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Research Article

ANALYSIS OF ALTERNATIVE ENERGY SOURCES IN LUBUMBASHI: DISPARITIES BETWEEN FORMAL AND INFORMAL SETTLEMENTS

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A B S T R A C T

This article is devoted to identify and analyze alternative energy sources used at the household scale in planned and unplanned settlements. The results show that most of surveyed households are located in unplanned settlements. The highest number of households per parcel and people per household are observed in Kenya and Kamalondo municipalities, while the lowest number is observed in Lubumbashi municipality. Furthermore, both collective (dynamo) and individual (solar panels) solutions are more often used in spontaneous settlements than in formal settlements. Charcoal and candle are frequently used for cooking and lighting in both formal and informal settlements.

INTRODUCTION

Urban morphology in most developing countries is highly diversified. Brunel (2004) speaks of a "fragmented and anarchic urban fabric divided into heterogeneous islands" resulting from modern, spontaneous, social and spatially segregated urbanization. Furthermore, the urban administration services are often in the logistical and technical inability to impose the urbanistic norms which would limit the anarchic urbanization (Manirakiza, 2015). The resulting form of urbanization leads not only in the exclusion of the poor but also in the environmental consequences for the majority of urban households already benefiting poor quality basic services (UN-Habitat, 2014). Under these precarity conditions dictated mainly by the lack of adequate urban management, households are forced to resort to alternative energy sources. In sub-Saharan Africa (except South Africa), for example, about 85% of energy needs are covered by wood (Sokona, 1997; IEA, 2002; World Bank 2007; Wadjamsse, 2008; Hütz-Adams, 2008; Shuku, 2011). Extreme poverty and lack of access to other fuels contribute to the total dependence of sub-Saharan Africa's population on traditional fuels (IEA, 2002).

In Lubumbashi, although the electricity access rate is about 61.6% at the urban scale, the number of load shedding is however very high (Banza *et al.,* 2016a).

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Actually, in most developing cities, households opt for the use of multiple energy sources, which provides a sense of energy security. Indeed, full dependence on a single fuel or technology can make households vulnerable to price changes and unreliable service (IEA, 2006).

In some cases, the used energy sources at household or neighborhood levels, although economically ecologically inefficient, are much more technically efficient comparatively to the access to an electricity grid (World Bank, 2010). The study of alternative energies is an effective way to identify sustainable and reliable sources as well as those that have a negative impact on both human health and the environment. In the context of rapid urban growth characterized by spontaneous urbanization, this article is devoted to identify and analyze various alternative energy sources used at the household scale in both spontaneous and planned settlements. This is to test the hypothesis that easily accessible energy sources are the most used and would be related to the type of habitat.

Study area, Data and Methods

Study area

Located at 11°40' latitude and 27°29' longitude, the city of Lubumbashi is the capital of Upper-Katanga province, DR Congo. Lubumbashi counted 413,000 inhabitants in 1973 and 700,000 inhabitants in 1988. Recently, the city counted 1769397inhabitants in 2014 (INS, 2016).From its origins, the city was powered by the thermal power stations of the UMHK (Union Minière du Haut-Katanga). In 1930, the connection to the interconnection network of the Lufira hydroelectric power stations was realized (Bruneau, 1987).

Electricity access rate in Lubumbashi varies from a municipality to another. Municipalities with a high percentage of electrification are those located in the center of the city such as Kamalondo and Kenya, with 80.4% and 79.7% respectively. Unlike, Annexe municipality grouping new quarters has the lowest electrification rate (Banza *et al.*, 2016a).

Methodology

Sampling method and data collection

The Stratified Random Sampling (SRS) method was chosen because this type of sampling (probabilistic) provides a representative sample. With this method, each individual in the population (household) has the same probability of being included in the sample (Vaillant, 2010, Gerville-Réach & Conallier, 2011, Lessard, 2013). The survey covered 26 neighborhoods in planned and unplanned settlements out of a total of 43 constituting the city of Lubumbashi. Furthermore, there is also a semantic multiplicity in the urban terminology reserved for the typology of the settlements (Manirakiza, 2015). For this article, neighborhoods constructed without spatial planning, nor development (without viabilization) and generally informal and unplanned are considered as spontaneous. They result from the continuous growth process of the city and the inadequate or lack of urbanization policies (Manirakiza, 2015). While the planned areas are those installed on the off sites and serviced with *ipso facto* the official status given formal, legal and structured (Josse & Pacaud, 2010; Manirakiza, 2015).

The initial sample size was obtained using the following formula:

$$n_1 = \frac{z^2 P(1-P)}{e^2} \text{(Eq.1)}$$

Where z is the value type of confidence level, P is the proportion of the actual population and e is the margin of error. The adjustment taking into account the size of the population N, was done using the following equation:

$$n_2 = n_1 \frac{N}{N+n_1} \text{(Eq.2)}$$

Ultimately, the adjustment to the response rate to determine the final size of the sample, n:

$$n = \frac{n_3}{r} \quad \text{(Eq.3)}$$

Where r is the expected response rate.

This final sample was thus grouped into strata (municipalities of the city). The proportion of the sample allocated to the stratum h is $a_h = n_h / n$. In each stratum h, the sample size n_h is equal to the result of the size of the total sample n and $_h$ the proportion of the sample from that particular stratum. In the case of these investigations all strata did not have the same size, an apportioning N was well used (Laurencelle, 2012), the sample size (n_h) each stratum is proportional to the population size (N_h) of the stratum (Levron, 2009). A larger part of the sample was therefore allocated to larger stratum. The following equation was thus obtained:

$$n_h = \frac{N_h}{N} n \text{(Eq.4)}$$

In the estimates, the level of accuracy was retained at +/- 5% (Levron, 2009), assuming a margin of error of 0.05, a confidence level of 95% for each stratum and a response rate of 50% (Ndongo *et al.,* 2012).

A total of 5270 households were surveyed in 26 neighborhoods. For each municipality the number of households to be surveyed has been previously defined (Table 1).

Table 1 Determination of the sample size in different strata

Strata	Number of households	Sample size
Lubumbashi	32357	740
Kampemba	48470	1110
Kamalondo	6499	148
Kenya	20496	470
Katuba	36976	846
Ruashi	41311	952
Annexe	43891	1004
Total	**230000**	**5270**

Since the survey covers a heterogeneous population, the representativeness of the sample itself can be verified by a statistical test, the chi-square adjustment test (Laurencelle, 2012). The total number of households is, N = 230000, distributed in 7 municipalities (strata), the sample is, n = 5270 households. Table 1 presents the respective household distribution in each municipality. The sampling fraction here is, f >0.02 (≈2%). The classical chi-square is the sum of the components (Greenwood, 1996).

$$x^2 = \frac{(ni - f*Ni)^{\wedge}2}{f*Ni} \text{ (Eq.5)}$$

By summing the values of all strata, k = 7 components, $x^2 \approx 13.5$. According to Laurencelle (2012) this chi-square is not adapted to a finite population sample; it is necessary to multiply its value by an overall population factor (fp) given by:

$$fp = \frac{N-1}{N-n} \text{ (Eq.6)}$$

From where x^2Corr. ≈ 14. For k - 1 = 6 degrees of freedom and a confidence interval of 95%, the fractile of the chi-square law is moreover greater than $x^2$6dl; 0.95 ≈ 12.592. From where x^2Corr. > x^2*6dl;* 0.95. According to Joffre (2014) this sample would be representative. Moreover, this test is better to ensure an accurate reflection of the population in its diversity (Laurencelle, 2012). Its application to the present case has shown that the obtained sample is scientifically acceptable (Joffre, 2014).

Data processing

Data from surveys were scanned and encoded in Excel software in binary form to facilitate statistical processing. After encoding, the data were subjected to Analysis of Variance (ANOVA) to highlight differences between municipalities (Durin, 2006; Madubansi& Shackleton, 2006), with *post-hoc* Tukey test (Ubani *et al.*, 2013). ANOVA allowed to differentiate the means of the use of different energy sources. A Principal Component Analysis (PCA) performed with the *Past2.01* software allowed to perform an energy-based characterization of municipalities.

RESULTS

The proportion of household belonging to planned or unplanned settlements varies from a municipality to other. Figure 1 shows that the totality of households surveyed in Kamalondo municipality are in the planned habitat. This is the highest proportion compared to other municipalities. In second place, comes Kenya municipality where more than 78% households are in the planned habitat. The general trend shows that the central municipalities are constituted in large part of planned neighborhoods. The largest proportion of unplanned settlements is observed in the Annexe municipality. In this municipality largely constituted of new neighborhoods, more than 67% households are self-build. In other municipalities such as Ruashi, Kampemba and Katuba, although the large proportion of households is in the planned neighborhoods, the difference with self-build settlements remains very low. Planned settlements are mainly the oldest and owe their existence to the colonial era, unlike the spontaneous settlements. Today these spontaneous settlements constitute the belt of the urban core constituted by municipalities such as Kamalondo, Kenya and certain neighborhoods of Lubumbashi, Kampemba and Katuba municipalities.

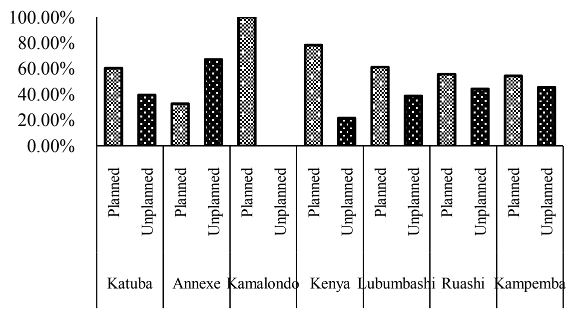

Figure 1 Proportion of households in self-built and formal settlements in different municipalities (Source: Survey-based data of Author).

The analysis of variance indicates a difference highly significant (P = 0.000) between municipalities regarding the average number of household per parcel and people per household. The highest number of people per household is observed in Kenya, Kampemba and Kamolondo municipalities (figure 2a). However, Lubumbashi municipality counts the lowest number of people per household. The same trend is observed for the number of households per parcel (Figure 2b).

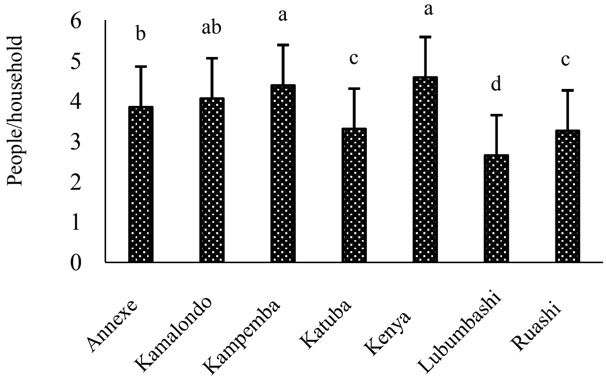

Figure 2a Number of people per household (Source: Survey-based data of Author).

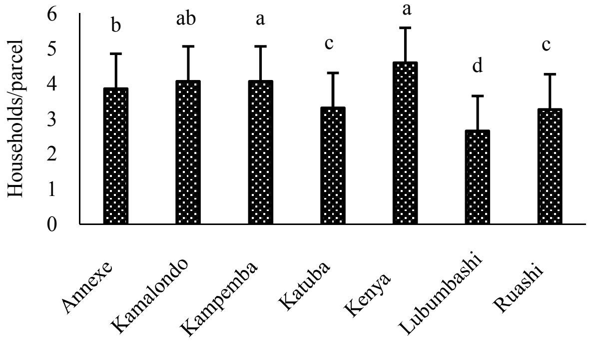

Figure 2b Number of household per parcel (Source: Survey-based data of Author).

The average number of rooms per dwelling is highest in Lubumbashi and Annexe municipalities. The results of the analysis of variance show that there is a difference highly significant between municipalities. Municipalities with the highest number of rooms per dwelling house group large houses, unlike small dwellings in Kenya, Kamalondo, Katuba and some neighborhoods of Ruashi municipality (Figure 3).

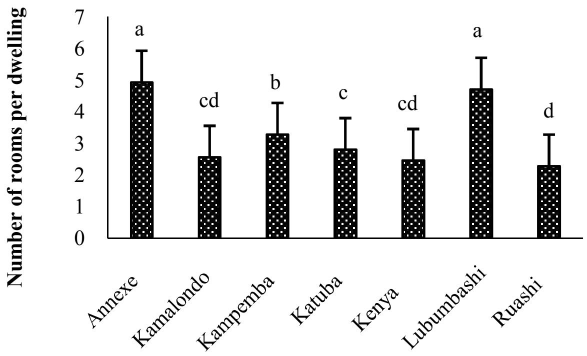

Figure 3 Average number of rooms per dwelling (Source: Survey-based data of Author).

The Principal Component Analysis (Fig. 4) shows the distribution of the different energy sources in different municipalities. As a result, solar panels are more commonly used in the Lubumbashi commune while the use of electric generators is more common in the Ruashi, Kamalondo and Kampemba municipalities. In the Annexe municipality, two energy sources dominate, *dynamo* and wood. Most households surveyed in this settlement (not being connected to the network) are using the *dynamo* as a source of electrical energy.

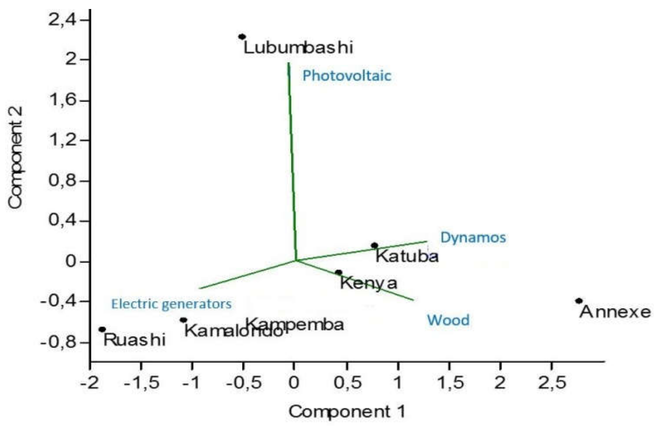

Figure 4 Energy source-based characterization of different municipalities (Source: Survey-based data of Author). ***Dynamo:*** diesel engine coupled to an alternator which electricity can be used by about 10 households.

The use of energy for lighting allow to classify the various municipalities into three categories. The first category constituted by the Ruashi and Kamalondo municipalities characterized by a greater use of candles as a source of energy for lighting. The second category (Lubumbashi municipality) characterized by an important use of petroleum lamps and rechargeable lamps. The third category consists of Kamalondo, Annexe and Katuba municipalities where the most commonly used light source is the flashlight (Figure 5).

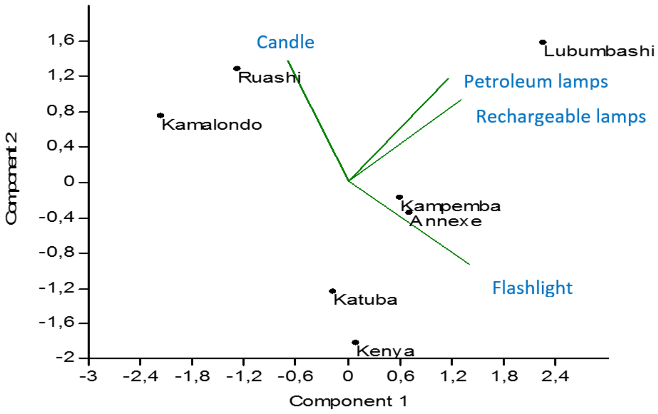

Figure 5 PCA presenting the energy used for lighting in the different municipalities (Source: Survey-based data of Author).

Figure 6 shows the proportion of households in planned and unplanned neighborhoods based on the use of alternative sources of energy. As a result, in the unplanned settlements, the most commonly used sources are *dynamo*, solar panels and the candle. Most of the households surveyed in the planned neighborhoods prefer the power generator and the charcoal. With regard to access to electricity, two fraudulent modes predominate in planned settlements: illegal connections and connections to neighbors.

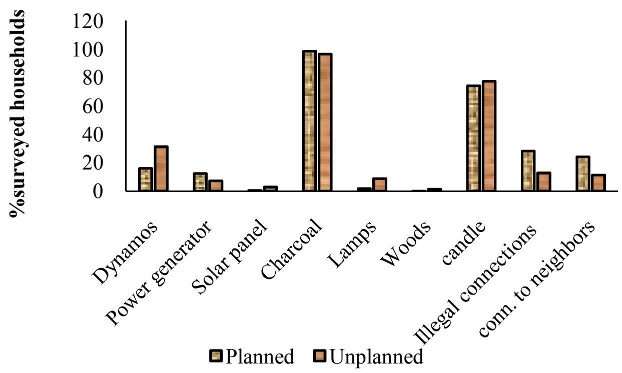

Figure 6 Use of alternative energy sources and modes of access to electricity formal and informal settlements (Source: Survey-based data of Author).

DISCUSSION

The general trend shows that the central municipalities are constituted in large part of the formal neighborhoods. Furthermore, the largest proportion of unplanned neighborhoods is observed in the Annexe municipality. In this municipality regrouping new spontaneous neighborhoods, more than 67% of surveyed households are in the neighborhoods of self-construction. Manirakiza (2015) in Kigali, for example, showed that spontaneous urbanization is caused by households that want to build their dwellings in the city but are excluded from the formal modalities of getting ownership. In addition, other dwellings emerge in unattractive sites and difficult to manage, such as shallows and steep slopes (Manirakiza, 2009). These illegal occupations are called *squatters* in english and *invasion* in Latin America (Dorier- Apprill, 2001). In Lubumbashi, near totality of settlements have not followed the formal validation and approval process (Group-Huit, 2009). For these settlements, not only traveling costs are highlighted, but also the low density of basic equipment. Yet the city is already facing three challenges in terms of access to electricity: (i) electricity grid extension to large non-electrified areas; (ii) rehabilitation of the existing electricity grid and (iii) electricity supply improvement (Group Huit, 2009).

In other municipalities such as Ruashi, Kampemba and Katuba, although they are largely constituted of the planned neighborhoods, the proportion of dwellings from spontaneous urbanization is very significant. The planned neighborhoods are mainly the oldest and owe their existence to the colonial era unlike clandestine housing estates that are born without any respect for urban rules. This observation would imply a great weakness of the public and municipal authorities since they are also involved in poor urban governance. Irregularities in urban development are amplified notably by the involvement of other actors, such as customary authorities, which lead to a disorder in the urban space management (M'Bassi, 2001). However, the absence of adequate urban planning generally results in horizontal growth of most developing cities. According to Djelal, (2005), it is more than urgent to move from the spreading city to the compact and dense one organized around a more intensive land use, managed from a better integration between the policies of serving electricity and urban growth planning (Camagni, 1997).

Moreover, the highest number of people per household is observed in Kenya, Kampemba and Kamolondo municipalities. These neighborhoods are very dense due to the presence of public facilities (Banza *et al.,* 2016b) and shops making them attractive (Group Huit, 2009). However, Lubumbashi municipality counts the lowest number of people per household. Some neighborhoods of this municipality are mainly inhabited by small wealthy families. In these quarters, one notices the presence of the villas and often inhabited by a single family. These realities could explain the obtained results, revealing the number of people per household and number of households per parcel relatively low in this municipality. Moreover, municipalities with high number of rooms per dwelling are regroup large houses, unlike small buildings in Kenya, Kamalondo, Katuba and Ruashi municipalities. These characteristics of surveyed households show similar number of rooms per dwelling in the old communes such as Kenya and Kamalondo. In Annexe municipality, electric equipment is becoming more and more scarce consequently. This is according to Banza *et al.* (2016b) one of the consequences of a very rapid urban sprawl unaccompanied by the actions of the National Electricity Corporation to electrify these areas.

Due to both geographical and socio-economic contexts, some municipalities use some sources more than others. The use of electric generators, for example, is more frequent in Ruashi, Kamalondo and Kampemba municipalities. As for the *dynamo* and the wood, their use is more frequent in Annexe, Katuba and Kenya municipalities. In Kenya municipality, most neighborhoods are planned, the majority of the households uses the *dynamo* in case of load shedding. In this municipality, economic activities are more frequent and dominated by trade. The presence of one of the largest markets of the city implies a strong demand for electricity. In this context, the resort to collective solutions including *dynamo* useis cheaper compared to individual solutions that require the use of personal electric generators. On the other hand, in Kamalondo municipality, 100% of neighborhoods are planned, the most used alternative source of electricity is the electric generator. Most surveyed households in this municipality prefer individual solutions because collective solutions would be limited by the perception of the inhabitants. Indeed, the access to electricity in this municipality is facilitated by several factors, notably the built-up density and the dominance of the illicit arrangements. Although, electrical service quality is poor (characterized by frequent and unscheduled shutdowns), households are forced to bear the whims of SNEL. Thus individual solutions related to the use of personal electric generators constitute the most used alternative source in Kamalondo. In Lubumbashi municipality, households prefer individual solutions as an alternative source of energy. Indeed, solar panels are the most widely used compared to other sources. In Annexe municipality two energy sources dominate, the *dynamo* and wood. In this part of the city the density of the building is decreasing and the rate of access to the electricity grid concerns only some wealthy households. In these precarious conditions, modest income households resort to the use of the *dynamo* (Banza *et al.,* 2016a). In the context of low access to electricity grid, the *dynamo* use is become the most reassuring means of assistance for these populations. Furthermore, the use of wood dominates in this part of the city, mainly for cooking. This situation would be justified by the fact that for these peripheral settlements the woods are closer compared to the central neighborhoods of the city. Furthermore, urban households prefer charcoal because they do not produce much smoke and their calorific value is twice that of wood and can therefore last longer.

Yet there are several disadvantages associated with the use of certain forms of energy. The use of generators, for example, requires a financial cost for fuel purchase and maintenance. Existing literature reveals that the use of certain alternative energy sources is more expensive compared to a direct connection to the electrical grid (Vu, 2011; Heuraux *et al,* 2011; Ntagungira, 2015). For example, electricity produced by a generator in SSA costs about 0.35 to 0.40 USD / kWh (Ntagungira, 2015), or 4 to 5 times the cost of the kWh sold by SNEL.

Furthermore, the use of multiple energy sources provides a sense of energy security. Indeed, full dependence on a single fuel or technology can make households vulnerable to price changes and unreliable service. Photovoltaic, although durable, its use is limited by the cost of access. Subsidies and improvements to the regulatory framework are identified as a means of serving market introduction programs and helping to reduce the initial costs of deploying photovoltaic technologies and help them overcome barriers (IEA, 2009).

As for the *dynamo,* the owners have set up a form of *business.* Indeed, they can connect up more than ten households that must pay 1000 FC a day after paying the subscription fees that can reach 10000FC. This is for an access of 6 hours (from 5pm to 11pm) and for limited use of light bulbs and other electrical appliances. In the city scale, this technique has become the most popular in new and unserved settlements. Facing electricity penury, small entrepreneurs in Ontario (Canada) have developed genuine power systems at the neighborhood or small town level, serving subscribers in their homes. According to a study by the World Bank, their installed capacity would represent 38% of that of the public company (Post de Beirut, 2013).

Furthermore, the charcoal use is considered as relatively affordable, economical and practical (Karekezi *et al.,* 2008). In many households, charcoal is normally considered purchased at low cost. But due to repetitive bought in small quantities, it ends up being more expensive in the long term compared to other energy sources (ESMAP, 2007). According to the International Energy Agency (2009), without substantial change in policy, the total number of people depending on biofuels will increase from 2,400 in 2010 to 2700 million by 2030 (IEA, 2009). In addition, there are health risks associated with the use of charcoal. When burned, charcoal produces carbon monoxide, if it is used in a poorly ventilated room, it could cause hazard to the user (Clancy, 2004; Karekezi *et al.,* 2008; Njong and Johannes, 2011; Kumlachew *et al,* 2014). Moreover, the scarcity of biofuels would also affect women and children, in particular, who would need to spend more time collecting these fuels; time that could be spent on other activities such as agriculture and education (Yonas *et al.,* 2013). It is clear that the lack of access to a reliable electricity system entails multiple consequences both socioeconomic and environmental. According to the World Bank (2010) this tends to make the poor poorer.

Regarding the use of the energy source for lighting, Ruashi and Kamalondo municipalities are characterized by a greater use of candles despite its multiple damages including fires within households. In addition, these fuels generate poor quality light to very low yields (Mills, 2005). For instance, 1 kWh is the energy released by 10 candles (Ntagungira, 2015) at a cost of about 1 USD in Lubumbashi, 11 times more expensive than electricity sold by SNEL ($ 0.087 / kWh) for a domestic use. According to Mills & Jacobson (2011), households that do not have access to an electricity grid spend about $ 40 billion per year in lighting, approximately 20% of all global lighting costs but receive only 0.1 % of the lighting service consumed by the world electrified in total.

Lubumbashi municipality by the cons is characterized by frequent use of oil lamps and rechargeable lamps. In addition to their good quality light, these lamps are economical. As for the Kamalondo, Annexe and Katuba municipality, the most used light energy source is the flashlight.

Regarding access to electricity, two fraudulent modes dominate in planned settlements, illegal connection and connection to the neighbor. Indeed, the built-up density in planned and equipped settlements favors illegal access to electricity. Households in Kamolondo and Kenya municipalities have such easy access to electricity without being influenced by income level. In the peripheral neighborhoods against, beyond the size of parcels that induces a significant urban sprawl their disposition is not optimal. They are usually square, or rectangular but with the long side along the way (Group Huit, 2009).

CONCLUSION

The main objective of this paper was to identify and analyze the different sources of energy used as alternatives in formal and informal settlements in Lubumbashi. The proportion of unplanned neighborhoods dominates the structured areas. Structured settlements respecting of urbanistic rules since their creation date from the colonial era. Most surveyed neighborhoods result from an uncontrolled urbanization. Normally, urbanization is to develop the territory before its occupation. Currently, access to housing difficulties in a formal setting for the majority of people contribute to the inapplicability of the principle of urban planning that precedes urbanization. The lack of rational allocation of housing structures and the lack of coordination between stakeholders lead in the proliferation of illegal settlements and the interweaving of precarious dwellings. The densification conditions present in planned and equipped settlements promote illegal access to electricity. In the peripheral neighborhoods against, beyond the size of parcels that induces a significant urban sprawl their disposition is not optimal, in these conditions, access to electricity is destined to wealthiest households. Given these conditions and irregular urban inequalities in the distribution of electrical equipment, the households surveyed in squatter are increasingly resorting to collective solutions such as the *dynamo* and individual such as solar panels as alternative sources of electricity. By cons, most of the households surveyed in planned neighborhoods prefer the electric generator. In some planned neighborhoods with high economic activity, the use of *dynamo* is also frequent. Furthermore, the use of charcoal as a source of energy for cooking concerns all surveyed settlements, planned and squatter. As for the source of energy for lighting, candle dominates in both planned and unplanned settlements. However, households in informal settlements also resort to economically less expensive solutions (flashlight).

The still limited use of solar panels yet producing clean and sustainable energy could be facilitated by the subsidy policies and improving the regulatory framework to promote the programs of introduction on the market and help reduce initial costs deployment of photovoltaic technologies and promote this clean energy source.

Finally, programs that would target improving and increasing access to sustainable and clean energy, should take into account of geographical disparities due to population growth and urban sprawl of Lubumbashi. The solutions (collective and / or individual) should be adapted to urban conditions present in each neighborhood.

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