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Availability of Liquefied Petroleum Gas and Potential Environmental Impact of its Adoption in GatangaSub-county, Kenya

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Abstract
Liquefied petroleum gas (LPG) is an efficiently combusting fuel suitable for household cooking and heating since it has no residual effects on humanity and the environment. Its adoption varies worldwide with most households in the developed world adopting it as their primary fuel. However, LPG adoption in lower and middle-income countries (LMICs) remains significantly low. In Kenya, LPG adoption is faced with various challenges associated with its availability, especially in rural areas where long distances to LPG depots and lack of delivery services to remote areas hinder adoption. The current study was carried out in GatangaSub-county to (i) assess the influence of distance to LPG depots on LPG adoption; (ii) assess the influence of LPG delivery services on LPG adoption; and (iii) make a comparison of household fuelwood consumption before and after LPG adoption. A structured questionnaire was completed by 315 respondents selected through stratified random sampling across six wards of Gatanga sub-county. A chi-square testcarried out founda statistically significant relationship between the rate of LPG adoption in Gatanga sub-county and the distance to LPG depots; X2 (3, N=315) = 95.03, P=.001 at the p < 0.05. Furthermore, there was a significant relationship between the availability of LPG delivery services and LPG adoption X2 (1, N=315) = 221.99, p= 0.001.Findings show that households nearest to LPG depots are more likely to adopt and use LPG compared to households further from LPG depots. Additionally, households with access to LPG delivery services are more likely to adopt LPG compared to households without access to LPG delivery services.A paired samples t-testat the significance level α= 0.05 shows that daily firewood consumed by households before and after LPG adoption was not equal. Therefore, firewood consumption at the household level decreased with the adoption of LPG. In conclusion, LPG has the potential to alleviate the overreliance on firewood and charcoal and provide gains by curtailing deforestation. The study, therefore, recommends availing of depots and suppliers in remote villages, as it will help to reduce the distance traveled to purchase and refill an LPG cylinder. The study also calls for LPG suppliers to provide door-to-door LPG delivery services as a strategy to enhance LPG adoption and thus increase their customer base.

Keywords*: deforestation; biofuels; LPG adoption; LPG delivery services; fuelwood; climate change*

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I. Introduction

Clean fuel provision remains one of the most severe challenges facing humankind, even in the wake of modern technology. In the rural areas of the lower and middle-income countries (LMICs), biofuels such as wood, charcoal, and crop residue are the main fuels used for domestic cooking and heating (Foell et al., 2011; IEA, 2010). Women and teenage girls spend a significant amount of their time gathering solid fuels and processing them for use e.g., chopping firewood (Wickramasinghe, 2011). They also use a considerable amount of time cleaning kitchen utensils which are often engulfed with soot from solid fuels. Consequently, girls end up losing valuable time that would otherwise be used productively doing schoolwork, while on the other hand, older women miss opportunities to take up commercial and income-generating activities (Shashni&Chander, 2014).

The use of non-clean fuels persists worldwide with the uptake of new clean fuel technologies progressing at a slow pace (IEA, 2016). Globally, about 3 billion people rely on biofuels for cooking and heating (Clean Energy Alliance, 2019). About 3.5 million deaths occur globally every year due to household air pollution (HAP) emanating from the burning of dirty fuels such as kerosene, firewood, charcoal, and crop residue (Oseni, 2012). More than 400,000 of these deaths occur in Sub-Saharan Africa where a majority (80%) of the population relies on dirty fuels (IEA, 2016; Rosenthal et al., 2018). Kenya is heavily dependent on biofuels, with 68% of the population still relying on non-clean fuels (IEA, 2016).

Fuelwood remains the primary cooking fuel for most households in Gatanga sub-county, like most rural areas in Kenya where the uptake of cleaner fuels such as LPG and electricity remains low (Osano et al., 2020). The use of solid fuels for cooking and heating has negatively impacted the livelihoods, the environment, and the health of many Kenyan communities. Demand for firewood and charcoal as a source of cooking fuel continues to exert pressure on the dwindling forest resources in Kenya (Osano et al., 2020). Additionally, exposure to indoor air pollution from the burning of solid fuels in homes has contributed significantly to the burden of death and illness, more so among women and children. Continued use of solid fuels is one of the main causes of disparities between girls and boys in rural areas, with girls spending more time fetching and preparing biofuels for domestic use at the expense of doing their schoolwork.

Liquified petroleum gas (LPG) is a non-renewable source of energy extracted from crude oil and natural gas (Imeda, 2020). The hydrocarbon-based fuel is comprised of propane and butane and is used for heating, cooking, and transport in developing countries. It is compressed into a liquid for storage in cylinders and can be easily imported and distributed without requiring complex piped natural gas distribution systems (Puzzolo et al., 2019). Despite all the potential environmental and economic gains that LPG adoption presents, LPG adoption is progressing slowly, especially in rural areas (Adeeyo et al., 2022). Studies have shown that LPG adoption is faced with many barriers that would need to be addressed to increase LPG uptake (Singh et al., 2017; Kypridemos, 2020; Wassie et al, 2021). According to Adeyemi &Adereleye (2016), energy transition is faced with various challenges and the promotion of higher levels of education and general economic development may be effective instruments for encouraging rural households to substitute traditional fuels with modern energy fuels.

Availability and distance to LPG refilling stations have been reported as some of the main factors hindering LPG adoption and use (Oteh et al., 2015; Srinivasan &Carattini, 2016). The availability of LPG for rural households is an even bigger barrier considering that most rural households are located far from retail shops and filling stations where there is limited transportation (Dalaba et al., 2018). Furthermore, rural filling stations and LPG retailers have reported shortages of LPG due to poor accessibility in these areas resulting in inconsistent availability of refilled cylinders (Anderson &Markides, 2007; Oduro et al.,2012). According to Bouzarovski et al. (2017), the availability of cheaper and more readily available biomass may result in low uptake of LPG among low-income households.

Wood fuel and charcoal are the major forms of biomass energy used in Kenya for household cooking activities meeting over 64.5% of household energy needs while charcoal meets 7% (Weismann et al., 2014). Charcoal is the dominant fuel in Kenyan urban households providing domestic energy for 82% of urban households (Ministry of Environments and Natural Resources, 2016). According to Githiomi (2012), charcoal will continue to receive considerable economic importance due to increased urbanization in Sub-saharan Africa. Charcoal, which is widely used as a cooking fuel, is produced by slow-burning of wood under low oxygen conditions and consumes far more forest resources per meal than using fuelwood directly (Zulu & Richardson, 2013). Because of rapidly increasing lower middle income (LMIC) populations and accompanying urbanization, charcoal-driven forest degradation is a fundamental problem in many Sub-Saharan African countries (Chidumayo& Gumbo, 2013; Ahrends et al., 2010). This article assesses the availability of LPG in GatangaSub-county and the potential impact its adoption may have on the environment, specifically forest resources.

II. Materials and Methods

A mixed methods research design was employed for this study to collect and analyze both quantitative and qualitative data. By use of this research design, the effects of LPG availability factors on LPG adoption were determined. Additionally, the potential effects of LPG use on the environment were assessed using quantifiable data.

Study Area

This study was conducted in Gatanga sub-county, Murang'a County, Kenya. Gatanga sub-county was purposely selected due to its rural population and its vast endowment of natural resources. As result, the sub-county is home to the Ndakai-ini dam which supplies 80% of Nairobi metropolitan dwellers with clean water (Mwangi, 2021). Therefore, deforestation through cutting down trees for fuelwood provision and charcoal burning threatens the catchment areas associated with the dam. The sub-county covers an area of 532.3 km2 and borders Gatundu North sub-county to the South, Kinangop sub-county to the West, Thika West sub-county to the East, and Kandara Sub- County to the North. GatangaSub-county is located between latitudes 000 45' and 010 0150 South and longitudes 360 45' and 370 25' East. There are 6 administrative wards in the sub-county with a total population of 187, 989, and a total of 56,430 households (KNBS,2019).

Sampling Procedure

a stratified sampling technique was used to sample the target population. The target population was divided into strata according to the six administrative wards of GatangaSub county: Kariara, Gatanga, Kihumbuini, Mugumo-iniKakuzi/Mitubiri, and Ithanga.GatangaSub-county has a total of 56,430 households in the 6 administrative wards. To determine the sample size, the following formula was adopted from Yamane (1973) with a 95% confidence interval assumed at p=0.05.

$$n = \frac{N}{1 + N(e)^2}$$

Where;
n = sample size required
N = population size
e = required sampling error (A 95% confidence level or 0.05 precision level, is assumed)

$$n = \frac{56430}{1 + 56430(0.05)^2}$$

n=397
The 397 samples were allocated proportionally in the six strata as shown in Table 1

Table 1: Sample Size

Strata/Ward	Households	Samples
Gatanga	13011	91
Mugumoini	4328	32
Ithanga	6040	44
Kariara	14209	99
Kihumbuini	8012	56
Kakuzi/Mitubiri	10830	75
TOTAL	56430	397

Data Collection

Questionnaires were used to collect data from all the selected respondents. Questionnaires are advantageous in that they take less time, and energy, and are less expensive to administer to residents distributed over an extensive location. Additionally, questionnaires allow respondents freedom of expression and allow them to make suggestions while maintaining anonymity. Trained research assistants administered semi-structured questionnaires. This ensured the quality of the data collected since it allowed those respondents that could not read and write to be assisted in completing their questionnaires. Section A of the questionnaire contained questions on demographic data while sections B and C contained data on the extent of LPG adoption and other fuel use characteristics, including questions concerned with the daily consumption of fuelwood before and after LPG adoption.

As a legal prerequisite, the researcher sought permission to conduct the research from the Murang'a County Government. Further, the researcher obtained a research permit from the Ministry of Education and the National Council for Science Technology and Innovation (NACOSTI) in Nairobi to be allowed to carry out the study.

Results and Analysis

The study targeted 397 respondents. However, out of the targeted respondent, 315 questionnaires were completed and returned, giving an overall response rate of 79%. The highest percentage of respondents came from Kariara ward (30%), whereas the lowest percentage came from Mugumoini and Ithanga wards (9%). According to Mugenda and Mugenda (2003), a response rate of 50% is acceptable while a response rate exceeding 70% is sufficient for analysis and reporting.The highest percentage of respondents came from Kariara ward (30%), whereas the lowest percentage came from Mugumoini and Ithanga wards (9%) (Fig.1).

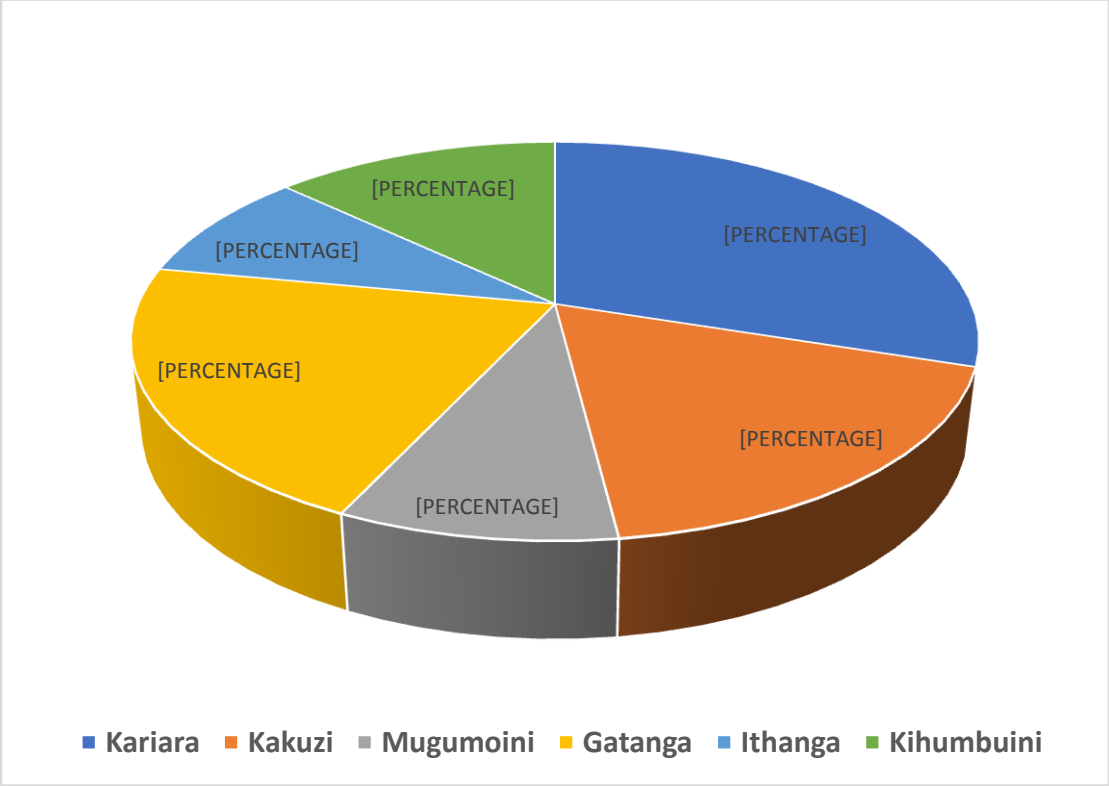

Figure 1: Respondents' Regions: proportion of respondents who responded from each ward

About 49.5% of households in GatangaSub-county have not adopted the use of liquefied petroleum gas (LPG), while 50.5% have adopted its use. Table 2 presents the finding of LPG adoption per each specific ward in Gatanga sub-county. First, In Kariara ward, about 72.6% of households have adopted the use of LPG, while only 27.4% are yet to adopt the use of LPG in their households. In Ithanga ward, 33.3% of the households have adopted the use of LPG while 64.3% have not yet adopted LPG.

Table 2: LPG adoption per ward

WARD	RESPONSE			
	YES		NO	
	N	*%*	*N*	*%*
Kariara	69	72.6	26	27.4
Kakuzi-Mitubiri	22	42.3	30	57.7
Mugumoini	10	35.7	18	64.3
Gatanga	30	44.1	38	55.9
Ithanga	10	33.3	20	66.7
Kihumbuini	15	35.7	27	64.3

Findings further show that about 49.4% of households in Gatanga sub-county have access to door-to-door LPG delivery services while 50.6% do not have access to door-to-door LPG delivery services.

Influence of Distance to LPG Depot on LPG Adoption

The respondents were asked the approximate distance to market centers where they purchase and refill their LPG cylinders. A chi-square test was carried out to test if there was any statistically significant relationship between the rate of LPG adoption in Gatanga sub-county and the distance to LPG depots. This relationship was found to be significant X2 (3, N=315) = 95.03, P=.001 at the $p < 0.05$ level (Table 3). Therefore, the adoption of LPG in Gatanga sub-county is influenced by the distance to market centers where LPG depots and retailers are located. Additionally, households nearest to LPG depots are more likely to adopt and use LPG compared to households further from LPG depots.

Table 3:Influence of Distance to LPG Depots on LPG adoption

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	95.037[a]	3	.001
Likelihood Ratio	114.503	3	.000
N of Valid Cases	315		

Influence of Delivery Services on LPG Adoption

A chi-square test for independence was conducted to establish if there was any relationship between the availability of LPG delivery services and LPG adoption in Gatanga sub-county. In this case, at p< 0.5, the test was significant X2 (1, N=315) = 221.99, p= 0.001. Therefore, there was a significant relationship between the availability of delivery services and the rate of LPG adoption in Gatanga sub-county. These test results indicate that households with access to LPG delivery services are more likely to adopt LPG compared to households without access to LPG delivery services.

Table 4: Influence of Delivery Services on LPG Adoption

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	225.364[a]	1	.001		
Continuity Correction[b]	221.988	1	.000		
Likelihood Ratio	265.850	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	315				

Assessing the Potential Effects of LPG Adoption on the Environment

A paired samples t-test at $p < 0.05$ significance level (table 5) shows that the p-value associated with t= -31.441 and degrees of freedom, (n-1) =157 is 0.001. There is therefore sufficient evidence to conclude that the means of the daily firewood consumed by households before and after LPG adoption were not equal and that LPG adoption positively affected the amount of firewood consumed in households in Gatanga sub-county (firewood consumption decreased with increasing adoption of LPG).

Table 5: A Paired Samples t-test Comparing Firewood Consumption Before and After LPG Adoption

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Lower	95% Upper			
Wood consumption before LPG adoption - Wood consumption after LPG adoption	-23.375	9.345	.743	-24.843	-21.906	-31.441	157	.001

III. Discussion

The findings show that households near market centers where LPG depots and retailers are located have highly adopted LPG. On the other hand, households further away from LPG depots and retailers exhibit lower LPG adoption of LPG. These findings agree with Gould et al. (2020) who studied LPG adoption among various Indian villages with different distances to LPG depots. In the study, Gould et al. (2020) observed less proportion of LPG-owning households in more remote villages relative to villages nearer to LPG depots. Similarly, Danlami et al. (2015) note that LPG adoption in most Nigerian households is highly dependent on LPG accessibility. According to Dalaba et al. (2018), availability and distance to LPG depots and filling stations are bigger barriers for rural households in Northern Ghana. Elsewhere, similar studies have shown that availability and distance to LPG depots and filling stations as factors that hinder LPG adoption and use (Oteh et al., 2015; Srinivasan and Corattini, 2016). However, among urban households of Northern Ghana, LPG depots and filling stations are readily available, and therefore, distance to those depots and filling stations do not present any hindrances to LPG adoption (Dalaba et al., 2018).

Households are more likely to adopt and use LPG when there is a door-to-door LPG delivery service in their locality. A study in Ghana shows that LPG door-to-door delivery systems have significantly increased

sustained use of LPG and other clean cookstoves (Carrion et al., 2018). Similarly, Ndunguru&Lema (2020) found that various strategies including LPG home delivery services have created an enabling environment for the adoption and usage of LPG by households. Elsewhere, Akter& Pratap (2022) reported that doorstep delivery of LPG cylinders in the rural areas of Bihar, India, increased between 2015 and 2018. In the same period, LPG adoption increased substantially. In another study in India, Siringi, (2013) reported that timely refill supply from the distributor has improved the rate of LPG adoption and its sustained use. However, households that did not have access to timely delivery services did not adopt LPG, or those that had adopted LPG and did not have home delivery services did not sustain LPG use. The delivery of LPG refills has also been used by retailers and distributors as a strategic marketing initiative (Siringi, 2013).

Based on the findings of the study, a reduction in fuelwood consumption occurred in most households that adopted LPG. Consequently, there was a significant decline in the general household demand for fuelwood and biomass, which therefore resulted in fewer trees being cut to provide firewood. Forests were thus spared from the menace of deforestation as the demand for firewood was not as high as it was before households had adopted LPG. These findings agree with several other reports such as WRI, (2018) which noted that since more than 90% of rural communities in Cameroon cook primarily with fuelwood, Cameroon lost 2.8% of her forest cover between 2001 and 2016. Similarly, Kypridemos, (2020) reported that increasing LPG users in Cameroon would contribute to mitigating the effects of climate change because less fuelwood and biomass would be used for cooking, contributing to forest protection. Transition to LPG can also contribute to deforestation mitigation, by reducing the demand for wood from non-renewable forests for firewood production, in turn positively impacting climate through reduction of CO2 emissions (Singh et al., 2017). A study in Tanzania shows that substituting 250,000 tons of fuelwood, and biomass fuels with 80,556 tons of LPG could save 10,000 ha of forests per year (Alem and Ruhinduka, 2020). Therefore, since Tanzania currently consumes about 145,000 tons of LPG per year, close to 18,000 ha of forest are potentially protected from deforestation annually. Consumption of fuelwood and other biomass fuels will continue to increase, especially in Sub-saharan Africa. However, there are clear pieces of evidence showing that substituting fractions of household biomass fuels with cleaner fuels such as LPG would contribute positively to forest protection, and in turn, reduce the effects of climate change.

IV. Conclusions

First, the rate of LPG adoption is influenced by distance to LPG depots/retailers and the availability of LPG delivery services within various localities of GatangaSub-county. Increasing the number of LPG depots and suppliers in remote villages will help to reduce the distance traveled to purchase and refill an LPG cylinder. This paper further finds the need for LPG suppliers to provide door-to-door LPG delivery services as a strategy to enhance LPG adoption and thus increase their customer base. Secondly, the study established that scaling up LPG adoption will havea positive contribution toward environmental conservation by reducing deforestation. Protecting forests is critical for Kenya to achieve the global goal of 10% forest cover and sustainable development goal 13 (SDG 13) on climate action. In the quest to achieve the 10% forest cover, the government of Kenya should be at the forefront in advocating for increased LPG adoption in rural areas. LPG has the potential to alleviate the overreliance on firewood and charcoal as the household cooking fuels of choice, therefore providing gains by curtailing deforestation. The government further needs to re-introduce subsidies on LPG purchases and refills by zero-rating LPG and exempting it from VAT taxation. This way, even the rural poor would be able to adopt LPG and sustain its use.

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