Validity of the Africa-wide Lang factor of 2.63 for estimating small biogas plant installation costs in Uganda

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Abstract: There is an increasing interest in popularizing small biogas plants to meet the bulk of domestic energy needs in Africa for cooking, lighting, and other activities such as cooling or refrigeration. As stakeholders (policy makers, donors, credit providers, sector experts, and product development professionals) contemplate programs, one of the key questions to which a reliable answer is needed is biogas plant installation cost that may vary from region to region. An Africa-wide materials' cost multiplier factor (Lang factor of 2.63) estimation approach has been proposed, based on data from only two locations. The factor's validity throughout Africa has been questioned. This study shows that the Africa-wide Lang factor of 2.63 is applicable in Uganda. However, differences in accuracy have been observed based on whether the installation is located in a rural or urban setting. Location-specific factors of 2.984 and 2.404 for rural and urban locations were established and validated, respectively, which produced more accurate estimates in comparison with a single composite non-location specific factor.

Keywords: biogas, fixed capital investment, Lang factor, Uganda, renewable energy

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1 Introduction

The role played by energy in society is ever expanding as energy affects all aspects of development—social, economic and environmental[1]. As such, provision of adequate, affordable, efficient and reliable energy services with minimum effect on the environment is crucial[2]. Unfortunately, many countries, especially developing countries, are limited to only a few options to meet their energy needs[3]. The increase in fossil fuel prices coupled with concerns about climate change due to air pollution by waste gases from fossil fuels burning have left the use of these fuels not an option for the future. This has led to increased awareness and wide spread research into the accessibility of alternative and renewable energy sources[4] which has in turn lent enormous weight to the argument for countries switching to renewable energy sources[5]. Suffice to say that biogas technology is one of the renewables that have continued to receive wide attention[6] due to its green potential, simplicity and relevance on both large and small scale in rural and urban locations[1,7].

Although biogas technology has been around for a long time and has been embraced by many developing nations, its adoption in most African countries has been disappointing[8,9]. Uganda is one of the countries whose biogas sector is still in its infancy. For example, by 2008, an estimated 700 small and medium size digesters (capacities of less than 100 m^3) had been installed in Uganda[5,10,11] in contrast to the estimated market of 2.5

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million households. Most of these digesters are of 8, 12 and 16 m^3 capacities and are mostly of CARMATEC design[12,13]. Other minor designs installed include floating drum, fixed dome, and plastic/bubble digesters[12,14]. The big difference between installed units and estimated market has been attributed to low cost availability of woody biomass, especially in rural areas[15,16]; however, the situation is changing, calling for the creation of an awareness, provision of support and incentives (financial and non-financial), and involvement of private sector such as micro-finance institutions or investors in the sector, among others, that will encourage the development of the biogas sector in Uganda[9,10,13].

As stakeholders (donors, policy makers, credit providers and sector experts) contemplate programs, one of the key questions to which a reliable answer is needed is the installation cost[17]. Since annual repair and maintenance costs for small to medium plant installations are minimal, the major area of concern is the capital cost for the installation – the one time set up cost required to construct a plant and bring it to the point of use. Amigun and von Blottnitz[10] have addressed this question. By using two African locations (Ghana and South Africa) and an approach originally proposed by Lang[18], a Lang factor value of 2.63 was established to provide cost predictions for small to medium scale biogas plants. The installed cost of an entire process plant is often estimated in preliminary project work as a multiplier or factor (Lang factor) of the total purchased cost of all equipment items.

Installed cost estimation has been successfully accomplished with the Lang factors approach for chemical plants and large size biogas digesters (>100 m^3), especially those running electric generators. Unlike chemical plants and large biogas plants, installations in Uganda are small scale and do not involve specialized equipment; inputs are predominantly local materials, such as bricks, sand, and stones. Also, the cost of these inputs may be strongly influenced by site location (rural vs. urban). For these reasons, we wondered about the validity of the generalized Lang factor for Africa of 2.63 for Uganda biogas installed cost estimation. The purpose of this paper was to evaluate the validity of the generalized or Africa-wide Lang factor in the Ugandan context.

2 Analysis

Fixed capital investment cost data for a total of 23 small (domestic) biogas digesters, with capacities of 6-18 m^3, were obtained from plant owners. The cost data for each plant were subdivided into construction material, direct and indirect costs as shown in Table 1. The data represent expenditures from construction to point of gas usage, including cost of auxiliary services. The list of biogas digesters was divided into two groups: eleven digesters were designated as the test list and the remaining twelve biogas plants were designated as the validation list. The approach adopted was to use the test list to determine the accuracy of the Lang factor (2.63) prediction of biogas installation expenditure in Uganda, using Conte criterion[19]. We hypothesized that use of 2.63 factor would not be adequate for both rural and urban installations and as such, factor modification was needed to satisfy Conte[19] accuracy criterion. After the factor modification, validation list was to be used to validate the accuracy of the modified Lang factor. Locations were designated "rural" if they had a low population density (10 to 20 people per square km) and the land was devoted to agriculture. Typically, such locations were more than 10 km away from urban centers or towns.

Table 1 Categorization of fixed capital investment cost data for biogas installations

Classification of costs	Items
Main materials (Construction materials)	Sand, Stone, Gravel, Bricks, Cement, Lime, Water proof cement, Chicken wire mesh, Square mesh, Reinforcement bar, Nails, Hooks and plastic bag (used on the plastic bag digester).
Direct costs	Pipes and fittings, Auxiliary equipment (mainly appliances), Start-up cost (such as cost of cow-dung for the urban digester), Specialty cost (Rubber straps for plastic bag digester) and Training services.
Indirect costs	Engineering and supervision/Contractors fee, Construction expenses as Labor (both skilled and unskilled) and Contingencies such as Transport, water (usually free), Construction string and timber piece, Support hooks.

Conte[19] accuracy criterion is based on mean magnitude of relative error ($\overline{MRE}$), prediction at error level r [$PRED$ (r)] and relative root mean square error

($\overline{RMS}$). According to the criterion, the prediction is satisfactory if $\overline{MRE}$ ≤0.20, $\overline{RMS}$ ≤0.25 and a prediction rate of equal or higher than 75% at an error level of 0.25 [*PRED* (0.25) ≥0.75]. Details of the calculations are provided below.

The magnitude of relative error (*MRE*) was computed for every test list of digesters according to:

$$MRE = \frac{|\,Actual\ Cost - Predicted\ Cost\,|}{Actual\ Cost} \tag{1}$$

According to Amigun and von Blottniz[10], actual cost can be obtained from:

$$Actual\ Cost = Actual\ Lang\ factor\ (Lf_A) \times Actual\ Material\ Cost \tag{2}$$

Similarly, the predicted cost is a product of the predicted/estimated Lang factor (Lf_P) and the actual material cost:

$$MRE = \frac{|\,Lf_A - Lf_P\,|}{Lf_P} \tag{3}$$

The test data set's $\overline{MRE}$ was then calculated from:

$$\overline{MRE} = \frac{\sum MRE}{N} \tag{4}$$

where, *N* is the number of digesters on the test list. It should be pointed out that although values in the 0.20 range are acceptable for $\overline{MRE}$, the smaller the value, the more accurate the estimate is.

$\overline{RMS}$ for the test data set was computed as follows:

$$\overline{RMS} = \frac{RMS}{Mean\ of\ \ Actual\ costs} \tag{5}$$

Where,

$$RMS = \sqrt{\left(\frac{\sum (Estimate - Actual)^2}{N}\right)} \tag{6}$$

The prediction rate [*PRED* (*r*)] was determined from:

$$PRED(r) = \frac{k}{N} \tag{7}$$

where, *k* is the total number of digesters on the list that yield $MRE \le 0.25$.

To incorporate site uniqueness (rural vs. urban) and as such improve prediction accuracy, we hypothesized that the following power law, where *n* and *y* are the site specific factor and Lang factor, respectively, was a reasonable approach.

$$y^n = constant$$

We set the *constant* equal to the Amigun and von Blottniz[10] African Lang factor of 2.63. Therefore,

$$(Lf_A)^n = 2.63 \tag{8}$$

We used the test data list and Equation (8) to calculate the value of n for each digester. The average value of $n(\overline{n})$ was calculated from all the digesters on the test list and the 'average' site-specific Lang factor was determined according to the Equation (9) below.

$$(Lf_x)^{\overline{n_x}} = 2.63 \tag{9}$$

where, x subscript can be set to R or U for rural and urban settings, respectively. The test data list was comprised of seven rural and four urban digesters, respectively.

The model with the modified Lang factor was validated with digesters on the validation data list using Conte[19] criterions, described above. The validation digester list was comprised of a total of 12 units; seven rural and five urban digesters, respectively. The question of interest was whether the modified Lang factor model yielded more accurate estimates according to Conte[19] criterions.

3 Results and discussion

Table 2 shows the actual and estimated installation costs (using Lang factor of 2.63), and *MRE* for 11 biogas digesters from the test list. The error between actual and estimated installation costs ranged between -5.5% and 21.1%. The accuracy of the prediction met Conte[19] criterion: $\overline{MRE}$ = 0.106, $\overline{RMS}$ = 0.128, and *PRED*(*r*) = 90.9%, as shown in Table 3, suggesting that the Lang factor of 2.63 was sufficient in obtaining meaningful estimates for biogas digester installations in Uganda as well. However, it was interesting to observe that Lang factors for rural installations (ranging between 2.784 to 3.107) were higher than Lang factors for installations in urban locations (ranging between 2.468 to 2.555). Comparatively, the Lang factor of 2.63 gave better estimates for urban digesters ($\overline{MRE}$ = 0.091) in comparison to rural digesters $\overline{MRE}$ = 0.115), confirming our suspicion of location effect. Since the Lang factor is inversely proportional to cost of main equipment (cost of main materials for this case), the higher Lang factor for rural installations implies that the actual cost of building materials is a smaller percentage of the total cost. Rural biogas installations are characterized by much higher indirect costs but lower material cost in comparison to urban installations; the costs responsible for the major component of the indirect costs for rural installations are for labor and transportation. Higher transportation costs in rural areas are mainly due to poor road network and limited access to vehicles. Also, the cost of hiring skilled builders to work in rural areas is higher due to poor living standards – the expert builders charge extra to make up for working in less desirable locations.

Table 2 Comparison of actual versus predicted digester installed cost using Lang factor (Lf_P) of 2.63*

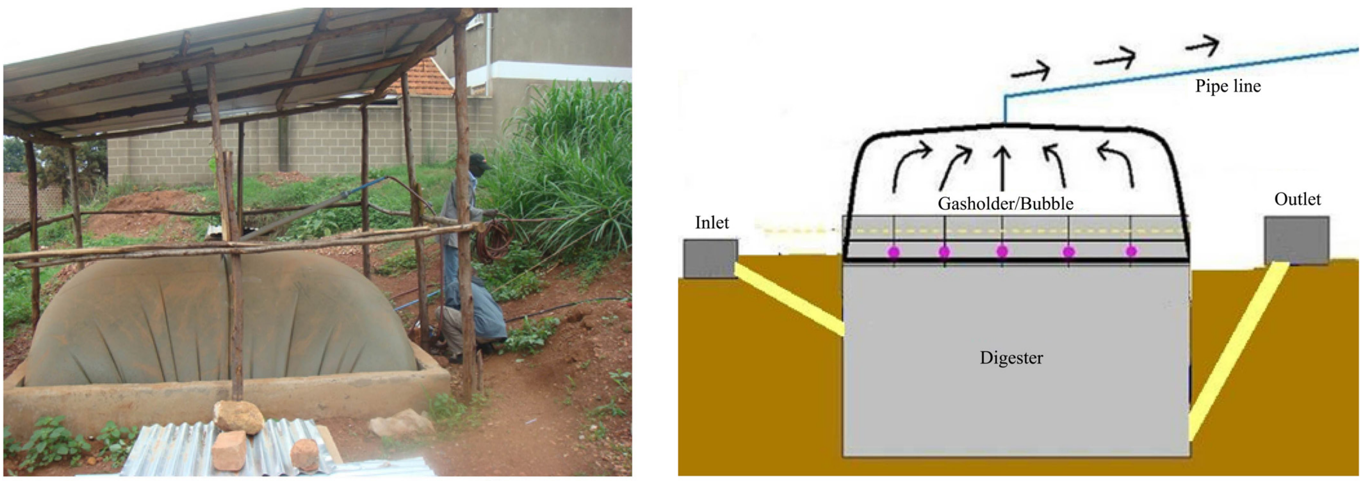
Location	#	Size/m^3	Actual total cost (US dollars)	Main material cost (US dollars)	Lf_A	Predicted cost (US dollars)	*MRE*	*n*
Rural	1	6	719.72	231.72	3.106	609.42	0.153	0.8532
	2	9	884.00	305.60	2.893	803.73	0.091	0.9103
	3	12	1 134.80	407.70	2.784	1 072.25	0.055	0.9444
	4	6	703.00	246.20	2.855	647.51	0.079	0.9218
	5	9	961.52	305.52	3.147	803.52	0.164	0.8435
	6	12	1 186.80	382.00	3.107	1 004.66	0.153	0.853
	7	12	1111.44	375.32	3.06	987.09	0.112	0.8646
Urban	8	6	651.64	255.04	2.555	670.76	0.029	1.0308
	9	9	832.64	337.44	2.468	887.47	0.066	1.0704
	10	12	1 082.20	435.40	2.486	1145.10	0.058	1.0618
	11†	18	1 074.20	494.68	2.171	1301.01	0.211	1.2474

Note: *Exchange rate used was UGX2500 = US$1.

†This is ‘bubble’ digester; the rest on the list were of CARMATEC type. The CAMATEC digester is a fixed dome design modified by the Center for Agricultural Mechanization and Rural Technology of Tanzania. See Figures 1 and 2 for detailed designs of bubble and CARMATEC digesters.

Table 3 Summary of results from applying Conte[19] criterion for test list digesters with a Lang factor of 2.63

Parameter	Whole test list (*N* = 11 digesters)	Rural installations (*N* = 7, digesters 1 to 7)	Urban installations (*N* = 4, digesters 8 to 11)
$\overline{MRE}$	0.106	0.115	0.091
$\overline{RMS}$	0.128	0.124	0.133
PRED(*r*)	90.9%.	100%	80%



a b

Figure 1 Actual (a) and schematic (b) bubble biogas digester located in an urban setting

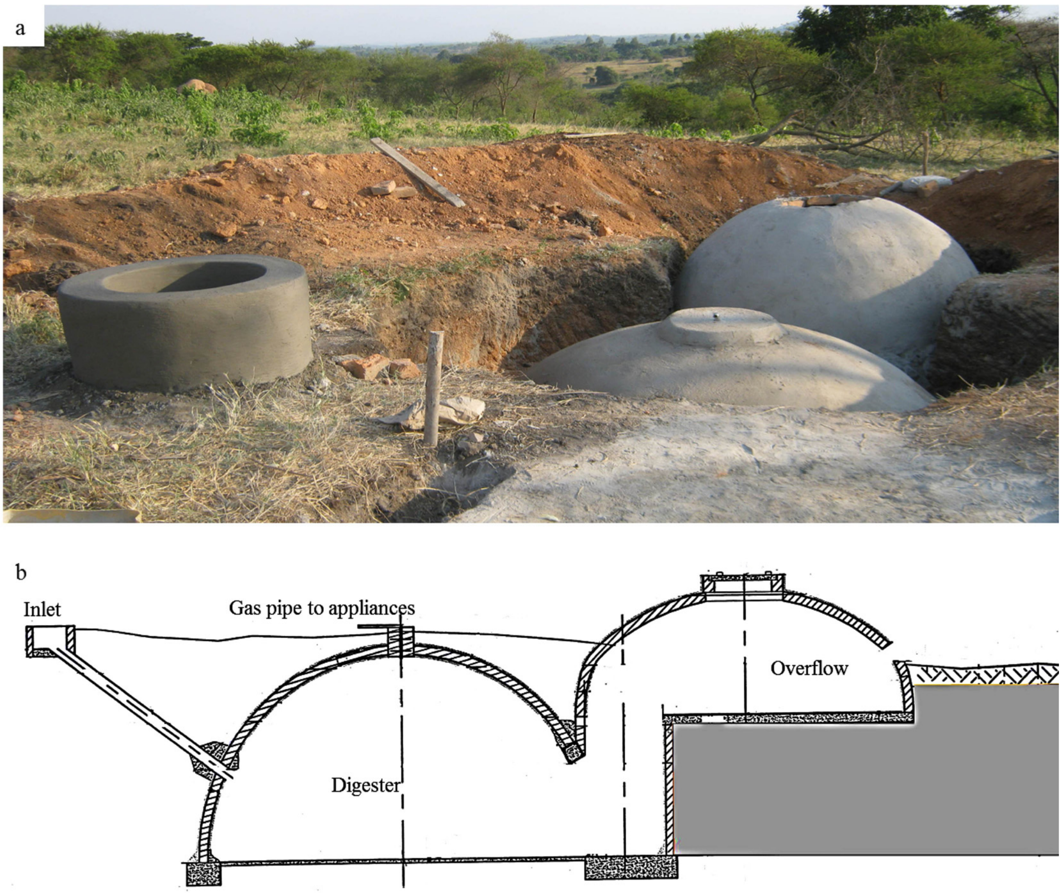


Figure 2 Construction of an actual (a) and schematic diagram (b) of a CARMATEC digester

The location-dependence of the actual Lang factor observed served as motivation to consider modifications with the goal of improving the Lang factor installation cost prediction accuracy. Following the procedure outlined under the Analysis Section, average modifying factors of $\overline{n}_R = 0.8844$, $\overline{n}_U = 1.1025$, and $\overline{n} = 0.9867$ were obtained, corresponding to Lang factors of $Lf_R = 2.984$, $Lf_U = 2.404$ and $Lf = 2.665$. To ensure absence of bias in $(\overline{n})$ value, due to number of digesters used in the calculations, a balanced number of digesters were used (four digesters each for rural – #4 to #7 – and urban – #8 to #11).

Comparing Lang factors 2.63 and 2.665 with validation data list yielded no significantly different results with regard to Conte[19] criterion (Table 4). We used the validation digester list to assess the accuracy of prediction using the rural Lang factor (Lf_R = 2.984) generated with test data set. As shown in Table 5, an excellent prediction of installed biogas digester cost was obtained with $\overline{MRE} = 0.031$, $\overline{RMS} = 0.034$ and $PRED(r)$ = 100%. The values of $\overline{MRE}$ and $\overline{RMS}$ were higher when either 2.63 or 2.665 was used (Table 4). It was also observed that $Lf_U = 2.404$ greatly improved accuracy of the Lang factor approach for urban biogas plant installation cost prediction ($\overline{MRE} = 0.055$, $\overline{RMS} = 0.089$, $PRED(r)$ = 100% in comparison with either 2.63 or 2.665 as shown in Table 6).

The Lang factor of 2.63 previously established for estimating fixed capital investment costs for biogas installations in Africa has been found to be applicable in Uganda. However, differences in accuracy have been observed based on whether the installation is located in a rural or urban setting. Improvements in the estimation accuracy have been demonstrated through establishment of separate rural and urban location factors of 2.984 and 2.404, respectively. It should be pointed out that the average of these two numbers is 2.694, which is close to the 2.63 figure from the study by Amigun and van Blottnitz[10], where three small to medium and one commercial scale biogas plants were used to generate, and six plants were ready to validate the number. No rural/urban information was provided, while the medium and commercial scale plants are likely to be located in urban areas, suggesting that there is a mix of the two types of plants. The closeness of the average factor from this and the Amigun and van Blottnitz[10] study factor attested to urban/rural plat mix speculation.

Table 4 Comparison of Conte[19] model accuracy between Lang factors 2.63 (Africa) and 2.665 (Uganda) with digesters from the validation list

#	Location	Size /m^3	Actual installation cost (US dollars)	Material cost (US dollars)	Actual Lang factor	*MRE* (*Lf* = 2.63)	*MRE* (*Lf* = 2.665)
12‡	Rural	12	1537.92	503.92	3.052	0.138	0.127
13		12	1250.68	402.00	3.111	0.155	0.143
14		6	883.92	314.40	2.811	0.065	0.052
15		9	978.24	337.04	2.902	0.094	0.082
16		12	1184.88	387.28	3.059	0.140	0.129
17		6	727.72	235.72	3.087	0.148	0.137
18		6	760.60	255.80	2.973	0.115	0.104
19	Urban	12	1395.92	568.40	2.456	0.071	0.085
20		12	1030.00	434.00	2.373	0.108	0.123
21		6	776.80	314.40	2.471	0.064	0.079
22[1]		10	925.60	452.00	2.048	0.284	0.301
23		12	1084.00	445.20	2.435	0.080	0.095
			$\overline{MRE}$			0.122	0.21
			$\overline{RMS}$			0.136	0.135
			PRED(*r*)			0.917	0.917

Note: ‡ #12 is a floating dome digester and #22 is an ARTI digester. The rest are CARMATEC types. The ARTI digester is a floating dome digester modified by Appropriate Rural Technology Institute in India. It is made of two plastic tanks; the larger tank contains the digestible materials and the smaller tank is inverted over the larger one to capture the gas.

Table 5 Validation of rural installation data

#	Actual installation cost (US dollars)	Material cost (US dollars)	*MRE* (*Lf* = 2.984)	*MRE* (*Lf* = 2.63)	*MRE* (*Lf* = 2.665)
12	1537.92	503.92	0.022	0.138	0.127
13	1250.68	402.00	0.041	0.155	0.143
14	883.92	314.40	0.061	0.065	0.052
15	978.24	337.04	0.028	0.094	0.082
16	1184.88	387.28	0.025	0.140	0.129
17	727.72	235.72	0.033	0.148	0.137
18	760.60	255.80	0.004	0.115	0.104
	$\overline{MRE}$		0.031	0.122	0.111
	$\overline{RMS}$		0.034	0.136	0.124
	PRED(*r*)		100%	100%	100%

Table 6 Validation list urban installations cost data, a comparison of Lang factors 2.404, 2.63 and 2.665

#	Actual installation cost (US dollars)	Material cost (US dollars)	*MRE* (*Lf* = 2.404)	*MRE* (*Lf* = 2.63)	*MRE* (*Lf* = 2.665)
19	1395.92	568.40	0.021	0.071	0.085
20	1030.00	434.00	0.013	0.108	0.123
21	776.80	314.40	0.027	0.064	0.079
22	925.60	452.00	0.174	0.284	0.301
23	1084.00	445.20	0.013	0.080	0.095
	$\overline{MRE}$		0.050	0.121	0.137
	$\overline{RMS}$		0.071	0.137	0.150
	PRED(*r*)		100%	80%	80%

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