{stove,wood}$ | 0.15 | - |

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| Quantity | Value | Unit |
|---|---|---|
| $\eta_{stove,bgas}$ | 0.25 | - |

## 5. Results and Discussion

*5.1 Problems and Approaches in Selo*

Based on the interviews, several problems in Selo and their causal-relationship and how it is seen from causal-relationship perspective. The problem started with a low awareness of the environmental problems by the community, which induces little policy making and monetary aid for RET development and adoption (Turnbull et al., 2014). This precipitates unsustainable activities in household energy production, namely cutting trees for firewood and burning LPG, which have negative effects on women's workload, health, financing, micro-environment (land degradation) and macro-environment (global warming). These problems are inter-related and are portrayed in Figure 1 in the form of a problem tree. Moreover, these problems are expected to reduce in size through biogas adoption, of which the solution tree is portrayed in Figure 2. Health problems and land degradation are phenomena difficult to measure in a short period of time, so only the effects of biogas adoption on the energy usage, workload and fertilizer consumption are analysed—land degradation cannot be solved with the help of biogas digesters, for, in Selo, creating room for agriculture forms the main cause for deforestation.

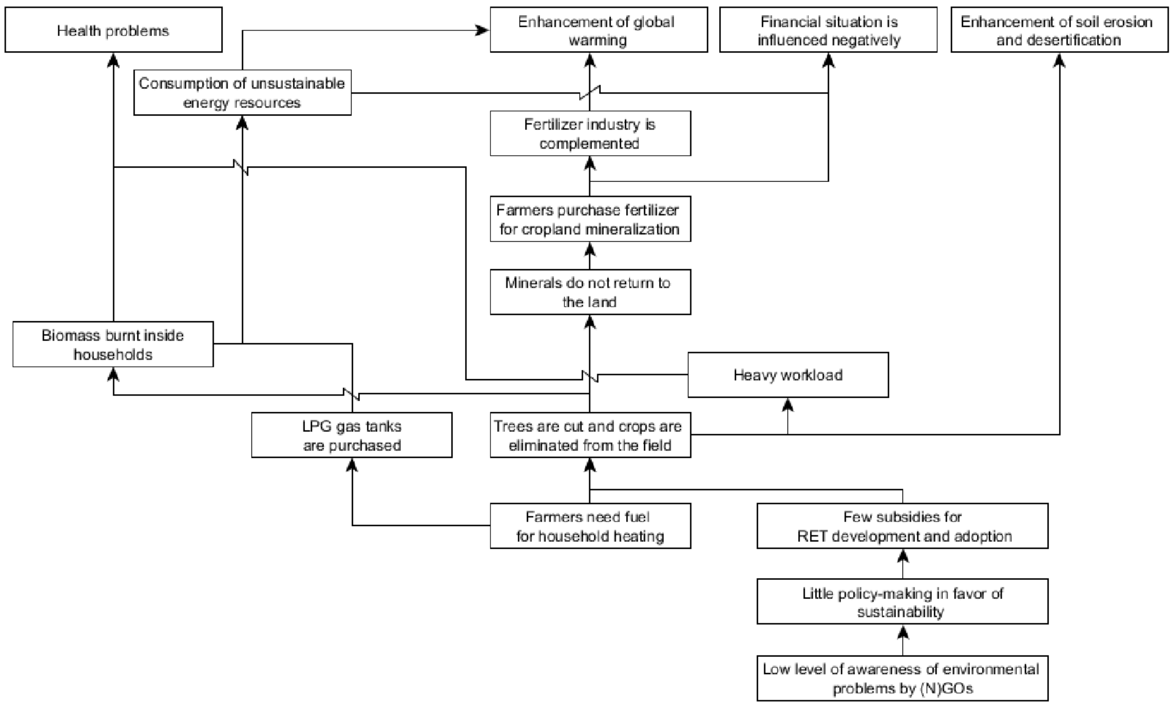


**Figure 1 Problem tree of Environmental-Energy Problems in a Rural Area**

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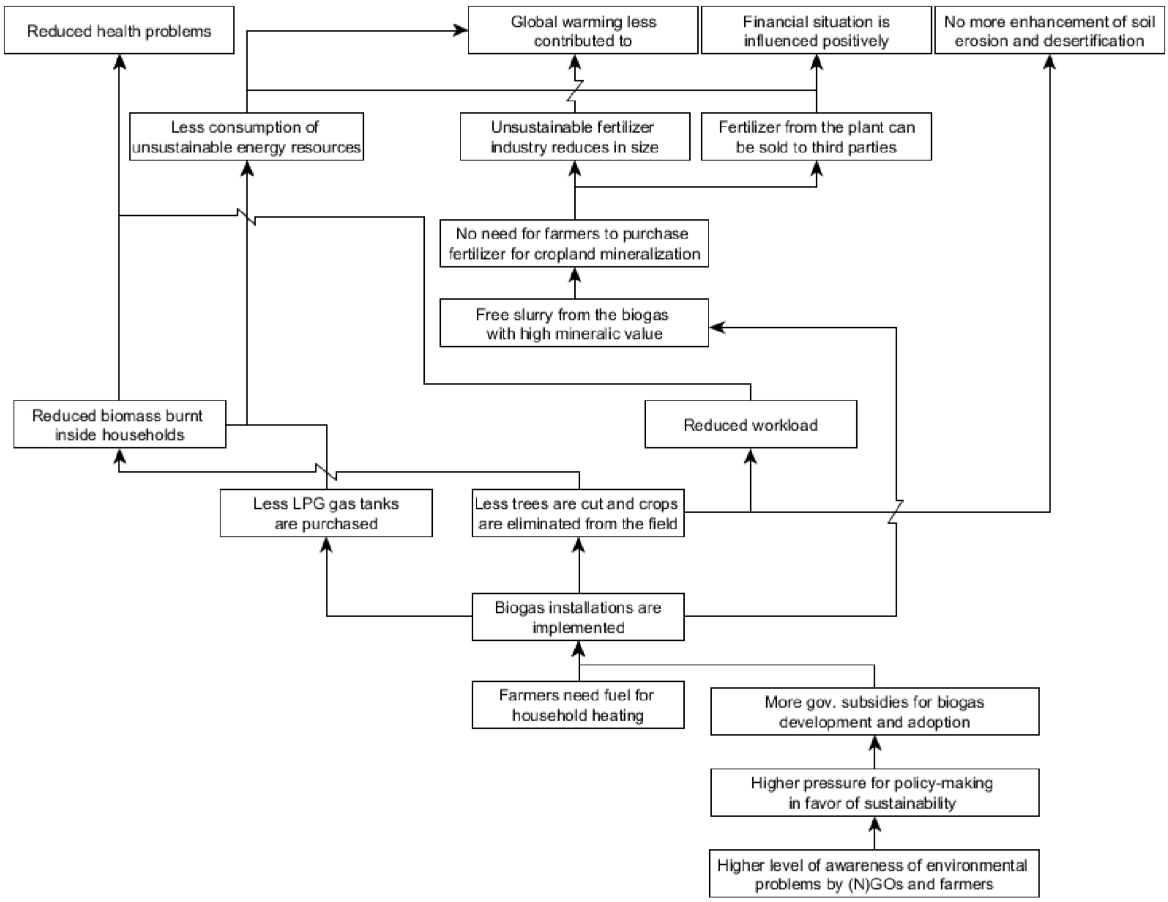


**Figure 2 Solution tree of Environmental-Energy Problems in a Rural Area**

*5.2 Rural household and biogas digester profile*

Tables 2 and 3 show an overview of rural biogas user's household and digester profile. Even though the farmers also cultivate other crops—primarily carrot, cabbage and tobacco—all surveyed biogas users only use cow dung and urine as their digester input, having digesters ranging from 4 $m^3$ to 12 $m^3$. Water is only added for making the dung flow through the pipes which connect the cowsheds with the digesters, of which water scarcity is a major factor. Further, a mean of 3.2 cows per household were measured, with a standard deviation of about 2.5 cows. Due to the large standard deviations, it is statistically impossible to connect the mean differences in income to not having adopted to biogas ($p=0.16$), although $4/5^{th}$ did mention their low income as the main factor for not having done so. One would need at least eight more samples for the difference to be significant ($p<0.05$). Furthermore, the farmers were not able to determine the amount of dung that was supplied to the digesters, nor could they mention the amount of biogas they would use per unit time, because none of the users had a flow meter installed—four users did have a water-filled U-tube manometer, yet it is difficult to use these to relate pressure differences in absolute amounts of biogas usage. Remarkably, biogas usage has not reduced monthly expenses ($p=0.33$). In the next section, energy consumption, costs and emission will be examined in detail, which will show that the differences in energy consumption in fact are considerable, which in turn may indicate a shift in overall consumption rather than the expected absolute reduction.

For determining the heat of combustion, the experiment mentioned in section 4.3 was conducted, due to time constraints, only twice and at one household that had adopted a 4 $m^3$-sized digester. The biogas had a heating value of only 16±1.5 MJ $m^{-3}$, with an MP of 31±6%, which resemble the values found in the literature in order of magnitude (40-70%, (Esfandiari et al., 2011)), although considerably lower. A slight correction through adding vessel calefaction showed it contributing only in the $10^{-1}$ MJ order of magnitude. A variable strongly influencing the calculation is the unknown—and thus assumed—stove efficiency: a variation of -5% would already lead to a calculated MP of 40%. Nevertheless, a more apprehensible explanation for the relatively low heat of combustion is that it may be caused by the household owner not mixing the dung with any water—and, in fact, not mixing the dung at all (Naik et al., 2014). The daily ambient temperature fluctuations of 15˚C to 31˚C during all seasons in Selo also negatively influence biogas quality (i.e. MP) (Sorathia et al., 2012). Finally, a heating value of 18.9 MJ/kg was found for the wood, which closely resembles the range of values one finds in literature.

Higher biogas quality could be obtained by creating more awareness amongst the users and by teaching them—women especially, as they are the main operators in the cowsheds—the skills to act upon it. Some principal steps that could lead to enhancing the quality are adding water to the dung and mixing it. The issue on water scarcity for mixing dung may demand water acquisition techniques such as rainwater harvesting. It is recommended to conduct additional research on this issue to further assess the possibilities in improving biogas production. Lastly, collective action at village level may help to increase digester benefits, for Sagala et al. (2009) found that collective action among the villagers in Mt. Merapi plays an important role in development and is found to be particularly effective in rural areas, since social capital is still high due to their common interests and close social ties.

**Table 3 Average biogas digester profile**

| Biogas | Age (years) | Household size (-) | Income (IDR $month^{-1}$) | Expenses (IDR $month^{-1}$) | Cows (-) | Land ($m^2$) |
|---|---|---|---|---|---|---|
| Yes (N=18) | 34 (σ =7) | 4.5 (σ =1) | 2,364,706 (σ =0.9x$10^6$) | 1,762,500 (σ =0.6x$10^6$) | 3.2 (σ =3) | 1971 (σ =2 x$10^3$) |
| No (N=4) | 41 (σ =19) | 5 (σ =1) | 1,875,000 (σ =0.9x$10^6$) | 1,575,000 (σ =0.7x$10^6$) | 2 (σ =0) | 1625 (σ =2 x$10^3$) |

**Table 2 Average household profile**

| Digester size ($m^3$) | Amount of digesters (-) | Purchasing costs (IDR) | Water supplied (litres $day^{-1}$) |
|---|---|---|---|
| 4 | 6 | 2,5 million | 0 (σ =0) |
| 6 | 3 | 3,3 million | 10 (σ =0) |
| 8 | 8 | 2,8 million | 0.9 (σ =2) |
| 10 | 1 | 5 million | 0 (σ =0) |
| 12 | 3 | 5 million | 3 (σ =6) |

*5.3 Energy and fertilizer consumption, costs and environmental impacts*

The survey clearly shows differences between biogas users and non-users in fossil fuel and fertilizer consumption, which directly influence the farmers' micro-economic conditions. Worth mentioning in particular is that all interviewees mentioned that, in a 6-year period, no costs for maintenance were disbursed at all—whether this is due to non-necessity or unawareness is unknown. The purchasing costs signified the only financial barrier for biogas usage. Moreover, a household saves approximately 490 kWh $month^{-1}$, replacing significant amounts of energy taken from LPG and wood in particular. See Tables 4 and 5 for an overview of the average monthly energy consumption and energy cost structure. Noteworthy is that they also show that chemical fertilizer consumption per surface area remains virtually equal, despite the advantage of having digester slurry available, which results in users missing out on the potential in the financial benefits from the digester. As the digester only provides 20,000 IDR monthly, an average of 13 years would be needed to cover the purchasing costs—over 10 years longer than initially projected by SLI. Finally, a considerably positive effect ($p<0.05$) of biogas usage is seen in the hours spent on activities related to the energy consumption, of which time saved through cooking and collecting firewood are particularly notable. Table 6 shows the emissions from the various products used that are expected to be influenced by biogas consumption and there indeed is a significant difference between users and non-users in $CO_2$ emissions through reduced consumption of LPG ($p<0.01$) and wood ($p<0.05$), which amounts up to an average of 185 kg

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$CO_2e$ emission reduction household$^{-1}$ month$^{-1}$. In total, the forty digesters in Selo save 90 tonnes of $CO_2e$ year$^{-1}$.

The economic benefits in terms of reduced workload, wood, LPG and fertilizer consumption have thus been measured: biogas implementation reduced the former three significantly, in contrast to the latter variable. Also, as a 13-year period for covering the purchasing costs seems relatively high, it is recommended to take more non-user samples in order to more accurately assess the financial benefits of biogas adoption. Nevertheless, measures have to be taken in order to more effectively make use of the benefits digesters may engender to further decrease costs and $CO_2$ emissions. In Nepal, it was needed to create awareness among the users to improve utilization of the biogas slurry (Galli and Pulchok, 2001), which is likely needed in the case of Selo as well, as observations in Selo pointed out that users still did not completely 'believe' in the effectiveness of the slurry. Analogous to paragraph 5.2, further research is needed to understand why chemical fertilizer consumption has not decreased among biogas users and to develop methods in tackling this phenomenon.

**Table 6 Average $CO_2$ emissions per household**

| Biogas | LPG (kWh) | Wood (kWh) | Electricity (kWh) | Fertilizer (kWh) | Total energy (kWh) |
|---|---|---|---|---|---|
| Yes (N=17) | $5.2x10^1$ | $2.4\ 10^2$ | $3.5x10^1$ | $1.7x10^2$ | $4.9x10^2$ |
| No (N=4) | $1.6x10^2$ | $6.6x10^2$ | $4.2x10^1$ | $1.1x10^2$ | $9.8x10^2$ |

**Table 4 Mean monthly energy usage**

| Biogas | LPG (IDR) | Wood (IDR) | Electricity (IDR) | Fertilizer (IDR) | Time spent[3] (h) | Total costs (IDR) |
|---|---|---|---|---|---|---|
| Yes (N=14) | 17,986 | ~0 | 24,233 | 31,917 | 109 | 71,069 |
| No (N=3) | 55,367 | 0 | 30,833 | 21,389 | 152 | 91,417 |

**Table 5 Mean monthly costs**

| Biogas | LPG emission (kg $CO_2$ eq.) | Wood emission (kg $CO_2$ eq.) | Fertilizer emission (kg $CO_2$ eq.) | Total emission (kg $CO_2$ eq.) |
|---|---|---|---|---|
| Yes (N=20) | 13 | 118 | 36 | 167 |
| No (N=4) | 38 | 293 | 21 | 352 |

*5.4 Potential*

To estimate the potential effects of large-scale biogas adoption, found results can be further extrapolated linearly for the case when the entire regency of Boyolali adopts to biogas. On a yearly basis, complete rural biogas adoption by farmers in Boyolali Regency (N=256,560 (Raharjo, 2010)) would save 1.5 TWh and 0.57 megatonnes $CO_2e$. These emission reductions can be further used by selling it as carbon credit for a total of US \$5.7 million year$^{-1}$, having assumed a price of US \$10 tonne$^{-1}$ $CO_2e$ (Pathak et al., 2009).

As to be observed in China (see section 2), financial support from the governmental, project management and information dissemination to raise awareness may all greatly increase biogas usage in Boyolali. Biogas implementation on a larger scale, across Indonesia—in particular Java due to the prevalence of dairy farms there (Morey, 2011)—is recommended in that it promotes sustainable energy consumption, increases self-sufficiency, enhances socio-economic status, improves health and sanitation, reduces GHG emissions and may act as a stepping stone into further national sustainable development. As not only cow dung, but also other crop residues may be used as digester inputs, biogas adoption is not be limited to cow holders exclusively. India numbers on livestock population in ASEAN countries indicate the possibility for rural biogas implementation there as well—70% in Asia live in rural areas (Ahuja, 2012).

[3] Collecting wood, cooking, walking, collecting and supplying dung

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However promising, purchasing costs are for some farmers a clear obstacle in biogas adoption. Besides, lack of space next to the house also acted as a barrier in installing a digester. Yet one household in Selo did have a digester directly beneath the cowshed installed, and thus effectively eliminated the problem regarding available space. Furthermore, as cattle are also held in free range, manure collection and feeding can become problematic. A weak industrial sector that facilitates the technologies may also be a constraint for the successful large-scale uptake of the biogas technology, whereas a lack of maintenance, repair and other services also form major limiting factors for biogas adoption. Furthermore, as observed in Selo, biogas quality is prone to reduce in quality from improper digester management. Nevertheless, as efforts can be made to increase digester plant effectiveness, the large potential of $CO_2$ emission reductions should spur policy makers in supporting national biogas development under the notions of environmental preservation, self-sufficiency and overall sustainable development.

## 6. Conclusions and recommendations

Biogas adoption lead to significant reductions in fossil energy consumption (50%) and overall workload has been reduced by nearly 30%. As farmers put virtually no effort in either time or money for, for example, supplying the digester with water, mixing the input or maintenance, additional methods have to be taken up by farmers in order to increase the digester's overall effectiveness, in terms of both its impact on energy and chemical fertilizer consumption. Collective action amongst the villagers and training the women-folk to more effectively operate the digester could be a method to increase digester performance and so further reduces their workload, yet it is unknown whether the women are prepared to adapt. Evaluating which methods would be most suitable to adapt to stands beyond the scope of this paper.

Despite the digesters not performing as well as anticipated, the biogas installations still induced significant GHG emission reductions. Moreover, when methods are found that will enhance household biogas quality, emission reductions are likely to increase as well, which should pursue policy makers and NGOs in expediting biogas development and awareness raising on larger scales: regency expansion (N=256,560) may save up to 1.5 TWh, 0.57 megatonnes $CO_2e$ and US $5.7 million from selling carbon credit per year.

Involvement of governmental and non-governmental stakeholders will be important to promote biogas implementation in rural areas in Indonesia. This can be supported by issuance of policy by its related local governments, such as the agriculturaland energy department.

Further research is needed using higher sample sizes for specifically non-users to more adequately assess the impacts of biogas adoption on a household's financial situation and energy consumption.

More experiments must be performed on determining the biogas quality of household digesters, using more appropriate methods for determining the amount of biogas used in particular. Also, fixed variables such as the efficiency of the stove must be known, as these may greatly influence the outcome of the calculations. Only then, one can say with more certainty the digesters underperform considerably, from which naturally follows that firewood consumption remains necessary to meet the energy needs.

Finally, it is important to point out that this research can be extended to other rural areas in Indonesia to provide further information on how rural biogas adoptioncan bring benefit to other agricultural-based villages.

***Acknowledgments***

This working paper is a result of intership activity by Zakaria Tazi Hnyine under the supervision of Dr. Saut Sagala at Resilience Development Initiative, Bandung. The authors would like to thank Dr. Clancy for her constant feedback throughout the research, Ms. Rianawati for facilitating the internship at Resilience Development Initiative, Mr. Lubis and Mr. Yamin for conducting the questionnaires, Mr. Sartono and Mr. Pramudiyanto for their assistance during the field survey and the farmers for their willingness and transparency in answering the survey questions. Finally, we would like to thank Mr. Deni Nugraha and Ms. Rintakasari Vitri for their assistance during the research preparation and data collection. This working paper benefits from a research grant entitled: "Economic Potential from Rural Energy Supply with Biogas from Community Owned Livestock" provided by the Institute of Technology Bandung under 89.10/I1.C10/KU/2015.

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