When energy transition fails to reach the urban poor

The case of Nakuru, Kenya

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Abstract

Most of the projected increase in world energy consumption in the coming years will occur in cities of the developing world. A lot of focus is placed on mega cities but most of the increase will happen in smaller urban centers – with less than 500,000 inhabitants. Knowledge on the evolution of household energy consumption in these cities is scarce. In order to fill the gap, this article retraces the evolution, over a 30 year time span, of energy consumption, CO_2 emissions and local environmental impacts of different income groups of households in a 400,000 inhabitants Kenyan city. Results of a survey completed in June 2010 on 120 households are compared with a survey performed in Nakuru in 1981 (Milukas, 1993).

The results hightlight the worrying path taken by the evolution of urban energy consumption so far. In particular, they show that: i) large scale deforestation occurred around the city despite the widespread adoption of more energy efficient charcoal cooking stoves; ii) the proportion of urban population with access to modern fuels slightly decreased over 30 years; iii) as income increases, households continue to use traditional fuels in relatively high quantities, it is thus not possible to talk of an "energy ladder".

Two policy options are proposed to foster pro-poor and environmentally sound urban household energy transition paths for Nakuru. The article stresses the need for tailored microfinance and technology packages to enable this shift. The results are specific to the case study but the trends highlighted can be extended to several other African cities.

Introduction

In 1981, the Stockholm Environment Institute[1] performed a series of surveys on energy consumption in urban and rural Kenya. Using survey data collected by the SEI, one author focused on a middle size city called Nakuru (Milukas, 1993). Milukas presented panorama of energy use in the city and detailed the various energy sources used by households, businesses and industries. Looking at the future, one of his conclusions was that *"without changes in the means of supplying Nakuru with energy and the nature of energy demand in the city, eventual deforestation of the surrounding region is inevitable."*

Concerns about local and global environmental impacts of urban energy consumption have been growing over the years. Today, two thirds of world energy consumption occur in urban areas (IEA, 2008) and 50% of the world lives in cities. Urban population will reach 60% by 2030, with the majority of this increase in developing countries. As a result, 81% of projected increase in world energy demand in the coming twenty years will take place in cities of the developing world. This is both a challenge and an opportunity for human development and the environment. It is an opportunity because of the possibility to avoid unsustainable urbanization pathways followed by developed countries. It is a challenge because of the lack of resources in developing countries to enable the shift.

As a matter of fact, one of the biggest challenges for research and policymaking is the difficulty to find reliable statistical databases on energy consumption in the developing world, and particularly on middle size cities. While a lot of focus is placed on large megacities, the bulk of population growth will occur smaller urban centers (UNDESA, 2010). In order to address this challenge, the paper provides a historical picture of household energy consumption in a middle size city. Milukas' results and analysis are compared to a survey carried out in 2010. These show that household energy consumption led to massive deforestation foreseen in the 1980s, despite the successful penetration of energy efficient cooking stoves. Technology gains could not compete with population growth. In addition, the share of urban population connected to the grid decreased. Finally, the poor continue to spend a higher share of their income on

[1] Then known as the Beijer Institute

energy, paying more per unit fuel than the rich - due to a combination of lack of technology provision and political will, as well as maladapted credit markets.

In order to invert the trend, the paper focuses on two pro-poor, sustainable energy transition solutions. These are not complete solution packages for development. But they have the potential of being self-financed, enabling the use of public funding for other types of public services. It appears that the most important household energy transition policy needed is the development of pro-poor credit markets and in order to do so, microcredit has a large role to play.

The rest of this paper is divided as follows: a literature review on urban households energy consumption in the developing world, a presentation of the survey methodology, a presentation of the results and a discussion on their relevance.

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Energy consumption patterns in East Africa are characterized by heavy reliance on traditional fuels[2], very low per capita energy consumption levels and low access to electricity. Annual per capita energy consumption in Kenya decreased from 22GJ in 1990 to 21GJ in 2010, revealing a growing gap between supply and demand for energy, and stagnating (or even declining) GDP per capita (WB, 2010). To place this in perspective, annual per capita consumption in developed countries is over 198 GJ, i.e. about ten times more, and GDP per capita is 40 times higher in the USA.

Traditional fuels represent 74% of Kenya's total primary energy supply (IEA, 2009), contrasting with the mix of developed countries largely dominated by oil and gas. Such a dependence on biomass reveals the absence of modern supply side energy facilities in the country. This dependence also stresses strong concerns for the future: forest depletion today induces lack of biomass fuel tomorrow, hampering future development. Such concerns are reinforced by the fact that Kenya's urban population is expected to rise from 22% of total population in 2009 to 41% in 2050 (UNDESA, 2008) – Urbanization being associated to increased demand for energy. In Kenya like in many countries, bulk of population and

[2] Traditional fuels are defined as fuels available before the industrial age, i.e. charcoal, firewood, straw. Modern fuels refer to electricity, gas or kerosene see table xx in the appendix.

energy increase will occur in “secondary” cities, i.e. under 500,000 inhabitants today. It is thus particularly relevant to develop detailed comprehension of energy consumption dynamics in these urban centers.

Focusing on the interaction between development, urbanization and energy use, Barnes et al. (2005) developed a simple conceptual model of an “energy transition” (i.e. the shift from traditional to modern fuels[3]) in a city of the developing world. In the initial stage, cities are highly dependent on woodfuel. Biomass is abundant around the city and the opportunity-cost of labor is low implying there are enough resources to collect the fuel. Modern fuel availability and use are low because the city is initially not well integrated in national and international transportation networks and markets – only fraction households can afford to import modern fuels.

Over time, urban population grows and surrounding biomass stocks decrease, due to land clearing for agriculture, housing and energy purposes. The depletion rate increases with the development of better transportation networks in and around the city (Barnes, 1990). This trend can be altered by several local factors: climate and vegetation leading to faster regeneration of biomass in tropical areas for instance (Dewees, 1989) or local pro-environmental policies (Barnes et al., 2005). In addition, as the wealth of the city grows and as biomass stocks decline, city dwellers are more likely to turn to “modern” fuels, thus reducing the per capita impact on local biomass, while increasing regional or global impacts (i.e. GHGs). This is the second stage of Barnes et al. urban energy transition: per capita pressure on biomass is reduced but the aggregate pressure on surrounding biomass increases due to population growth. But eventually, with rising income and modern fuel availability, households turn to other fuels and aggregate biomass consumption decreases. The final stage of the energy transition is thus one with limited use of biomass, and large reliance on imported oil, gas and electricity. In their analysis of the trends for 45 cities with a quasi geographic information system, Barnes et al. remark that there is no reduction in aggregate pressure on surrounding biomass up to a population threshold (1 million people in the sample) after which cities tend to disconnect from their local wood stocks. This conceptual model is illustrated in figure 3. While being very simple, this three-stage representation of urban energy transition in the developing world highlights interactions between local woodstock, urban development and rise in modern fuel consumption.

[3] See appendix 1 for a categorization of modern and traditional fuels

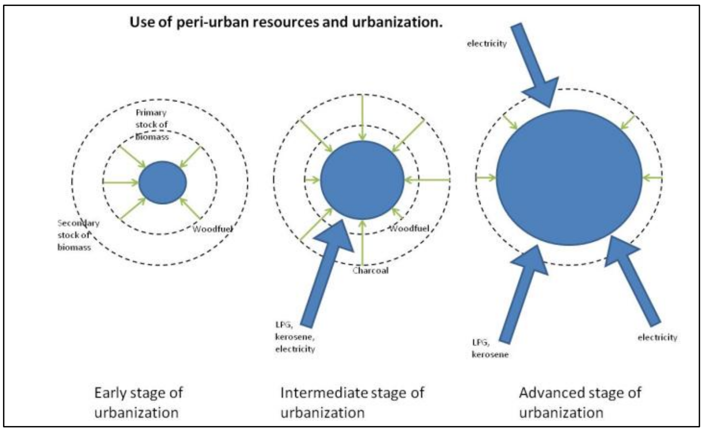

Figure 1 - Use of peri-urban resources and urbanization

Many attempts have been done to translate this transition at the household level. The hypothesis of an "energy ladder" in developing countries has been the most debated. Initially conceptualized by Leach (1992), the energy ladder posits that income determines the quality of fuels used by households. Poor households use traditional fuels, starting with agricultural bi-products and firewood, moving towards charcoal, kerosene, LPG and eventually electricity as income rises (fig xx).

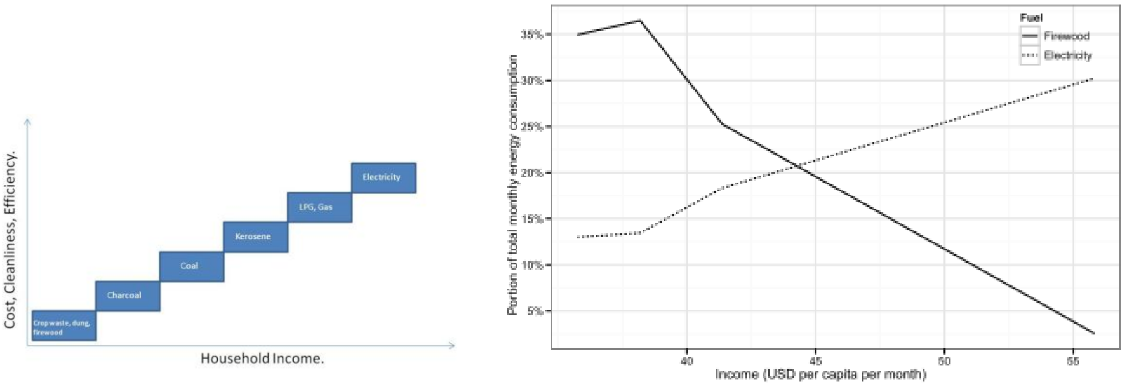

Figure 2 - The "energy ladder"
Source: Author (left) and Barnes(2005)

The energy ladder hypothesis has been criticised for its oversimplification. Essential factors not taken into account can be geography and resource endowment of the area (Milukas, 1993; Barnes, 1990), education of the head of the household (Masera et al., 2000), gender of the family head (Narashima Rao and Reddy, 2007), national and local energy policies (MacDonald, 2009) and cultural preferences

(Kerekezi, 2002). In addition, the literature highlights the actual diversity of household energy transition patterns. Elias and Victor (2005) remark that the energy transition is not a series of simple and discrete steps but rather a diversification of fuel options as income and education level increase. Masera et al. (2000) state that complete substitution of one fuel by another is an exception rather the rule. Using multiple regression analysis to account for the use of several fuels and cooking technologies at the same time, Heltberg (2004) states that income is the only statistically significant determinant of fuel choice but suggests studies should look at the composition, size and diversification of the portfolio rather than at the (overly) simplistic step by step energy ladder. In response to the energy ladder model, the more recent concepts of "fuel portfolio" or "fuel stack" were thus developed (Pachauri, 2004; Campbell et al., 2003).

The conceptual models of the household and city level "energy transition" presented above focus on the link between income or contextual factors on energy consumption but do not discuss how energy consumption can influence or alter income and contextual factors. A growing body of literature focuses on the feedbacks between energy use and household well being. In fact, income influences fuel choice but use of fuel can also have a positive or negative impact on household well being. Traditional fuels can alter health (Indoor air pollution due to smoke is recognized as the fourth cause of cause of mortality in SSA (WHO,2000) - it harms women and newborn babies in particular), reduce life expectancy as well as productivity. Fuel collection also limits time for education, especially among girls (McDonald, 2009). Woodfuel depletion contributes to salinization, acidification and degraded soils (UNEP, 2004) as well as to global warming. These two impacts are more likely to hit the poor as they have fewer resources to adapt to local or global environmental changes. Figure 3 is a schematic representation of an "energy poverty trap"

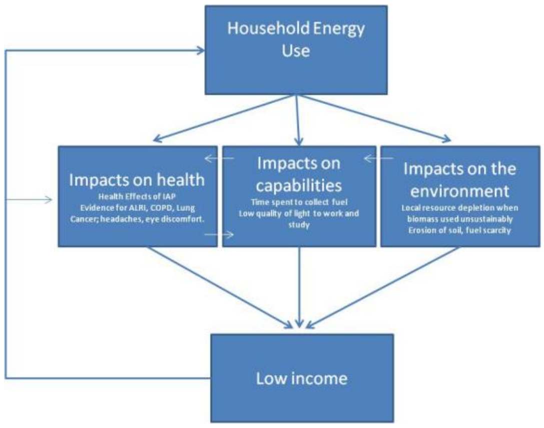

Figure 3 - Fuel choice and feedbacks

Much has been written on urban household energy transition in the developing world but very few studies have actually looked at the evolution of energy consumption among different income groups over time. More data is needed on the distributional dynamics of energy consumption. Expression of this need is especially clear among statistical offices in Kenya (Makau, 2010). The city of Nakuru in Kenya's rift Valley[4] was a good case study to compare energy consumption at two distant points of time: thanks to the Stockholm Institute studies design, it is possible to look at the evolution of energy consumption of different categories of urban households and local environmental impacts. In particular, it is possible to see if the poor have better access to energy today than in 1980 and to monitor evolution of biomass stocks around the city.

III. Methodology

Household energy consumption data presented in this paper stems from a set of surveys performed by the Stockholm Environmental Institute in 1981 (Milukas, 1993) and by the author with a team of UN-Habitat researchers, with the help of Nakuru Municipal Council, in June 2010.

[4] The Great Rift Valley is also famous for being the birthplace of the first hominids, 7 million years ago (Coppens, 1994).

Milukas' study focused on three income groups of households as defined by Kenya Bureau of Statistics (KNBS) in 1981. These were households earning respectively less than Ksh 4,000, ($5[5]) from Ksh 4,000 to 10,000 ($10) and above Ksh 10,000 per month. In 2010, KNBS definition of low income corresponds to households spending less than Ksh 23,670 ($29) per month, mid income spending from Ksh 23,670 to Ksh 120,000 ($149) and high income households spending over Ksh 120,000.

The 2010 survey targeted three areas of the city, defined as low, mid and high income by Nakuru Municipal Council[6]. Rent in low income areas is inferior to Ksh 1,000 ($1.24). Rent in middle income falls in the Ksh 1,000 Ksh 5,000 ($6) bracket and high income area are above Ksh 5,000. The three areas identified were Rhonda, Langa-Langa and Sector 58, respectively for low, mid and high income zones. Table xx presents the main characteristics of the sectors. Within each area, households were surveyed on a random basis. The number of households surveyed is proportional to area size in the total of the three areas. This design was chosen for logistics constraints: it was not possible to randomize households at the city level for security reasons.

Name of area	Type of dwelling	Mean rent	Facilities	N° HH	HH surveyed
Rhonda	Low income	0-1,000	No sewer lines, less than 50% electricity connection and 30% access to water	8,757	73
Langa-Langa	Middle-income	1,000-5,000	Sewer lines, 100% access to electricity, 70% access to water	3,358	27
Sector 58	High Income	>5,000	Sewer lines, 100% access to water, 100% access to electricity	2,279	18

Table 1 – presentation of the three areas surveyed

Descriptive statistics of the three income groups as per KNBS definition are presented in table 2.

	Mean income (Ksh)	Income range (Ksh)	Population (Hab/HH)	Number of rooms	HH
Low income	9,900	<23,670	4.6	1.7	73
Mid income	57,600	23,670-120,000	3.5	3.8	35
High income	135,500	>120,000	4.5	6.4	8

[5]Conversion rate in July 2010: $1 = 80.62 Ksh; Ksh 1 = $ 0.00124

[6] This definition is based on the rent in the area, which is th only information available for all households at the Municipal Council level.

Table 2 – descriptive statistics for the three income groups

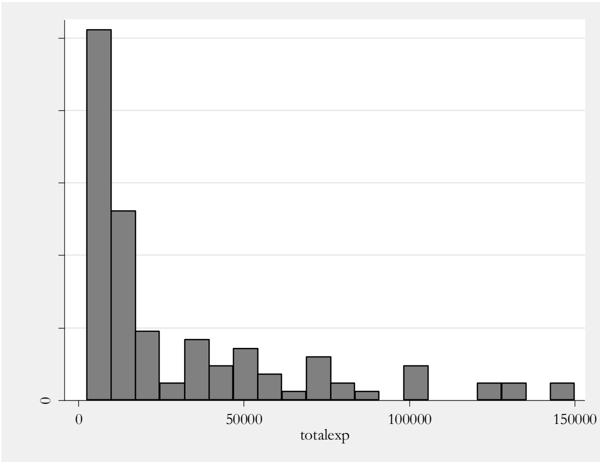

Figure 4 - Income distribution among the 118 households surveyed

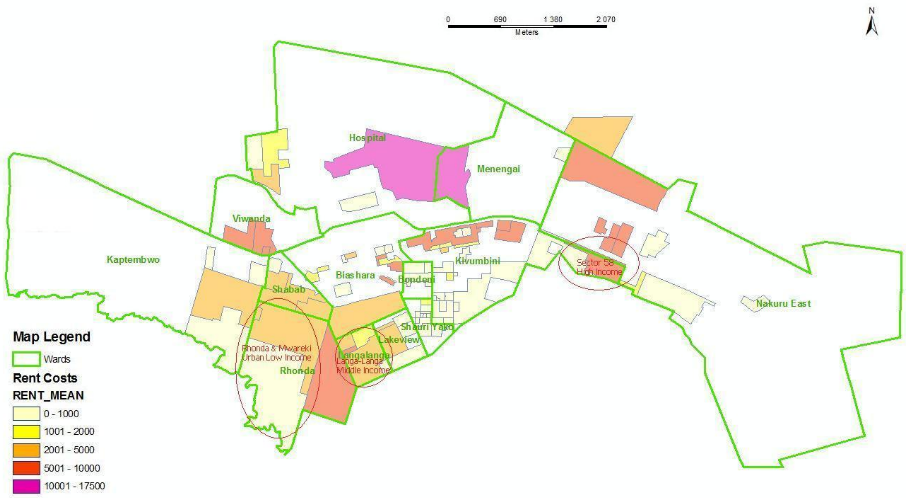

Figure 5 – map of Nakuru Municipality boundaries

Aerial photographs

In order to track the evolution of local resource consumption around the city, the Kenyan Department of Resources Surveys and Remote Sensing (DRSRS) was asked to provide historical aerial photographs of the region. DRSRS collects aerial data since 1990 with a plane taking photos at each intersection of a 2.5km by 5km grid. One photograph covers 45-50 hectares and has an approximate scale of 1:30,000. Estimation of forest cover is done by projecting a 100 dot grid on each photograph. Each dot hitting either a forest, riverine forest, bush, wood lot or a hedge is counted as forest cover. It is then possible obtain a percentage of the area of forest cover for each photograph and hence the total forest area.

Results & Analysis

1981 household energy consumption survey

Results drawn from Milukas' study are presented in table 3. In 1981, low income households consumed 37.7 GJ of primary energy[7] per year. Charcoal, used for cooking and water heating, represented 77% of poor households' primary energy demand. Kerosene, regarded as a fast heating and lighting fuel, represented 11% of their energy consumption. On average, electricity represented only 1% of low income households' primary energy demand in 1981. Mid income households consumed more primary energy over all but used less charcoal and kerosene, in line with the energy ladder hypothesis. Middle income households consumed substantially more wood than low income households as well a more LPG and electricity. High income households used more electricity (15 GJ) and LPG (4.9 GJ) than the two other income groups. Interestingly, high income households consumed less primary energy than mid income households. This is very likely due to higher efficiency of energy conversion devices used in high income households, inducing lower primary energy requirements than mid income households, while guaranteeing higher useful energy consumption levels.

	Low	**Mid**	**High**
Wood	3.1	18	14

[7] I define primary energy as the energy content of the fuel used, i.e. amount of energy required by households before conversion into useful energy. See the appendix for conversion factors.

Charcoal	29	22	9.4
Kerosene	4.1	1.5	0.27
LPG	1.4	6.0	4.9
Electricity	0.43	4.3	15.2
Total	**37.7**	**51.4**	**44.1**

Table 3 - Energy consumption by household type in Nakuru in 1981, GJ per year
(GJ/year/household) Energy content of fuel, without taking into account efficiency of the conversion device

	Low	Mid	High
Wood	8%	35%	32%
Charcoal	77%	43%	21%
Kerosene	11%	3%	1%
LPG	4%	12%	11%
Electricity	1%	8%	34%
Total	**100%**	**100%**	**100%**

Table 4 – Share of fuel in total primary energy consumption of households in 1981

It is interesting to note that mid and high income households used large quantities of wood and significant amounts of charcoal in 1981. This tends to contradict the energy ladder hypothesis. In fact, wealthier households could transport wood by car while the poorest relied on charcoal – the fuel has a higher energy content and is much more practical to carry. In brief, two main results stem out of the 1981 survey: income inequality translated into inequality in access to fuels. Electricity use clearly increased with income, and the opposite was true for charcoal. The second results was that sustained trends charcoal consumption in the city would lead to local biomass stocks depletion.

2010 household energy consumption survey

Results from the 2010 survey are presented in table xx. Physical quantities and confidence intervals are reported in the appendix. On top of household heating, lighting and electrical energy needs, I also report personal transportation fuel requirements. For mid and high income households, petrol is the main source of energy. It is clear that use of modern fuels (petrol, electricity, LPG) increases with income. Electricity consumption is almost inexistent among low income households and rises to 10 GJ per annum among mid income and to 37.7 GJ among high income (respectively 5%, 30% and 55% of households' energy needs –excluding petrol). However, an interesting result is that charcoal consumption decreases among mid income households but reaches high level among high income households – against the energy ladder hypothesis.

	Low	Mid	High
Wood	5.3	0.0	0.0
Charcoal	16.1	9.9	20.3
Kerosene	2.7	1.1	0.8
LPG	0.1	3.5	8.4
Electricity	1.7	10.2	32.2
Petrol	0	21.6	37.7
Total (w/o petrol)	24.7	24.7	61.7
Total (inc. petrol)	**25.9**	**46.3**	**99.4**

Table 5 - Annual GJ energy consumption of Nakuru's households
(GJ/year/household) Energy content of fuel, without taking into account efficiency of the conversion device

	Low	Mid	High
Wood	22%	0%	0%
Charcoal	61%	51%	28%
Kerosene	11%	11%	1%
LPG	1%	8%	16%
Electricity	5%	30%	55%
Total	**100%**	**100%**	**100%**

Table 6 – Share of fuel in household energy use

	Low	Mid	High
Wood	88	0	0
Charcoal	841	390	458
Kerosene	540	230	110
LPG	24	899	1,750
Electricity	237	1,702	5,833
Petrol	0	3,529	6,150
Total	1,732	6,752	14,302
Share of income	**17%**	**12%**	**11%**

Table 7 - Monthly energy expenditure per household in 2010
In 2010 Ksh

Table 7 presents monthly household energy expenditure on fuels. High income households spend eight times more on energy than low income households but the latter spend 17% of their total budget on energy against 11% for high income households – this result is standard in the household energy consumption literature. Energy being a good of primary necessity, they spend a larger share of their income on it than the rich.

Historical evolution of household energy consumption

Table xx compares energy consumption of low and mid income groups in 1981 and 2010, as per KNBS definition.

	Low income		Mid income		High Income	
	1981	**2010**	**1981**	**2010**	**1981**	**2010**
Wood	3.1	5.3	18	0.0	14	0.0
Charcoal	29	16.1	22	9.9	9.4	20.3
Kerosene	4.1	2.7	1.5	1.1	0.27	0.8
LPG	1.4	0.1	6	3.5	4.9	8.4
Electricity	0.4	1.7	4.3	10.2	15.2	32.2
Total (GJ)	**38.0**	**24.7**	**51.8**	**24.7**	**44.1**	**61.7**

Table 8 – comparison of energy consumption of low and middle income groups
GJ per year per household

Several striking facts come out the comparison of 1981 and 2010 results. Firstly, there is a sharp reduction in total energy requirements among low and middle income groups. This is due to a reduction in charcoal use: over the 30 year time frame, charcoal decreases from 29 GJ to 16GJ among low income households (from about 80kg to 41kg consumed per month). Consumption is also halved among mid income households. As discussed in section xx, this is due to the adoption of more efficient cooking stoves. Fuelwood completely disappears from mid income households' fuel choices, presumably due to changes in practices among mid and high income households and fuelwood depletion. But its use increased among low income households. One possible explanation suggested by the survey is the migration factor: households using firewood are more likely to have recently moved from rural areas to the city[8]. It is plausible that the proportion of rural migrants is higher than in 1981. The mid and high income group considerably increased their electricity consumption while consumption among low income households is maintained at very low levels (1.7 GJ per year per household in 2010). Consumption of LPG and kerosene substantially decreases among low and mid income households, in part replaced by electricity and charcoal. At the other end of the income spectrum, high income households significantly increase their total energy consumption, with sharp increases in charcoal, kerosene, LPG and electricity. It is apparent that the evolution of energy consumption over the years fits better to the "fuel stack" or "fuel

[8] Statistically significant difference at the 95% level

portfolio" than the energy ladder model. Nevertheless, overtime, the evolution disproportionately benefits high income group, able to capture gains associated to new energy technologies.

Measuring wood requirement of Nakuru's households.

From the survey results, it is also possible to estimate biomass requirements of the city's households. These will be used to assess the evolution of biomass stocks around the city. In 2010 Nakuru's households required about 58,000 tonnes of charcoal and 34,000 tonnes of firewood per annum[9] (appendix xx). In comparison, the total amount of charcoal consumed per year in Kenya is 1.6 million tonnes (ESDA, 2005). Nakuru's households, while representing 1.2% of the country's population, use 3% of the country's charcoal production – urban households use more charcoal than rural households since transportation costs are lower. In terms of total wood requirements, this translates into an estimated 498,000 tonnes of wood equivalent[10] used by Nakuru households for their energy needs in 2010. The associated forest cover requirement is about 6,900 hectares per year[11] in 2010. These could be sustainably harvested, but another set of results shows that it is not the case.

Historical evolution of local biomass stocks

In order to monitor evolution of biomass stocks, six areas have been identified as sources of charcoal in Nakuru (Ochodo, 2006): Molo, Bahati, Njoro, Mogotio, Rongai, Marigat. The Department of Resource Surveys and Remote Sensing (DRSRS) was asked to update its database on forest cover in these six divisions in order to track deforestation in areas of charcoal production around the city from 1990 to 2010. Aerial photographs were not available before 1990 and the most recent were from 2009. The results are presented in Figure xx.

[9] Results are not presented here by income category as per KNBS definition, but by income category as per NMC definition, which is based on household rent.
[10] Charcoal is produced from wood which undergoes pyrolisis. The production of one tonne of charcoal requires eight tonnes of wood as the mean energy efficiency of charcoal kilns in western Kenya is 12.5%.
[11] Appendix xx displays the density of wood per hectare around Nakuru. The average given for the Rift Valley is 107 cubic meters per hectare. This is the average density of biomass stocks around Nakuru and takes into account forests, riverine forests, bushes, wood lots or hedges (FRIR, 1983). It translates into 72 tonnes of wood per hectare of forest.

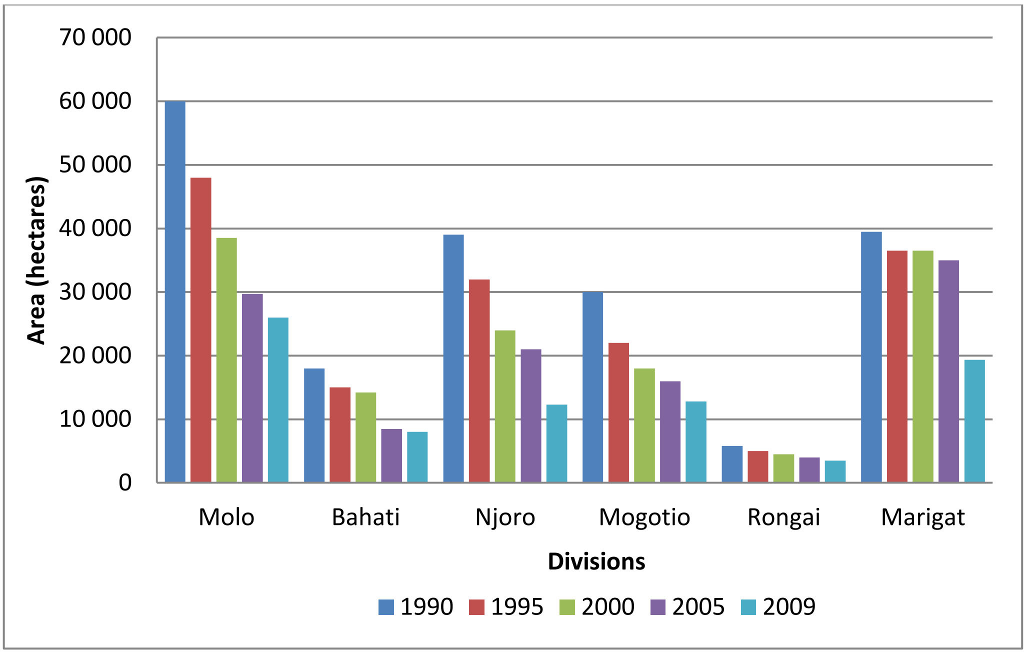

Figure 6 - DSRS and Ochodo (2006)

The analysis of local biomass stock depletion is compelling. Forest cover in areas of charcoal production for Nakuru Municipality decreased by 57% in twenty years, from 192,300 hectares of woodland in the six divisions to 82,000 hectares. Second, the rate of deforestation in the six areas has accelerated over the last five years, especially due to intense deforestation in one division (Marigat) [12]. The annual rate of deforestation for the last period, 2005-2009, is an impressive 8,000 hectares deforested per year. It is clear from the results that large scale deforestation occurred in these six divisions over the past two or three decades[13]. Assuming all charcoal in Nakuru comes from the areas identified, households contributed to 75% of deforestation in the areas in the recent years.

Discussion

New technology could not compete with population growth

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[12] This new charcoal frontline can be due to stricter controls in other division and/or better infrastructures to transport charcoal produced to the city.

[13] A trend confirmed by interviews with Kenya Forest Service officers who pointed out severe of deforestation around Nakuru in past three decades (KFS, 2010).

In 1981, Milukas found that Nakuru's households consumed on average 7.5t of wood equivalent per year. The average estimated by the 2010 study is of 3.9 tonnes. The annual use of biomass by Nakuru's average household was divided by two in thirty years. The main reason for this decrease is the penetration of new charcoal cooking stoves: before 1997 only 13% of Kenyan urban households had an improved ceramic jiko (a charcoal cookstove), and over 85% after 2002. The 2010 survey carried out in Nakuru found out that 91% of low income households had an improved cookstoves in 2010. The 1981 study does not provide such information but given the countrywide statistics in 1997 it is reasonable to assume that less than 10% of poor households in Nakuru in 1980 had an improved cookstove. The improved cookstove (Kenyan ceramic jiko) was introduced on the Kenyan urban market in the early eighties. It has an efficiency of 20 to 40% while the traditional stove has an efficiency of 10 to 20%. The shift from a traditional cookstove to an efficient one enables the saving of 30 to 60% the amount of fuel previously required (Ezzati et al., 2000). This explains the sharp reduction in charcoal requirement among low and middle income households.

However, from an aggregate point of view, Nakuru's households consume almost four times more woodfuel in 2010 than thirty years ago (124,000 tonnes vs. 498,000 tonnes). Consumption grew by a factor four while the number of households grew by 7.6, i.e. from about 17,000 to 123,000 dwellings in thirty years[14]. Had the stoves not been introduced and all other factors remained equal, biomass consumption would now be twice higher than today (figure 7).

[14] Author's estimates based on Milukas (1993) and KNBS (2010)

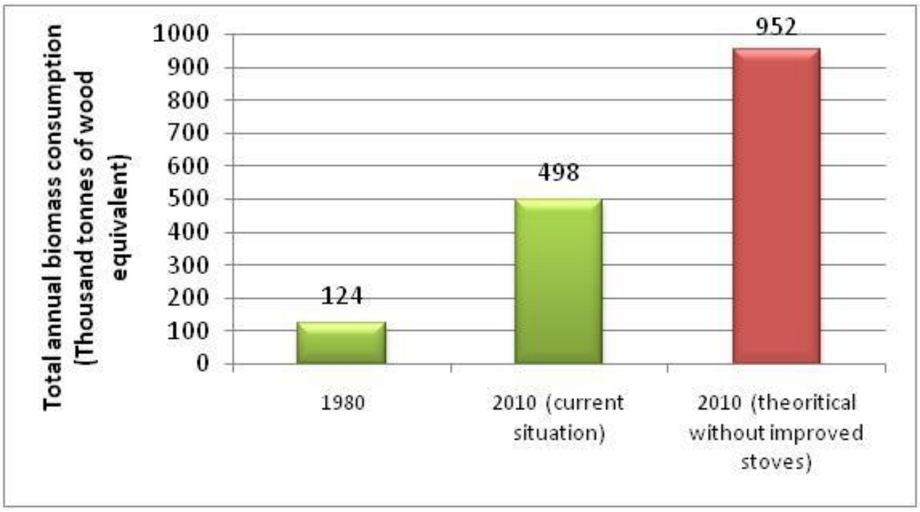

Figure 7 - Annual biomass consumption of Nakuru's households in 1980 and today

Despite the introduction of more efficient stoves, energy consumption dynamics so far resulted in a substantial increase in pressure on surrounding biomass stocks around Nakuru. Technology gains could not compete with population growth.

Global environmental impacts of Nakuru's households

Given that woodfuel is not sustainably harvested around the city, charcoal can be considered as a fossil resource. This translates into much higher household carbon budgets than the mean in SSA countries (which is about 1tCO2 per household). Low income area households reject more CO_2e than the mid income (3.1 t against 2.9 t CO_2e). High income area households reject 6.1 tCO_2e: this is comparable to the 6.6 tCO_2e emitted by UK's average households for their direct energy needs[15].

	Assuming sustainable harvest	Actual emissions
Low income households	0.46	3.1
Mid income households	1.3	2.9
High income households	4.3	6.1

Table 9- Mean household CO_2e emissions
tCO2e per household/year

[15] 3.2 tCO2e for home combustion and 3.4tCO2e for electricity use (DUKES, 2009 and author's calculations)

The poor are locked out of modern fuels

In 1980, 66% of households in Nakuru were connected to electricity. In 2010, the share of households connected to the grid stood between 55% and 61% (KPLC, 2010)

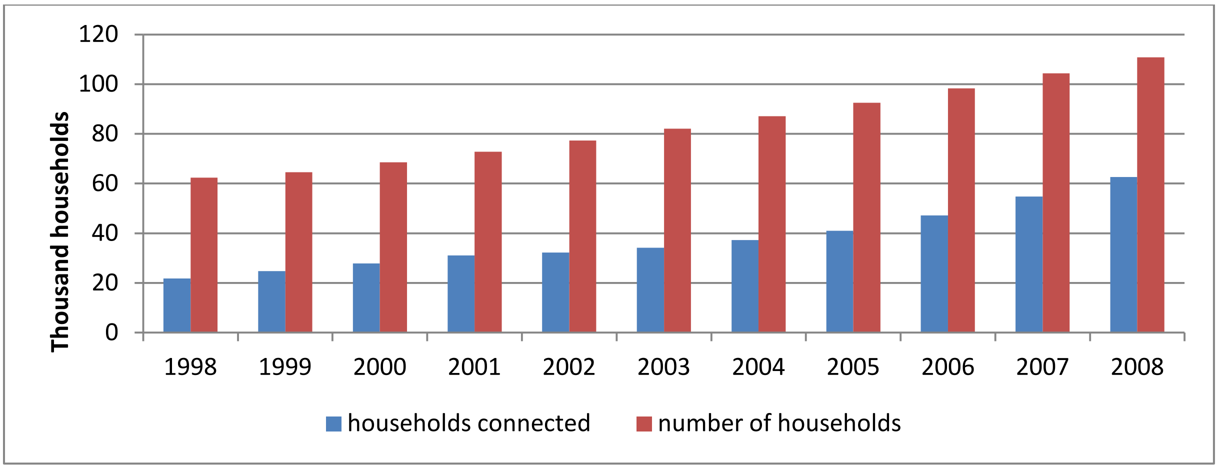

Figure 8 - Households connected to the grid in Nakuru
Source: KBS (2010), KPLC personal communications and author's estimates

In absolute terms, the number of connections was multiplied by a factor seven from an estimated 10,900 households in 1980 to 77,400 households[16] connected today. The share of households connected went down to 35% in 1998 before rising up again. This suggests that for a decade or so, population increase in the city largely outweighed the amount of new connections and that this has been corrected in the past ten years. However, electricity in Nakuru still fails to reach the poorest. In fact, grid connection was a luxury good in 1980 and it is still the case, as the majority of poor households in Nakuru are deprived of it (even though survey results show that 81% of poor households would get electricity if they could affort it).

The failed energy transition – assessing its causes

What are the drivers of this socially and environmentally unsustainable evolution of household energy consumption and provision? Figure xx presents the cost per unit of useful light (taking into account capital costs) of kerosene and electricity. On the long run (ten years), electricity is ten times

[16] Using the higher estimate, i.e. 61% of households connected

cheaper than kerosene for the same amount of useful light. But a quick look at fig. xx shows that upfront costs of modern fuels act as a barrier for the poorest and middle income households.

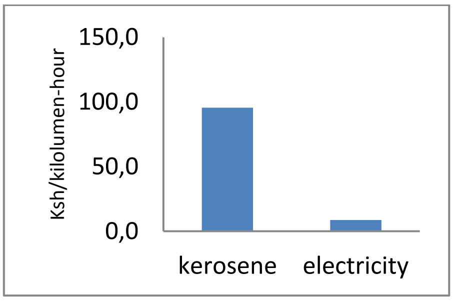

Figure 9 - Total cost per unit of useful light for kerosene and electricity
10% interest rate on capital costs

The logarithmic scale in fig. 10 shows that the upfront costs for electricity and LPG are a hundred to a thousand times higher than for traditional fuels. While it costs only Ksh 15 to Ksh 20 ($ 0.25) to buy a kerosene tin lamp, it costs Ksh 250 ($3) to buy a charcoal stove and Ksh 4,300 ($ 53) to buy a LPG stove with a recharge. This is half of the mean income of poor households in Nakuru. In the case of electricity, the cost of a connection is Ksh 35,000 ($ 434), without the lighting equipment and wiring. This is the equivalent of almost four months of earnings for the mean poor household in Nakuru. Hence, even if the per unit fuel cost of electricity for lighting is much lower than for kerosene lighting, the upfront cost for electricity is 2,300 times higher than the cost of access to kerosene lighting. Electricity connection is thus not an option for the poor, unless their landlord shares his or her connection with them – or unless they have access to credit.

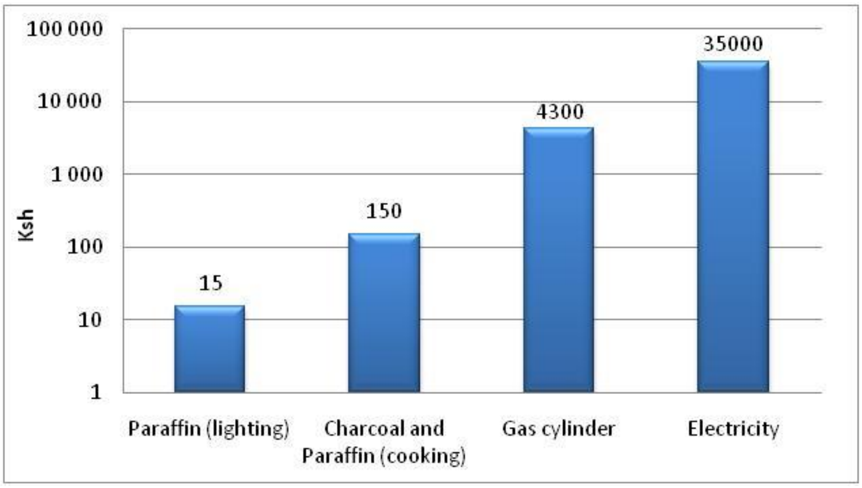

Figure 11 - Upfront cost of fuel options (Ksh), logarithmic scale
Note: In the case of electricity, upfront costs represent the costs grid connection and of the conversion devices (2 lamps). In the other cases, the upfront cost represents the cost of a cooker or kerosene lamp.

The upfront costs of modern fuels appears as the main barrier preventing low income households to shift to modern fuels. The irony of the situation is that the poor also pay more per unit fuel than the rich, for charcoal and electricity – simply because they are unable to purchase in large quantities (fig. 12).

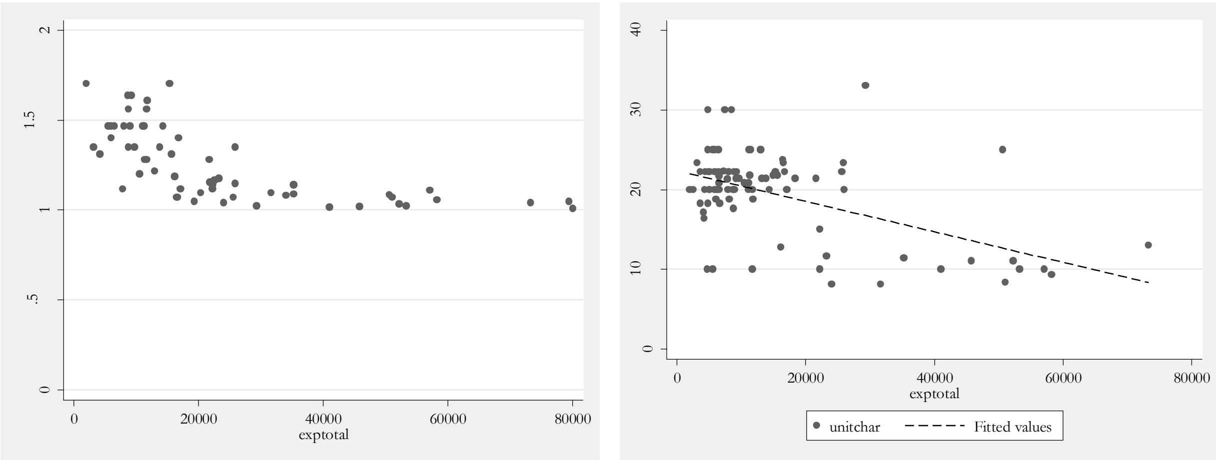

Figure 12 – price per unit kWh electricity (left); kg charcoal (right)

Inverting the trend: microfinance for urban energy transitions

The picture presented above is one of a socially and environmentally unsustainable evolution of household energy consumption in Nakuru over the past 30 years. The analysis of households' budgets shows that the transition to modern technologies is not a matter of solvability but of liquidity of households, i.e. access to credit. The following paragraphs show that a combination of microcredit with small scale household biogas technology could be economically, socially and environmentally viable.

Households reject organic waste and faeces which contain energy. Anaerobic digestion, the chemical process which transforms organic matter into a mixture of methane and carbon dioxide, is growingly recognized as a solution for improved sanitation and as a clean cooking fuel option in the developing world. Installation of small scale household biodigesters would thus be a suitable option for a city like Nakuru. In low income areas, the majority of plots has an area of unused land, with shared toilets and a large open space. This type of housing allows the installation of biodigesters as well as the disposal the biproduct of biogas, which can be used as an organic fertilizer for crops.

A study on Municipal Solid Waste in Nakuru estimated that poor households in the city produce on average 1.5 kg organic kitchen waste per day (Denchuko, 2008). An average household in the developing world produces an average 0.6 kg of feces per day and 6 Litres of urine (Ogunbiythe i, 1998). Under conservative assumptions, the resulting energy produced is 22MJ translating in 11MJ of useful energy[17]. The recycling of human and organic kitchen waste could thus theoretically replace 90% of an average poor household's charcoal needs and 70% of its total energy needs for cooking.

The survey showed that poor households in Nakuru spend on average 841 Ksh per month on charcoal. Assuming the households can replace 70% of their charcoal by biogas, a household can repay the biodigester with the money saved on charcoal in two years and five month at a 10% interest rate. The cost of a 1m^3 biodigester is 13,500 Ksh. Covering the cost of installation, maintenance and fee collection would come up to 15,000 Ksh per household and a monthly fee of Ksh 600. [18] In order to equip half of Nakuru's poor households with the technology, the total amount of the loan required would be would be of Ksh 750 million[19] ($ 9.3 million). Pressure on surrounding biomass would be reduced by 35%.

Solar Home Systems

Solar home systems have the potential to provide electricity at an affordable cost and are particularly attractive in highly insulated countries. Solar panels have a limited capacity and hence limit the amount of electric services users can have – hence they shouldn't be seen as complete electrification package. The SHS solution is in fact a transitional option which is complementary to grid connection – once the household is connected to the grid, the solar system can actually send electricity back to the grid

[17] The energy content of methane is 33.81 MJ/m^3, assuming a volumic mass of 0.67 kg CH_4 per m^3 (Bingemer and Crutzen, 1987) and an average daily production of methane for a household of 0.35kg. Energy efficiency of gas device is about 50%.

[18] The price are converted from Indian Rupees and 10% is added for transport (Biotech, 2010). The total calculation assumes it takes three hours to install, needs three hours maintenance per month and four hours dedicated to fee collection each month – with a monthly salary of 10,000 per month for 150 hours.

[19] 50,000 households equipped at 15,000 Ksh each

or simply reduce users' monthly electricity bill. Hence, while it has the potential to be developed on the short run, it will also last on the long run.

A 30W panel installed on the roof of Nakuru's low income areas can generate a safe 230 Wh per day[20]. This is enough to cover the energy requirement of 3 CFL light bulbs for five hours, a mobile phone charger, a radio with amplifier for eight hours a day and a 40W television for one hour per day. The price for the equipment is 17,500 Ksh (Sollatek, 2010). The provision of the device to households and the collection of monthly fees over 3 years is assumed to add an extra 1,000 Ksh per household[21]. If households repay 590 Ksh per month (the average amount currently spent on paraffin and battery charging), the loan would be repaid in 3 years at 10% interest rate. These options need to be looked at further in detail. In particular, social and technical feasibility must be explored in the specific context of Nakuru. However, examples provided here show that from an economic point of view, it is sound to develop renewable energy sources and that what is needed is access to credit.

Only 25% of households in Nakuru were able to access credit in 2005. Among these, 51% of households did it from friends or neighbors (KNBS, 2006). It is clear that credit markets are not adapted to the energy transition challenge in the region.

Policy implications

The paper showed that high income households considerably increased their energy consumption over the years in Nakuru. On the opposite, low (and middle) income households actually reduced their primary energy consumption. The analysis revealed that this reduction is due to the adoption of more efficient cooking devices - useful energy consumed by low income households remained more or less constant. Access to modern fuels (electricity and gas) did not significantly pick up over the past thirty years among the poor, while electricity connection increased among middle and high income groups. In order to invert the trend, comprehensive microfinance and technology packages should be provided to households in need. This may require administrative initial funding from local or national public actors but activity will generate income and local jobs for installation and maintenance. Nevertheless, charcoal

[20] Assuming 11 hours of daily sunlight at 70% efficiency.
[21] Ksh 1,000 covers the installation costs by one trained technician.

production/consumption should be taxed (implying its production is legalized), provided basic amounts are available for the poor during a transition phase.

This is necessary since surrounding biomass stocks were depleted due to charcoal consumption and will continue to be depleted if innovative financing instruments are not provided to the population and if its consumption is not considerably reduced.

Research in Kenya carried out thirty years warned against the very biomass stock depletion highlighted in this paper. The adoption of efficient cookstoves in East Africa contributed to reducing its extent. Policy makers and NGOs played a role in this diffusion, presumably influenced by researchers. But it seems that research was not sufficient enough in guiding policy making.

A further point must be made on the concept of a "self financed" household energy transition. The two options presented above can be implemented without subsidies, freeing public money for other sectors like health or education. However, grid electrification cannot be integrated in any microfinance package without significant amounts of subsidies. It would in fact take more than 30 years for a low income household to repay a loan for grid connection without any subsidy[22]. Unlike the sustainable options presented above, electricity does not pay for itself – as users will continue to pay a fee. Investment is profitable, but on the very long run.

Scope and limits of the study

While the trends presented in this study are clear, the precision of the estimates must be treated with precaution. Given the small size of the initial sample, estimates for electricity, gas and charcoal for high income households are not statistically different from zero. This calls for the use of a larger sample for high income households in the future. Meanwhile, when using municipal definition of high income households (i.e. area type and household rent), the size of the top income group increases and mean estimates for energy consumption fall in the same range and are statistically different from zero (see the appendix). The main insights of the analysis hold, i.e. that high income households consume more electricity, gas and petrol than low and middle income households - as well significant amounts of charcoal.

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[22] Monthly repayment of Ksh 150 at 10% interest rate. This may appear to contradict fig xx. But on a monthly basis, connection to the grid and electricity would cost Ksh 400 at a 10% interest rate.

Estimates on the amount of hectares required to support Nakuru's households fuel consumption are supported by a UNEP report (2006) which estimates that one tonne of charcoal leads to the depletion of 0.1 hectares of land and one tonne of wood to the deforestation of 0.0125 hectares of land in Kenya. In the case of Nakuru this would into the deforestation of 7,300 hectares of land in 2010, which is close to the value obtained (6,900).

Conclusion

This article retraced the evolution of energy consumption over the past thirty years of different income groups in an East African city. The first set of results shows that the energy consumption gap is very likely to have increased between top and bottom income groups. Energy consumption of the poor decreased while it increased at the top of the income distribution. This study calls for more research on inequalities in resource use on the long run.

The second set of results reveals that large scale deforestation occurred around the city in order to support its energy consumption over the past thirty years. Despite the adoption of energy efficient charcoal cooking stoves, forest cover was reduced at an impressive rate. Evolution of energy consumption is thus alarming from a social and environmental point of view. The results presented in this article are specific to the case studied but are likely to be similar in many other cities of the region sharing the same characteristics in terms of economics, demography and geography.

Options for sustainable energy transitions exist and they have the potential to considerably reduce the city's pressure on its surrounding biomass stocks and to free disposable income for low income households. The article focused on the rationale for the development of a pro-poor credit market to help poor households break the upfront cost barrier of modern technologies. If local and national level policies do not address the challenges, trends foreseen over the past thirty years will continue.

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Appendix

Fuel type	Energy content		Efficiency	
	Mega joules	kgoe	For cooking (%)	For lighting (Lumen/Watt)
LPG (kg)	45.2	1.08	59.7	NA
Electricity (kWh)	3.6	0.09	50.0	42 (CFL) 10 (Bulb)
Paraffin (Litre)	39.1	0.93	38.4	0.1
Charcoal (kg), 5% moist. C. 4% ash.	33.1	0.79	30.0	NA
Wood (kg), 15% moist. C. 1% ash	16.0	0.38	15.6	NA
Dung (kg) 15% moist, 20% ash	14.5	0.35	10.2	NA
Straw (kg), 5% moist, 4% ash	13.5	0.32	10.2	NA

Modern fuels — Transitional fuel — Traditional fuels

Table 10: Energy density of fuels and mean efficiency of conversion devices in Kenya
Note : for kerosene, conversion efficiency of a kerosene tin lamp is used
Sources: (Barnes et al. 2005, RoK, 2002)

	N	Mean	Min	Max	Std. Deviation	Mean 95% conf. interval
CHARCOAL (kg)	73	40,2	,0	81,0	19,4	35,5 – 44,8
FIREWOOD (kg)	73	28,8	,0	331,1	56,7	15,2 – 42,3
ELEC. (kWh)	73	31,2	,0	270,0	47,4	19,8 – 42,5
PARAFFIN (L)	73	6,0	,0	37,5	5,3	4,8 – 7,3
LPG (kg)	73	,3	,0	6,8	1,3	0,02 – 0,61
PETROL (L)	73	,0	,0	,0	,0	NA

Table 11 - Fuel consumption in among low income households

	N	Mean	Min	Max	Std. Deviation	Mean 95% conf. interval
CHARCOAL (kg)	37	26,5	0	81,0	3,8	18,1 – 34,4
FIREWOOD (kg)	37	0	0	0	0	0
ELEC (kWh)	37	265,2	50,0	1040	40,4	183,9 – 347,1

PARAFFIN (L)	37	2,4	0	12,0	,52	1,4 – 3,5
LPG (kg)	37	6,8	0	6,0	,9	4,9 – 8,8
PETROL (L)	37	34,3	0	133,8	8,6	21,8 – 56,9

Table 12 - Fuel consumption among middle income households

	N	**Mean**	**Min**	**Max**	**Std. Deviation**	**Mean 95% conf. interval**
CHARCOAL (kg)	7	46,9	0	160,0	57,3	-5,9 – 99,8
FIREWOOD (kg)	7	0	0	0	0	0
ELEC (kWh)	7	511,5	185,0	1880,0	655,8	-94,3 – 1117,2
PARAFFIN (L)	7	3,7	0	12,0	5,1	-1,2 – 8,4
LPG (kg)	7	10,6	3,8	20,0	9,3	1,9 – 19,3
PETROL (L)	7	70,1	23,9	167,0	66,7	8,9 – 132,2

Table 13 - Fuel consumption among high income households

Given the small size of the high income households sample, most results are not different from 0 at the 95% confidence level. However, when looking at results with municipal definition (area type), mean values fall in the same range and confidence intervals are reduced. Main insights of the analysis hold, i.e. high income households use more electricity, gas and petrol than mid and low income households.

	N	**Mean**	**Min**	**Max**	**Std. Deviation**	**Mean 95% conf. interval**
CHARCOAL (kg)	19	32,9	,0	160,0	42,3	12.4 – 53.2
FIREWOOD (kg)	19	,0	,0	,0	,0	NA
ELEC. (kWh)	19	532,5	185,0	1880,0	428,8	325.9 – 739.2
PARAFFIN (L)	19	1,2	,0	12,0	3,5	-0.4 – 2.9
LPG (kg)	19	12,2	3,8	28,0	7,2	8.7 – 15.4
PETROL (L)	19	80,1	23,9	167,0	48,4	56.0 – 104.1

Table 13 - Fuel consumption among high income *area* households

	Charcoal (t)	Wood (t)	Wood equivalent (t)
Low rent area	0.48	0.35	4.2
Mid rent area	0.35	0	2.9
High rent area	0.39	0	3.2
Total for all HH	57,900	34,000	498,000

Table 14: Annual use of woodfuel by Nakuru's households in 2010

1t of charcoal = 8t of wood equivalent