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Relevance of biogas technology to Vhembe district of the Limpopo province in South Africa

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ABSTRACT

Biogas is a clean and renewable form of energy available to low-income households through anaerobic digestion of readily available organic waste. A biodigester converts fermentable organic matter into a combustible gas and organic manure. Anaerobic digestion is a process of subjecting the material to microbial decomposition in the absence of air, yielding finally, methane, carbon dioxide, and water inside the biodigester. In the recent years, biogas has attracted wide attention in view of the fuel crisis and the environmental pollution associated with the fossil fuel, and its importance as an efficient and non-polluting energy source is now well appreciated. The objectives of this desktop study are to investigate the relevance of biogas technology use for substitution of solid fuels in rural areas of Vhembe district, the subsequent health co-benefits, and the constraints to adoption of domestic biogas technology in South Africa. The correlating factors influencing decisions in the sustainable adoption and utilisation of biogas technology in Vhembe district of Limpopo Province in South Africa are examined. In this study, the sampled households involved 72 biogas users and 128 non-users. The sampling techniques was purposive and simple random. The study was based on primary data that was elicited using open and closed-ended questionnaires. The logistic regression model was employed for data analysis. The energy demand of low-income South African households for cooking with fuelwood was found to be 27 MJ/day and the total energy demand 68 MJ/day. Approximately 625 000 households in Vhembe district can potentially benefit from bio-digester fed with cattle and pig waste, on the basis of livestock numbers. Most governments worldwide are now considering locally accessible, available, and renewable substitute energy options.

1. Introduction

According to [1], Africa is a net energy exporter, but the majority of its population lacks access to clean energy, and many African countries rely on imported energy. Biomass, mainly in the form of fuelwood and charcoal, is the dominant energy source used in sub-Saharan Africa (SSA), and this accounts for approximately 74 % of total energy consumption there, compared with 37 % in Asia and 25 % in Latin America. Half a billion of people living in SSA do not have access to electricity in their homes and rely on solid fuels (fuelwood, agricultural/crop residues and animal wastes) to meet basic energy needs for cooking, heating and lighting [2]. However, these traditional fuels do have disadvantages and are as follows: (i) they are inefficient energy carriers and the heat release rate is difficult to control; (ii) they release harmful gases; and (iii) the current rate of extraction is unsustainable [3].Reliance on fossil fuels for energy provisions is well documented all around the world [2]. South Africa depends largely on coal as the main energy source contributing, and this contributes about 77 %, with 92 % production of the total coal consumed on the continent. According to the research done by the World Bank [2], in South Africa, 15 % of households did not have access to electricity in 2014 and used fuelwood as the main energy source. Approximately 54 %, 46 % and 29 % households without access to electricity rely on fuelwood as the main energy source for cooking, water heating and space heating, respectively [23]. In the South African context, fuelwood can be considered the major solid fuel of concern for substitution with biogas (DoE, 2013). The proportion of South African households that rely on coal as the main source of energy for cooking and space-heating declined from 3 % to 0.8 % and 5 % to 1.8 %, respectively, from 2002 to 2012 [4,5]. Mpumalanga province remains the main user of coal, with 5.7 % and 10.5 % of households still relying on it for cooking and space-heating respectively [5].

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Biogas energy is currently employed in the developing world, especially Asia to meet energy demand by low-income households and combat the environmental and health effects of solid fuel use (SFU) [6]. Biogas has proven to be a promising, realistic and feasible technology in providing clean and reliable energy [7]. Biogas, as an alternative is a renewable and sustainable energy source that can offer green energy [3]. This energy source can be used for domestic purposes, such as cooking and heating, and can also be converted into electricity which still must be exhausted for rural areas [8]. Biogas technology is of particular significance in rural households, where energy crisis thrives [9]. It is produced through anaerobic digestion (AD) of organic waste (i.e. kitchen, animal and human waste), making the technology ideal for developing countries that lack waste handling and sanitation facilities. South Africa, unlike its Asian counterparts, is amongst the African countries that have seen limited growth in terms of domestic bio-digester installations, which Bond and Templeton [10] attribute to limited research.

The level of dissemination and development of the technology remainsvery low, despite the relatively high potential endowed in the country for its expansion [24]. Although there has been widespread academic research into the position, projections and limitations of domestic biogas technology in the developing world [1,3,6,8,10–13], scant research is available in the South African context. Hennekens [14] conducted a study aimed at gaining a sociological understanding of the potential of biogas practices to address the problem of domestic energy in low-income households, in rural and peri-urban areas in South Africa. A study was also conducted by Austin and Blignaut [26], as cited in Smith et al. [25], which highlighted some of the social, economic and environmental benefits associated with implementation of a rural bio-digester programme in South Africa. The objectives of this desktop study are to investigate the relevance of biogas technology for substitution of presently used solid fuels in rural households, the consequent health co-benefits and the constraints to adoption of domestic biogas technology in Vhembe district.The correlating factors influencing decisions in the sustainable adoption and utilisation of biogas technology in Vhembe district of Limpopo Province in South Africa are examined in this article.

2. Description of the study area

The Vhembe District Municipality (VDM) is situated in the northern part of the Limpopo Province. The district municipality shares borders with Zimbabwe and Botswana in the north-west, and Mozambique in the south-east through to the Kruger National Park. The Limpopo River valley forms the border between the district and its international neighbours. It is comprised of four local municipalities: Musina Local Municipality (LM), Mutale Local Municipality (LM), Thulamela Local Municipality (LM) and Makhado Local Municipality (LM). The region is well endowed with abundant agricultural resources and it is one of the prime agricultural regions noted for production of fruits and vegetables [27].The district is regarded as one of the lowliest in the province, with a high unemployment rate and socio-economic challenges that persist in the rural parts. In the rural areas of the district, most of thehouseholds, which comprise much of the population, depend on government grants, pension and remittances from family members. Compared to other districts, household affluence is comparatively lower. At the time of this study being conducted, the major feedstock for biogas digesters was cow dung and it is hoped that it can potentially influence the level of adoption of the technology due to adequate supplies of the raw materials.

3. Data collection and sampling methods

This study was centered at household survey conducted in Vhembe District of Limpopo Province. The district was chosen specifically because of the government pro-poor energy alternatives, organic waste-to-energy and other low carbon technologies that are being promoted. Self-administered semi-structured questionnaires and interviews were used to elicit primary data from the respondents in the households. Ethical considerations were strictly adhered to. The data collected include socio-economic and demographic information, resource availability, awareness and perception, experience and promotion of biogas technology. These instruments were developed on the basis of the research objective and reviews of literature related to the adoption of technology which were pretested before the actual field survey. Relevant information for this study was gathered from unpublished and published research which elicited the secondary data. The sample for the present study was drawn from households with both biogas digesters (users) and without biogas digesters (non-biogas users), henceforth referred to as 'biogas adopters' and 'non-adopters', respectively. These are those who are using biogas technology as their source of energy for cooking and non-users are those who are not using biogas either for cooking or lighting. After an in-depth review of households with biogas digesters in the province, 72 households were purposively sampled, while 128 households without digesters were randomly sampled. From the households with biogas digesters, at least one household without a digester was chosen randomly, in order to elicit their view regarding whether a household with a digester influences their perception about the technology. The sampling technique was not based entirely on one sampling type because in the study area, the number of households with biogas digesters was smaller, compared to households without digesters and thus the inference from the sample could not be drawn from one sampling technique.

4. Results and discussion

Energy demand for cooking and the total energy demand by an average sized household were found to be 27 and 68 MJ/day/household (energy cooking needs per household) respectively.The biogas requirement for fuelwood replacement used for cooking is estimated at 2 500 L/day/household. This concurs with the biogas requirement for cooking of 1 500-2 400 L/day/house- hold of biogas [10]. In low-income South African households, approximately 80 % of the total energy used for cooking, space-heating and water-heating is derived from burning fuelwood [15]. This concurs with the assumption made by Pathak et al. [16] and Surendra et al. [13] that 80 % of the produced biogas would be used for replacement of fuelwood and the remaining 20 % would replace paraffin used in households for cooking and lighting respectively. Complete substitution of conventional domestic fuels with biogas requires 5 000 L/day/household for cooking, water- and space-heating and 1 250 L/day/household for lighting. Due to the low efficiency of biogas lamps and their associated safety concerns, the use of biogas for lighting is discouraged. The use of alternative lighting technologies such as PV solar home systems, comprising a solar panel, battery, light-emitting diode lights and a cell phone charger, are recommended.

Cooking represents one of the most energy-intensive applications. For example, Fig. 1 shows that in rural areas of Vhembe district fuel wood is the significant energy source for cooking at 63 %, followed by electricity at 34 % and other between 1 and 2 %. But the high percentage of cooking is represented by firewood which is a concern; hence biogas is a viable option for the district (Fig. 2).

Concerns caused by reliance on traditional biomass for cooking are now well known. The smoke emitted by burning offire wood in

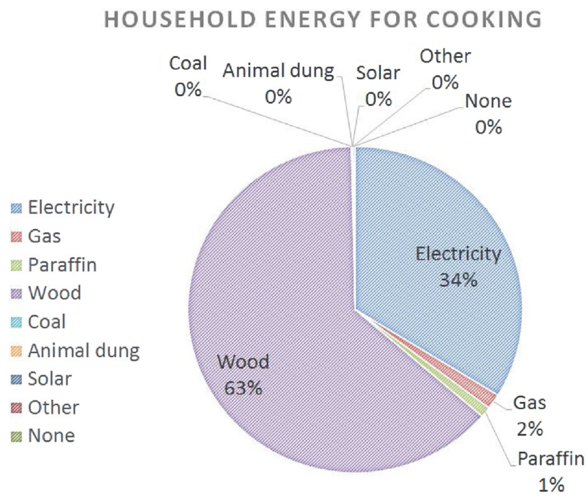

Fig. 1. Household energy usage percentages for cooking in Vhembe district SSA, 2011).

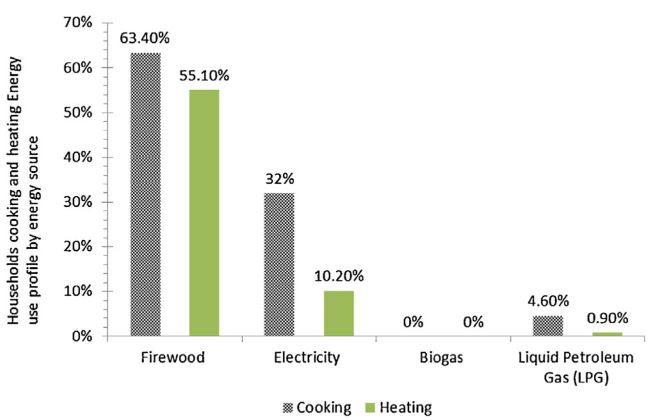

Fig. 2. Households cooking and heat energy use profile in the study area.

traditional cook-stoves contains harmful pollutants including particulate matter [17]. Indoor air pollution levels in rural households are often much higher than outdoor air pollution because of burning especially firewood. For instance, typical levels of particulate matter i.e. PM10 in rural households range from 300 to 3000 μg per cubic metre [17] and these causes serious threat to the users thereof. World Health Organization has reported that almost 40 % of acute respiratory infectionand about 20 % of chronic obstructive pulmonary illnesses are caused by indoor air pollution from the burning of fuelwood (Arcenaset al., 2010). This is a problem in rural areas because of indoor air pollution caused by using fuel wood. Also the use of fuel wood for cooking also causes deforestation.The net direct-use value of fuelwood is approximately R1 250 per household per year, where net direct-use value is the gross market value of fuel-wood (R1 970) less the opportunity costs associated with collecting fuelwood (R720) [15]. Census 2001 showed that 2.3–2.8 million households rely on fuelwood, which translates to a total gross national net direct-use value of fuelwood at about R3-R3.5 billion/annum in 2008 values [15].

Installation of a 2 500 L/day capacity bio-digester per household will result in a 50 % reduction in total household fuelwood use whereas a 5 000 L/day capacity bio-digester would result in 100 % reduction in the total household fuelwood use. This is comparable with the 74 % and 84 % reduction in household fuelwood use because of domestic biogas implementation in China and Sri Lanka respectively (Remais et al., 2009; [10,28]). Based on the inflated net direct use value of fuelwood (R1 808/annum) and the inflated upper band in the income range of low-income household (R21 013/annum), the installations of a 2 500 L/day capacity bio-digester will result in 4.3 % household income savings. Installation of a 5 000 L/day capacity bio-digester will result in 8.6 % household income savings. There are approximately 1.581 million households in South Africa that still rely on fuelwood as the main source of energy for cooking [4]. This translates to a national cost savings of R1 billion/annum by replacing fuel-wood used for cooking with biogas, not taking into account the value of wood as an environmental asset.

Various studies have shown reasonably consistent and strong relationships between the indoor use of solid fuels and a number of diseases [17]. They estimate that indoor smoke from solid fuels causes about 35.7 % of acute lower respiratory infections, 22.0 % of chronic obstructive pulmonary disease and 1.5 % of trachea, bronchus and lung cancer. Indoor air pollution (IAP) may also be associated with tuberculosis, cataracts and asthma. Various estimators of the health impact of air pollution were employed in recent health impact assessments.

Bembridge and Tapson (1993) and Gaudex [18] reported that in Southern Africa 68 % of communal farmers own fewer than ten cattle, with an average of six per household. Approximately 613 662 South African households can potentially benefit from a 2 500 L/day bio-digester installations fed with cattle dung. Approximately 131 391 households can potentially benefit from installations of a 5 000 or a 6 250 L/day capacity bio-digester fed with cattle dung (Table 1).The number of households involved in poultry production was estimated at 1.4 million [19]. The total number of chickens in South African households reported by Statistics SA [20] was 22.8 million. The number of chickens per household (involved in poultry production) can be estimated at 16. Based on the number of chickens required, it is infeasible to operate a bio-digester fed solely with chicken waste at house hold level in South Africa. A chicken farm is required for such an application.

Table 1 clearly shows that if there are a required number of livestock and the amount of manure produced, about 0.2 cubic meter of methane gas can be produced which can provide cooking needs. A case study at a local cooperative where they use chicken droppings as the main feedstock of a digester revealed that when biogas technology is fully implemented can provide the much needed biogas benefits. Evidence from the monitoring process and expression by the biogas users at the cooperative for cooking

Table 1
Showing the estimated number of animal available and biogas potential (Vhembe District).

	Animals Number	Manure outcome Kg/animal	Organic dry matter (ODM)	Methane outcome
Cow manure	1050685	12 kg/animal	16 %	0.2 Nm3 CH4
Pig manure	373037	5kg/ animal	17 %	3.6 Nm3 CH4
Chicken manure	1542903	0.08 kg/animal	25 %	0.35 Nm3 CH4
Sheep manure	253139	6kg/animal	50 %	0.053 Nm3 CH4
Goat manure	1147987	6kg/animal	50 %	0.367 Nm3 CH4

suggests that biogas if used to its full capacity can provide enormous benefits. The cooperative members revealed that their lives have dramatically changed ever since the introduction of the biogas digesters. They also have reported that their monthly expenses on cooking energy sources has been reduced dramatically since they no longer have to depend on fuelwood and LPG but rather biogas. In addition to saving on fuelwood purchases, they identified that they no longer needed to constantly manage cooking fires and that they were saving time as they were simply able to turn the gas on, light it and begin cooking without the need to watch over the process. Time saving, as a result of more efficient cooking practices and reduced fuelwood purchases and collection, reveals that a biodigester could contribute to promoting gender equality and empowerment of women as women are relieved of time-consuming domestic duties, while efficient cooking fuel and reduced wood harvesting also have the potential to ensure environmental sustainability.

The average size of a South African household is estimated at four [4,5]. Based on the number of people required, the average size of a South African household is insufficient to produce enough human excreta for feeding a 2 500, 5 000 and 6 250 L/day capacity bio-digester.A community bio-digester used by 15, 30 and 39 households is consequently recommended for feeding a 2 500, 5 000 and 6 250 L/day capacity bio- digester.The total food waste generated by South African households is estimated at 1.44 million tons/annum [21]. The number of households in 2011 was estimated at 14.6 million [4]. The average food waste generated can therefore be estimated at 270 g/day/household. Based on the calculated food waste, an average South African household produces insufficient food waste for feeding a domestic bio-digester.

Co-digestion of a 1:1 mixture of cattle dung and human waste is infeasible in South African context because of many people required per household. The majority of households that own cattle are necessarily in rural areas [19]. Co-digestion of cattle dung and human waste in a community digester is also infeasible for either rural or urban households because of the unavailability of cattle dung in urban areas and the segregated nature of rural households.Co-digestion of a 1:1 mixture of food waste and human waste requires a household with at least 19, 38 and 47 members and food waste of 9.5, 19 and 23.5 kg/day for feeding a 2 500, 5 000 and 6 250 L/day capacity bio-digester respectively. Based on the average amount of food waste generated by a South African household and the average household size, there is insufficient kitchen and human waste for feeding a domestic bio-digesters per household. A community digester in a peri-urban area/informal settlement is recommended, due to the availability of both food and human waste.In terms of water availability, non-sewered households generate sufficient grey-water for feeding a domestic biogas digester for cooking purposes (2 500 L/day/bio-digester). Grey water is therefore recommended over drinking water. Water consumption by non-sewered South African households with access to on- and off-site water supply is approximately 200 L/day and 105 L/day respectively [22]. In cases where greywater is insufficient, augmentation with harvested storm water or water from nearby rivers, dams and streams is recommended.

Traditional biomass use for cooking and heating is principal in most rural communities [46]. Rural communities are dominated by the poor households living there with limited or no access to energy services. This deficiency of access to energy services not only affects economic production but is also a stumbling block to the proper provision of other crucial basic services such as health care and education [29]. The over dependence on fuel wood to meet cooking and heating needs is a primary driver for deforestation in disadvantaged communities [17]. Biogas technology can providemuch cleaner access to energy for rural communities, thus helping to create new economic opportunities, generate more income and bring about rural development (FAO, 2009). Although the potential is very high, Amigu et al. [1] stated that the level of biogas technology use and adoption for household purposes is very low in many African countries. In conclusion, most studies focused on the application of biogas technology rather than the technical, social and economic potential of biogas technology. Thus, biogas technology is indeed relevant to the rural areas of Vhembe district because it solves the issue on indoor air pollution which is known to be a threat to the health of users, at the same time providing the much needed green energy.

5. Conclusions and recommendations

In order to meet the energy demand for cooking in all low-income South African households like Vhembe district, 2 500 L/day of biogas per household would be required.Biogas requirement for complete substitution of household fuelwood use is 5 000 L/day and for complete substitution of conventional domestic fuels is 6 250 L/day of biogas. Substitution of fuelwood used for cooking with biogas will result in the significant avoidance of the total attributable mortalities from IAP due to SFU. Based on livestock numbers, approximately 625 000 households in South Africa can potentially benefit from bio-digesters fed with cattle and pig waste. It is infeasible to operate a domestic bio- digester fed solely with either chicken waste, human waste or food waste, because of insufficient feed- stock. Co-digestion of human with cattle waste and human with food waste is also infeasible at household level. Non-sewered South African households generate sufficient greywater to mix with organic waste for feeding bio-digesters for cooking purpose.The study reveals that further academic investigation would be of great value to future project appraisals relating to biodigester use in rural communities. Specifically further studies relating to local and global environmental benefits, integrating other renewable energy sources with biogas technology to really enjoy green energy.

Declaration of Competing Interest

There are no conflict of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.btre.2019.e00412.

References

[1] B. Amigun, W. Parawira, J.K. Musango, A.O. Aboyade, A.S. Badmos, Anaerobic biogas generation for rural area energy provision in Africa, in: S. Kumar (Ed.), Biogas, InTech., 2012 Online at: http://www.intechopen.com/books/biogas/anaerobic-biogas-generation-for-rural-area-energy-provision-in-africa [Accessed: May 2017].

[2] World Bank, Sustainable Energy for All (SE4ALL) Database from the SE4ALL Global Tracking Framework, (2017) . [Accessed 17th May 2017] http://data.worldbank.org/indicator/eg.Elc.Accs.Zs.

[3] W. Parawira, Biogas technology in Sub-Saharan Africa: status, prospects and constraints, Rev. Environ. Sci. Biotechnol. 8 (2009) 187–200.

[4] Statistics South Africa, General Household Survey, Statistics South Africa, Pretoria, South Africa, 2013.

[5] Statistics South Africa, In-depth Analysis of the General Household Survey Data. GHS Series, Volume V, Energy, 2002–2012 Pretoria, South Africa, (2013) .

[6] R. Gautam, S. Baral, S. Herat, Biogas as a sustainable energy source in Nepal: present status and future challenges, Renewable Sustainable Energy Rev. 13 (2009) 248–252.

[7] T.M. Everson, M.T. Smith (Eds.), Rural Livelihoods Through Biogas Generation Using Livestock Manure and Rainwater Harvesting, Vol. 1, Report to the Water Research Commission, 2015 Research report.
[8] J. Van Nes, T.D. Nhete, Biogas for a better life: an African initiative, Appropriate Technol. 34 (4) (2007) 58–62.
[9] H.A. Greben, S.H.H. Oelofse, Unlocking the resource potential of organic waste: a South African perspective, Waste Manag. Res. 27 (2009) 676–684.
[10] T. Bond, M.R. Templeton, History and future of domestic biogas plants in the developing world, Energy Sustain. Dev. 15 (2011) 347–354.
[11] P.C. Ghimire, SNV supported domestic biogas programmes in Asia and Africa, Renew. Energy 49 (2013) 90–94.
[12] I. Pérez, M. Garfí, E. Cadena, I. Ferrer, Technical, economic and environmental assessment of household biogas digesters for rural communities, Renew. Energy 62 (2014) 313–318.
[13] K.C. Surendra, D. Takara, A.G. Hashimoto, S.K. Khanal, Biogas as a sustainable energy source for developing countries: opportunities and challenges, Renewable Sustainable Energy Rev. 31 (2014) 846–859.
[14] E. Hennekens, Biogas as Domestic Energy solution? Potentials and Barriers of the Technology for Low-income Households in South Africa Master thesis, Wageningen University, Netherlands, 2012.
[15] O. Damm, R. Triebel, A synthesis report on biomass energy consumption and availability in South Africa, GTZ (GesellschaftfürTechnischeZusammenarbeid) Programme for Basic Energy and Conservation (ProBEC), ProBEC and LHA Management Consultants, Pretoria, South Africa, 2008.
[16] H. Pathak, N. Jain, S. Mohanty, N. Gupta, Global warming mitigation potential of biogas plants in India, Environ. Monit. Assess. 157 (2009) 407–418.
[17] WHO (World Health Organization), The World Health Report 2002: Reducing Risks, Promoting Healthy Life Geneva, Switzerland, (2002) .
[18] L. Gaudex, A Health and Demographic Surveil Lance System of Cattle on Communal Rangelands in Bushbuckridge, South Africa: Baseline Census and Population Dynamics Over 12 Months MSc. dissertation, University of Pretoria, South Africa, 2014.
[19] Statistics South Africa, Agricultural Households, Statistics South Africa, Pretoria, South Africa, 2011.
[20] Statistics South Africa, General Household Survey, Statistics South Africa, Pretoria, South Africa, 2010.
[21] Department of Environmental Affairs, National Environmental Management: Air Quality Act (39/2004): Highveld Priority Area Air Quality Management Plan - Gazette No. 35072 Pretoria, South Africa, (2012) .
[22] K. Carden, N. Armitage, K. Winter, O. Sichone, U. Rivett, Understanding the Use and Disposal of Greywater in the Non-sewered Areas in South Africa, Water Research Commission, Cape Town, 2007.
[23] Department of Energy, 2013. http://www.energy.gov.za/files/biogas/2013-National-Biogas-Conference-Report.pdf.
[24] Tiepelt, Biogas in South Africa, Renewable Energy Conference, South Africa UCT, 2015.
[25] Improving rural livelihoods through biogas generation using livestock manure and rainwater harvesting, in: M.T. Smith, T.M. Everson (Eds.), Guideline Report, Vol. 2, Report to the Water Research Commission, 2013.
[26] G. Austin, J. Blignaut, South African National Rural Domestic Biogas Feasibility Assessment, s.l., AGAMA Energy (Pty) Ltd., 2008.
[27] DBSA, 2014. https://www.dbsa.org/EN/About-Us/Publications/Annual%20Reports/DBSA%20Integrated%20Annual%20Report%202013-14.pdf.
[28] A. De Alwis, Biogas – a review of Sri Lanka's performance with a renewable energy technology, Energy Sustainable Dev. 6 (1) (2002) 30–37.
[29] IEA, 2011. "International Energy Agency. World Energy Statistics," Paris