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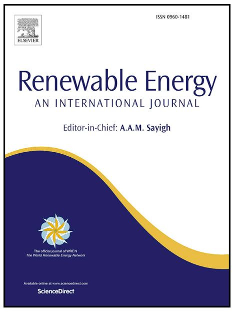

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Rural electrification in Africa – A willingness to pay assessment in Niger

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Rural electrification in Africa – A willingness to pay assessment in Niger

Abstract

About 84% of the population in Niger live in rural areas and only about 8% of them have access to electricity. For rural population, renewable energy use is an expensive option. This paper seeks to answer the question: Can collaborative consumption and community ownership increase the willingness to pay for the electricity generated through solar photovoltaics (PV) systems among the villagers of a rural area in Niger?

Surveys were conducted in a rural village in Niger to assess the WTP for electricity services. These results were compared to the costs of off-grid electrification systems considering collaborative consumption and community ownership approaches. This was done by assessing the willingness to pay through household surveys and comparing the results to different electrification systems under the mentioned concepts.

A reduction of about 80% monthly expenses could be achieved by using both collaborative consumption and community ownership. This translates to a possible increase in the WTP from 17% to 81% of the villagers for solar PV based electrification systems. Collaborative consumption, provided its acceptance and equipped with the proper policies and regulations, can thus contribute to a wider access to electricity in the rural areas of the country.

Keywords

Willingness to pay, rural electrification, ownership scenarios, solar photovoltaics, collaborative consumption

Highlights

- For a case study site in Niger, a field research combined with survey was carried out
- Novel approach of collaborative consumption and ownership model was applied
- A possible reduction of about 80% of the monthly energy costs can be achieved
- The WTP in collaborative consumption operational model increased from 17% to 81%
- Through demand side management, off grid renewables can be accommodated

1. Introduction

About 84% of the population in Niger lived in rural areas in 2014 [1] and out of them, only about 8% had access to electricity [1]. The population in rural areas is generally composed of a high percentage of poor households. These areas usually have a low population density. Because of this, there are not attractive economic benefits for private investors or electricity supply utilities to offer electricity services to these villages [2]. In addition, because the transmission and distribution systems have not reached all the populated areas in the country, it is more economical [3] [4] to electrify gradually from the urban centres out than to extend the grid [5] to reach all the remote villages [6] in rural areas [7]. This leaves the vast majority of the population in Niger without electricity access. There exist low expectations of grid infrastructure expansion to rural villages anytime soon.

Renewable energy technologies (RETs) contribute to the reduction of the greenhouse gases emissions that fossil fuel based electricity generation plants emit [8]. RETs deployment in West Africa could prove an effective solution to the lack of electrification of both rural and urban areas, as it has been proven in other regions [9]. Also, there are many success stories, where RETs contribute to supply other energy needs beyond electricity (e.g. cooking, space heating, transportation). Studies have been carried out with a low carbon development model in which the West African Power Pool (WAPP) was assessed with the aim of achieving higher levels of electrification while keeping the emissions as low as possible using renewable energy technologies [10]. Gifted with high solar irradiation, Niger lies in the zone where the solar photovoltaics (PV) technology could be economically most viable [11]. Therefore, solar PV has been considered as the rural electrification technology in this study.

The deployment of renewable energy technologies does not come without recurring obstacles [12]. These can be categorized as financial and profitability barriers, awareness and behavioural barriers, regulatory and institutional barriers, technological barriers, and company resources barriers [13]. Among them, when talking about rural populations, the most influential barrier is the high initial investment that the renewable energy generation plants require, including solar PV systems. Which usually make them require governmental support [14]. One shall not wait the supplying of electricity to rural population until the technology becomes cheaper, therefore different operational approaches that do not focus only on technology type and investment costs are needed. The diffusion of social innovations can have effects on energy transition through multilevel perspective [15]. Social learning can aid in the promotion of renewable energy for domestic use [16] and can serve to show how societal perspective helps in the assimilation of renewable energy technologies among the remote population [17]. In this context, two concepts of interest are community ownership [18], [19] and collaborative consumption [20]. These concepts present possibilities for overcoming some of the financial barriers [21] to the deployment of renewable energy technologies. Collaborative consumption could lead to cost saving [22] and resource conservation [23], while community ownership can have the effect of lowering the costs for individuals [18].

User's satisfaction with the generation systems [24] leads to the surrounding communities to become interested in such systems and also to a potential increase in their willingness to participate. To ascertain the satisfaction of the communities electrified, the generation systems' value need to be perceived by the communities. This can be achieved through local ownership of the systems [25]. Which also helps to increase the sustainability [26] of such projects [27].

Community ownership, as its name says, is a model of ownership in which a good or service is not owned by a single individual, but by the whole community. As one of its objectives, it has to allow for the wealth generated within a community to remain within the said community [28]. Among its advantages are (i) the possibility for communities to influence the design and development of projects [28], (ii) well planning the distribution of the produced goods or services [29], and iii) support in the building of a greater sense of local identity, achievement and belonging as well as the capability of employment generation [30].

Collaboration, as a demand side management [31] tool, has been studied as a way to bring together consumers into user groups in order to balance the demand [32], minimize the cost for consumers [33], and balance the loads to meet supply constraints [34]. This method, often called “collaborative load”, has been proposed only in tandem with smart grids in urban areas. Applying this concept to rural areas could mean, instead of grouping households into “time-zones” to demand electricity, the electricity appliance itself is taken out of individual household and made a common service.

Collaborative consumption is defined as the “events in which one or more persons consume economic goods or services in the process of engaging in joint activities with one or more others” [35]. Alternatively, it is the shared use of a good or service by a group. Its main difference with normal consumption models resides in who bears the cost, as it is not borne by an individual rather by a group [36]. It has the side effect of reducing the perceived risk as well as promoting sharing, product reuse and inciting the participation and desire to “co-produce together” [21].

Although the concepts of shared ownership and collaborative consumption have been studied mostly in the fields unrelated to energy supply, these show positive possibilities to find their application also in energy sector. The studies show that shared ownership and collaborative consumption can produce economic savings for the users. In the energy sector, collaborative consumption has not yet been studied. Most of the recent articles tackle the issues of rural electrification from the justifiable assumption of individual ownership of appliances [37], [38], [39], [40], or focusing on the technology used for consumption [41]. Although the potential benefits of applying these concepts on the energy sector are not limited to purely economic ones, they also include energy conservation and the reduced resource consumption tied to it. There are different approaches to understand the barriers for rural electrification and ways to overcome them. These range from policy [42] and effects of market-based power generation [43] to infrastructural [44] and ways to finance the off-grid systems [45]. This study targets the consumer side and aims to analyse and compare the effects of different models of ownership and consumption to bypass some of the barriers to rural electrification.

Comparative analyses are made in multiple disciplines such as social sciences, law, economics, etc. to find contrasts and commonalities between two or more case studies. There are no specific rules to be followed when applying comparatives, although there are some suggestions in linguistics [46], [47]. To generalize this into other fields, the following steps can be considered: (i) gather and order the datasets, (ii) find common variable(s) between the sets, (iii) establish when the common variable(s) stops being common (no longer in both sets), (iv) establish a hypothesis for the change, (v) find whether the hypothesis can be defended against other ones. Current study makes the use of this generalized method to answer the main question: do collaborative consumption and community ownership affect the willingness to pay for electricity in rural Niger? The datasets to compare are the willingness to pay of the village under consideration and the cost of electricity supply using renewable energy systems, when either (a) appliances are individually owned, or (b) electricity intensive services are collaboratively consumed. The common variable that join the datasets is “affordable electricity fee”. And the hypothesis becomes “collaborative consumption and community ownership has the potential to increase the willingness to pay for electricity services”.

2. Method

A comparative analysis method was chosen to ascertain whether the population of a non-electrified rural village in Niger would be willing to pay for electricity services provided through renewable energy technologies, and whether the concepts of collaborative consumption and shared ownership had any influence on it. This was performed in two major stages: a field visit and desk research. The major activities and themes undertaken within each stage are shown in Figure 1. The desk research included both the research design prior to the case study site visit as well as analysing the data after the visit. The on-site work included gathering data from the stakeholders, including offices and ministries located in the city of Niamey, the selection of the a specific village at case study site, and gathering data from the village/villagers. The researchers travelled from the capital city Niamey to the village for the purpose.

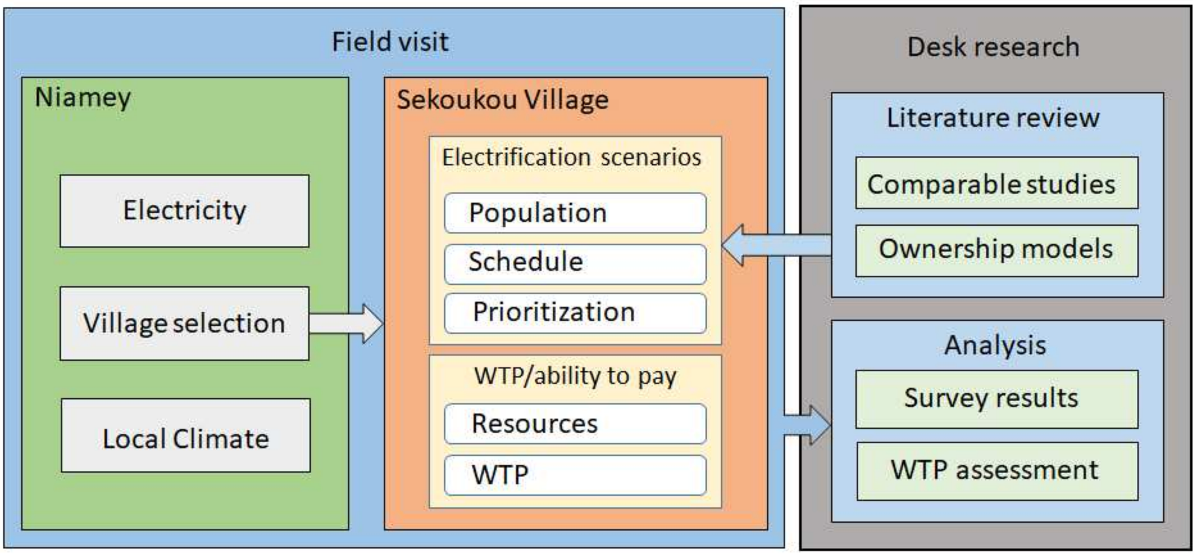

Figure 1: Research methodology followed

Electricity consumption data of the city of Niamey was gathered directly from the electric power generation and transmission utility in Niger (NIGELEC) and later it was analysed to find out how the consumption changed during a year (seasonal variation). The consumption of electricity was expected to increase in the hot periods of the year due to cooling energy demand, and the data confirmed this assumption. This variation was applied later to the studied village to get the adjusted load curve. After a selection process, a village was chosen as case study site. The climate data of the location was collected from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

The site selection consisted of a two-step filtering process where the considered villages were required to comply with the set criteria of (i) having no previous electrification schemes, and (ii) being located in the surrounding of Niamey (easier access for daily commuting from the city). The second step of the selection process further filtered the villages by using the criteria of being easily accessible (socio-political) and of having a considerable number of households. Based on these conditions, Sekoukou village was selected as a case study site. The site can be seen in the map in Figure 2. Table 1 shows general information about this village.

Figure 2: Location of Sekoukou village in Niger (Map: Google Inc.)

Table 1: General data about the village

Name	Sekoukou
Location	13˚16'25.49" N, 2˚22'0.66" E
Population	About 2000
Households	About 300
Main income generation activities	Agriculture, fishing, irrigation
Farm animal heads	About 500
Main agricultural product	Millet, sorghum, rice, beans
Main language	Zarma
Main energy source	Solid biofuel (firewood)

How might the decision to invest in electrification projects be affected by the concepts of community ownership and collaborative consumption approach was studied. The willingness and ability to pay of the selected village for electrification scenarios were analysed based on what villagers prioritized as to their most urgent electrification needs. For this purpose, a structured questionnaire based survey was conducted with the help of local school teachers (who facilitated the interaction between villagers and researcher) in 100 (out of total 300) households of the village. With this, the population distribution per household, the average indoor/outdoor schedules of the villagers, the electricity need prioritization, the currently used energy sources and their willingness to pay for electricity were identified.

Among all the surveyed households of Sekoukou village, 38% households had three to five family members, 38% had six to nine, and 24% had more than 10 members at the time of the survey. The average in-house schedule was defined as time spent inside the household and was characterized by wake up time of the day, time they leave home, time they return back home and time they go to bed. In this section of the survey two answers were sought, their current schedule and the (hypothetical) schedule they would have had if they had access to electricity. On average, the population wakes up at 05:00, leaves home between 07:00 and 08:00, returns back home between 14:00 and 15:00, and goes to bed between 21:00 and 22:00. With access to electricity, most of the population stated that they would shift their schedules to fit more recreational activities. This meant that some would be waking up a little earlier and others a little later (between 05:00 and 06:00) and most would go to bed later (between 23:00 and 24:00).

As it was obviously visible at the site, biomass is the mostly used energy source in rural Niger. It includes firewood, charcoal and agricultural waste. These energy forms are used to cook food and heat water on open fire stoves. All of the respondents said they use firewood for such activities. On average, each household consumes between one and two bundles of wood per week. The survey results showed that the amount of wood purchased by household (in bundles of 10 kg, regulated by law [48]) was varying among the household types in a weekly basis: 55% of the households use at least one bundle per week, 35% use two bundles, 9% use three bundles, and 1% use 4 bundles. They pay for them, according to the surveys, between about 3 and 4 US$ weekly, depending on from which trader they purchase it. The price of wood is assumed to be an unmovable expense because none of the electrical appliances considered include electrical stoves. Therefore, the amount spent on firewood is not taken into account as money available for electricity services.

The villagers have been using dry cell battery powered torchlights (lamps) for lighting. They buy replacement batteries either on a weekly basis (51% of the households) or on a bi-weekly basis (49% of the households). The majority of households owned between two and four lamps (about 36% owning two, 31% owning three and 13% owning four lamps; as can be seen in Table *2*). The average numbers of batteries used on a weekly basis can also be seen in Table *2*. The average market price for one battery was 0.18 US$.

Table 2: Means of lighting and batteries used by villagers at the time of visit

Torchlights owned	Households share	Dry cell batteries	Households share
1	6%	2	5%
2	36%	3	2%
3	31%	4	37%
4	13%	6	28%
5	5%	8	12%
6	4%	9	2%
7	2%	10	6%
8	1%	12	4%
10	2%	14	2%
		16	1%

	20	1%

The villagers produce their own food for consumption and trade. The agricultural waste is used mostly as construction materials and as a food reserve for animals for the dry season. As reported by 100 households, the amount of agricultural production can be seen in Table 3.

Table 3: Agricultural production of Sekoukou village

Produce*	Quantity [kg]
Millet	73,750
Rice	84,400
Beans	16,500
Sorghum	14,300
Gombo	3,950
Corn	600

* Quantities in table represent for 100 households.

As mentioned earlier, at the time of the visit, the village was not electrified and any electrification plans were not known. In order to develop the electrification scenario according to the perceived needs of the population, the survey included questions that asked which services they wanted the most and in which priority order. The main services the villagers thought were the most important for them were lighting, TV, radio, refrigerators, and fan/ventilation, each of which with perceived importance of 30%, 24%, 22%, 15% and 9% respectively. Besides the options shown, other answers given were humidifier, telephone charger, battery charger and general machinery. These represented perceived importance of lower than 0.3%, and therefore are not considered in the calculations in the next section.

In order to have a reference case while comparing whether collaborative consumption and community ownership had an influence in the willingness to pay for electrical services, an additional scenario was considered where none of these concepts are applied. This scenario was named as “individual ownership scenario” and it considers the nowadays-normal situation where an average household owns its own set of appliances. The other two scenarios considered are the named as “community ownership scenario” and “mixed ownership scenario”. In the community ownership scenario, each household still individually owns (what are considered to be) basic necessary electrical services. The concept of collaborative consumption is applied to this scenario by considering the refrigerators and television sets are owned and managed by community. The other scenario considered is a combination of the previous two, where in addition to the community ownership scenario 80 televisions are privately owned (about 27% of the households would own a television set). Table 4 presents the total amount of appliances each scenario takes into account.

Table 4: Electrical appliances per ownership scenario

	Individual	Mixed	Communal
Light bulbs	600	600	600
TV	300	100	20
Radio	300	300	300
Fridge	300	100	100

Fan	600	300	300

The individual power rating of the appliances is used to estimate the theoretical electricity demand of the village. Table 5 presents the power rating used for calculation of the load curve.

Table 5: Power rating per appliance

Appliances	Power [W]
Light bulbs	30
TV	188
Radio	7
Fridge	45
Fan	77

Niger is characterized by having a seasonal climate with four distinctive seasons: a rainy season from June to September, commonly characterized by an average temperature of 33°C. From October to mid-November, the weather is usually characterized by being warm and with no rain, yet relatively wet. The average temperature of this period ranges around 35°C. From November to late February, the weather changes, becoming cold, with temperatures going sometimes below 10°C. Finally, from March to the end of May, the weather is characterized by being hot, dry and windy. The temperatures during this season can reach around 45°C even in the shade [1]. Figure 3 presents the climate data of Niamey, Niger for the year 2015.

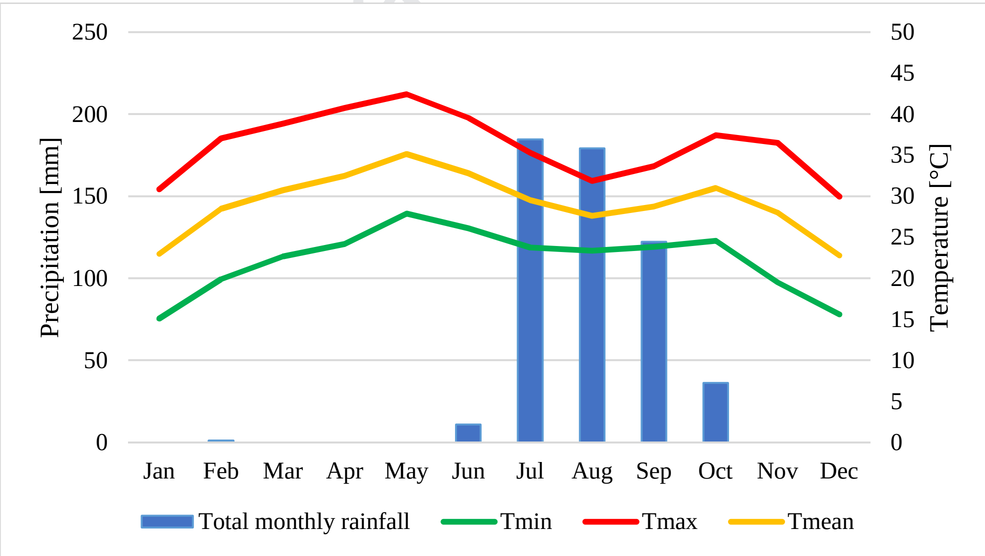

Figure 3: Precipitation and temperature in Niamey, Niger in 2015 [49]

Separate surveys were conducted in the city of Niamey to assess how this seasonality affects the electricity consumption patterns of the urban population. The results showed that the urban population have two separate consumption patterns that followed the temperature of the region. These consumption patterns were stratified into what could be considered as “hot” and “cold” period profiles. The hot period was defined when the average temperatures reaches 30°C or more. In 2015, for the city of Niamey, this was true for the months of March, April, May, June, part of July, October and part of November as can be seen in Figure 3. Therefore, in this study, these months are considered as "hot period" while the rest of the months are considered as "cold period". The load curves of the village were then developed based on these identified consumption patterns. Because the case study village was located relatively close to the city of Niamey, the identified consumption patterns were considered to be valid and representative to the consumption in the village.

In order to build the load curves, only the electric needs prioritized by the population of Sekoukou village were considered, as shown in Table *4* and Table *5*. These are: (1) lighting, (2) television, (3) radio, (4) refrigerator, and (5) fan. The schedule of the population as reported by them during the surveys was used as a base to determine when the electrical equipment would be turned on or off. The assumptions used to develop the village load curves are:

- Village demand follows the same pattern (trend but not absolute demand) of consumption as the population of the electrified areas (i.e. the residents of Niamey city consume more electricity during the hot periods of the year)
- The population of Sekoukou village use their appliances as per schedules they reported and always turn off the electric equipment when not in use (e.g. fans are always off when no one is inside the household)
- The equipment rated power remains the same (as considered in Table *5*)

Applying these assumptions, an on-off table was made for each equipment as shown in Table *6*. This on-off table was assumed to be representative of the village consumption regardless of the scenario discussed before. The load curve data was generated by multiplying the values from the on-off table with the respective values per appliance and per scenario from Table 4 and Table 5.

Table 6: Appliances on-off table

COLD PERIOD						**HOT PERIOD**				
Lighting	TV	Radio	Fridge	Fan		Lighting	TV	Radio	Fridge	Fan
0	0	0	1	0	01:00	0	0	0	1	1
0	0	0	1	0	02:00	0	0	0	1	1
0	0	0	0	0	03:00	0	0	0	0	1
0	0	0	1	0	04:00	0	0	0	1	1
1	1	1	1	0	05:00	1	1	1	1	1
1	1	1	0	0	06:00	1	1	1	0	1
1	1	1	1	0	07:00	1	1	1	1	1
0	0	0	1	0	08:00	0	0	0	1	0
0	0	0	0	0	09:00	0	0	0	0	0
0	0	0	1	0	10:00	0	0	0	1	0
0	0	0	1	0	11:00	0	0	0	1	0
0	0	0	0	0	12:00	0	0	0	0	0
0	0	0	1	0	13:00	0	0	0	1	0
0	1	1	1	1	14:00	0	1	1	1	1
0	0	1	0	1	15:00	0	0	1	0	1
0	0	1	1	1	16:00	0	0	1	1	1

0	1	1	1	1	17:00	0	1	1	1	1
0	1	1	0	1	18:00	0	1	1	0	1
1	1	1	1	0	19:00	1	1	1	1	1
1	1	1	1	0	20:00	1	1	1	1	1
1	1	1	0	0	21:00	1	1	1	0	1
1	1	1	1	0	22:00	1	1	1	1	1
1	1	1	1	0	23:00	1	1	1	1	1
1	1	1	0	0	00:00	1	1	1	0	1

Assuming that the values of the load curves are true, the total sum of the hourly consumption was taken as the daily energy requirement. The total power needed was taken as the sum of the rated power of each appliance (Table 5) multiplied by the number of appliances per scenario (Table 4). The components of the system that would supply the demand of the village was sized using a simplified approach in which the size and characteristics of individual components is known. These characteristic were gathered by requesting quotations from solar companies and can be seen in Table 7. The number of components needed to supply the energy defined by the load curves was derived by first calculating the number of inverters needed:

$$Num.inverters = \frac{P_{Load}[W]}{P_{inv.Rated}[W]} \qquad \text{Eq.1}$$

Followed by the number of batteries for autonomy:

$$Num.Batt.parallel = \frac{\left({E_{Load}[Wh]}/{\eta_{Inv}[\%]} \right) / Syst.voltage[V]}{Battery\ capacity[Ah] \times DoD[\%]} \qquad \text{Eq.2}$$

$$Num.Batt.series = \frac{Syst.voltage[V]}{Battery\ voltage[V]} \qquad \text{Eq.3}$$

$$Num.Batt.autonomy = Num.Batt.parallel \times Num.Batt.series \times AD \qquad \text{Eq.4}$$

Where E_{Load} is the energy required by the load, η_{Inv} is the efficiency of the inverter DoD is the depth of discharge of the battery (60% assumed in the calculations), and AD are the autonomy days (2 days considered).

Then, the number of charge controllers will be:

$$Num.Chrg.Cntrl = \frac{{P_{Load}[W]}/{\eta_{Inv}[\%]}}{Chrg.Cntrl\ voltage[V]} \qquad \text{Eq.5}$$

Finally, the number of solar panels:

$$Num.PV\ series = \frac{Syst.voltage[V]}{V_{mp}[V]} \qquad \text{Eq.6}$$

$$Num.PV\ parallel = \frac{E_{Load}[Wh]}{\eta_{Inv}[\%] \times \eta_{Chrg.Ctrl}[\%] \times \eta_{Batt}[\%] \times V_{mp}[V] \times I_{mp}[A] \times S_h[hr] \times (1 - Gen_{loss}[\%])} \qquad \text{Eq.7}$$

Where V_{mp} is the maximum power voltage of the solar panel, η_{Batt} is the efficiency of the batteries, $\eta_{Chrg.Cntrl}$ is the efficiency of the charge controller, I_{mp} is the maximum power current of the solar panel, S_h represents the average sunshine hours (7 hours), and Gen_{loss} are the losses in generation (considered as 20%).

Table 7: Equipment data used for electricity system calculations [50]

	Solar panel	**Charge controller***	**Inverter**	**Battery**	**Racking**
Voltage (V)	36	96	96	12	
Power (kW)	0.3		10		
Current (A)		100, (30)			
Ampere hours (Ah)				250	
Efficiency (%)		90%	95%	85%	
Cost (US$)	124.8	585, (112)	1,755	258	48.8**

*: Charge controller data includes two different sizes: mini grid and (stand-alone).
**: Price per unit. One unit per solar panel

After knowing the number of components needed in each scenario, the total cost of the system was calculated by multiplying the number of component by their respective acquisition costs. These costs can be seen in Table 7, these represent the price of purchasing the equipment when the field visit was made (and are subjected to change with time). Due to lack of local data for mini-grid installation costs, the value of 0.57 US$/W [51] was assumed as valid for Niger. The value calculated of the total cost of the system was used as the initial investment for the rest of the calculations. With this, the simplified levelized cost of electricity (LCOE) was calculated by using equation (8):

$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad \text{Eq. 8}$$

Where I_t represents the investment costs in year t, M_t represents the operations and maintenance (O&M) costs in year t, F_t represents the fuel expenditures in year t, E_t represents the electricity generation in year t, r represents the discount rate, and n represents the economic lifetime of the project. For the calculations, the assumptions made were a degrading factor of 1% [52] per year for electricity generation using solar PV, and a discount rate of 6% [53]. Fuel costs are considered as zero for solar PV systems.

The ability to pay was calculated by taking into account the income and expenses of the village, as well as the current amount of money spent to acquire batteries. Both the ability and the willingness to pay of Sekoukou village are presented later in the results section.

The willingness to pay was taken as the monthly expenditure the residents of Sekoukou village expressed in the survey they would be willing to pay for electricity. Therefore, the amount of money that would be needed on a monthly basis for each scenario was calculated. This was done by using equation (9):

$$\text{Monthly costs} = \frac{\text{NPC}/\text{Project lifetime}}{\text{Num. households} \times \text{Months in a year}} \qquad \text{Eq. 9}$$

Where the net present costs (NPC) is calculated with equation (10):

$$NPC = \sum_{t=1}^{n} \frac{\mathrm{I_t} + \mathrm{M_t} + \mathrm{F_t}}{(1+\mathrm{r})^{\mathrm{t}}} \qquad \text{Eq. 10}$$

The LCOE from different systems was compared to the willingness to pay by the population to find the effects of shared ownership and collaborative consumption and to ascertain whether they are positive or not.

3. Results and discussion

The willingness to pay was derived by asking the villagers how much they thought the people in the city pay for the electricity in a month and if they would agree to pay the same price. All of the respondents answered they would pay the same price they thought the population of the city paid, although the opinions varied on how much this could be. This variation was taken as the WTP by the villagers and is presented in Figure 4.

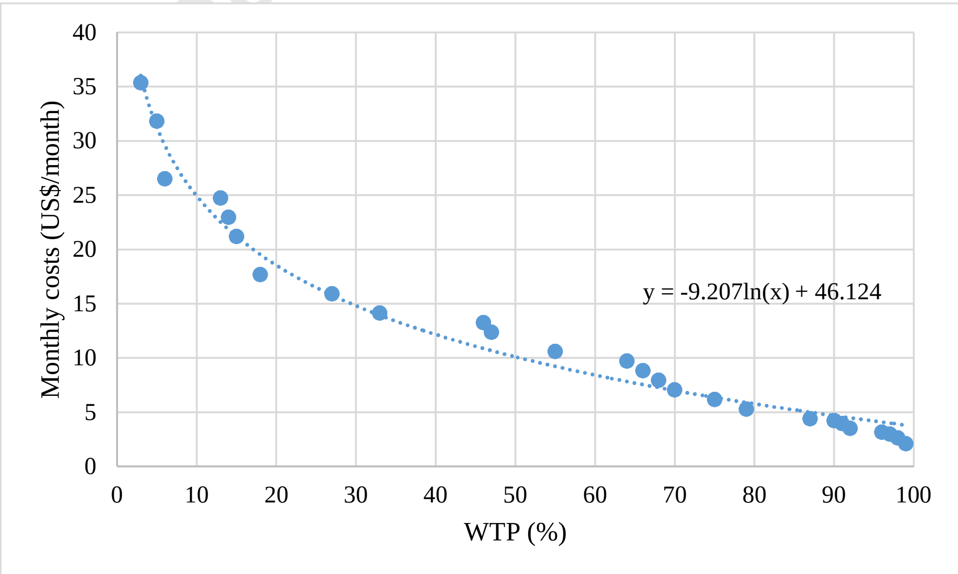

Figure 4: Willingness to pay by the villagers in Sekoukou

The ability to pay was calculated to have an understanding of the financial resources of the village. For this, the daily income and daily expenses of the population were taken into account, as given in Table *8*.

Table 8: Income and expense characterization of Sekoukou village

Daily income US$	Households	Daily expense US$	Households
1.79 or less	70 %	0.89 or less	24 %
1.79 – 3.57	9 %	0.89 – 1.79	61 %
3.57 – 4.46	13 %	1.79 – 2.68	10 %
4.46 – 5.36	2 %	2.68 – 3.57	4 %
5.36 – 7.14	4 %	3.57 – 4.46	1 %
7.14 and up	1 %		

Even though the average daily income was 2.31 US$, which is slightly higher than the international poverty line of 2015 of 1.90 US$ [54], 70% of the households of the village live with 1.79 US$ or less as shown in Table *8*. The reported daily expenses averaged at 1.51 US$, while the average WTP for electricity was of 12.44 US$ per month. The difference between income and expense is taken as the daily saving, which amounts to 0.80 US$. Converting the daily savings into monthly savings and adding to that the money spent in torchlight batteries in a month, it was found that the population, as a community, would have the ability to meet their average willingness to pay. The average income, expenses, and savings can be seen in Table *9*.

Table 9: Average economic data of Sekoukou village

Average daily income	2.31	US$/day
Average daily expenses	1.51	US$/day
Average daily savings	0.8	US$/day
Average monthly savings	24.08	US$/month
Monthly expenditure in batteries	4.43	US$/month

Separate interviews were carried out to assess the amount paid for electricity services in the city of Niamey. This resulted in an average monthly cost for electricity of around 4.60 US$/month during the rainy season, and around 15.30 US$/month during the dry season (a "middle class" household has 4 light bulbs, 1 TV, 1 radio, 3 fans and 1 personal computer (PC)). Comparing these prices to the willingness to pay of village, 82.63% of the population would be willing to pay for the rainy season consumption bill, but only 34.45% would be willing to pay for the dry season consumption bill even if the theoretical average monthly savings would be enough to pay for consumption in both seasons.

As previously mentioned, the urban population of Niger (with electricity access) was found to consume more electricity during the "hot period". This consumption pattern was found to be due to the increased use of room acclimatization systems such as air conditioners and fans, both in the workplaces and in the residences. When designing the theoretical load curves for the rural population of the village Sekoukou, this consumption pattern was used as the most probable consumption pattern as mentioned earlier. The load curves of the different ownership scenarios can be seen in Figure 5 and Figure 6. During the hot season, the maximum hourly demand reached around 140 kWh in the individual scenario (IS). The maximum for the mixed (MS) and communal ownership scenario (CS) was around 65 kWh and 50 kWh, respectively.

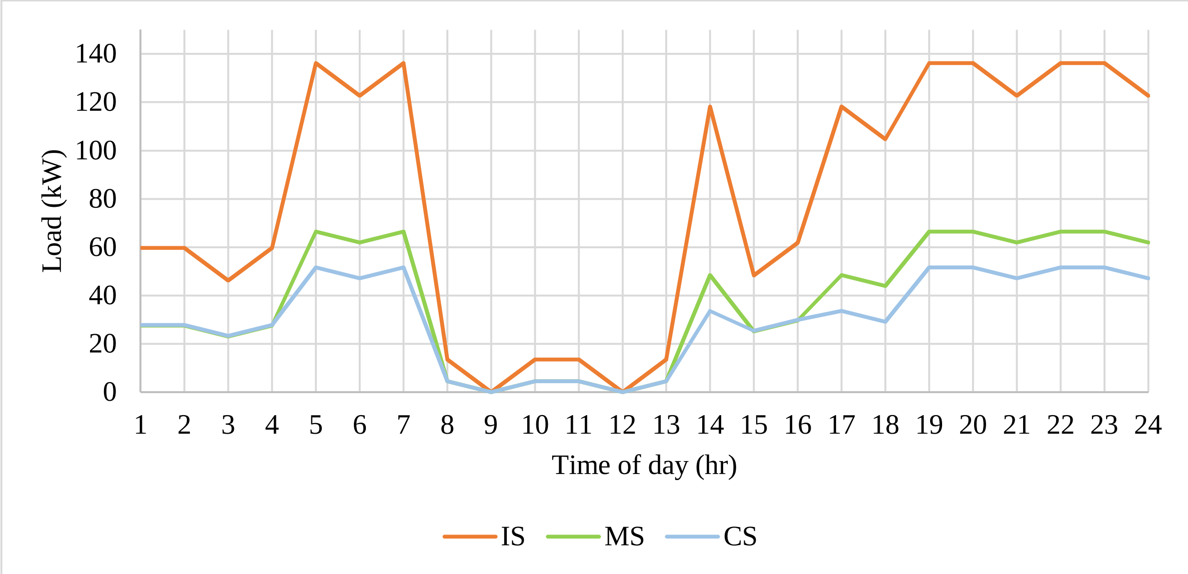

Figure 5: Load curves of "hot season"

During the cold season, the maximum demand at any given hour is close to 120 kWh for the individual ownership scenario, close to 50 kWh for the mixed ownership scenario, and close to 35 kWh for the communal ownership scenario.

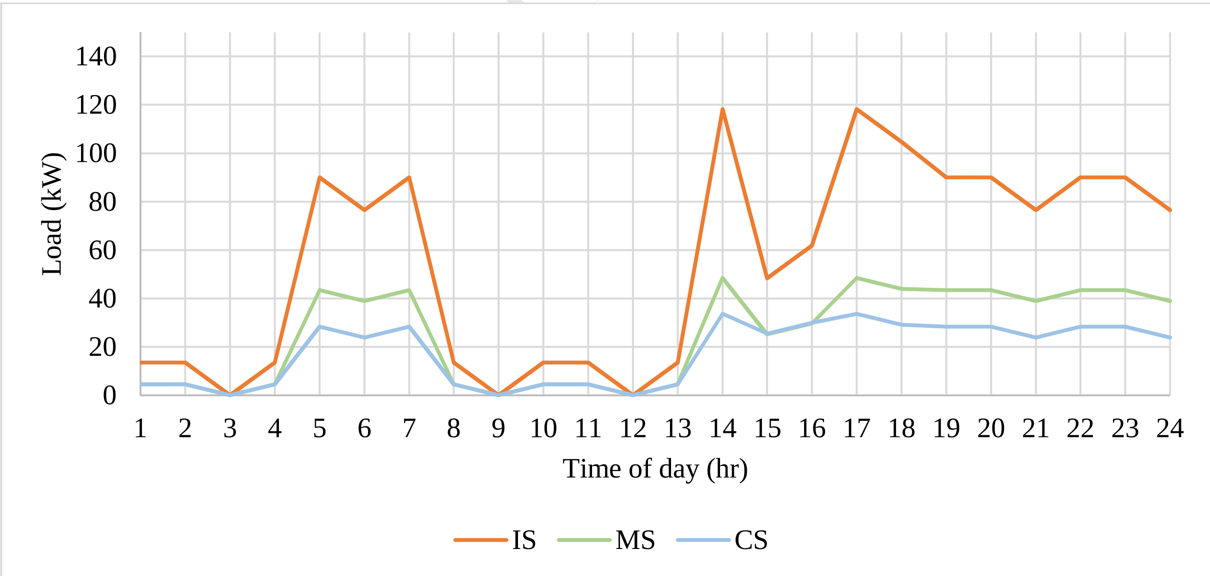

Figure 6: Load curves of "cold season"

Following the approach mentioned in the method section, the systems that would supply for each scenario can be seen in Table *10*. As mentioned, two approaches were considered: mini-grid and standalone systems.

Table 10: Number of equipment per electrification system

	IS	MS	CS

	Mini-grid	Stand alone	Mini-grid	Stand alone	Mini-grid	Stand alone
Inverters	14	2	7	1	6	1
Charge Controllers	15	2	8	1	6	1
PV panels	1,494	6	706	3	565	2
Batteries	2,244	9	1,060	4	848	3

The investment cost, NPC and LCOE for the systems in mini-grid configurations for different percentages of operations and maintenance costs can be seen in Table 11. For the stand-alone systems, the investment cost for individual, mixed and communal scenarios would be 3,396.8 US$, 2,044.4 US$ and 1,661.6 US$ respectively.

Table 11: Investment cost, NPC and LCOE per scenario

IS			
O&M (%/yr)	Investment (US$)	NPC (US$)	LCOE (US$/kWh)
10	871,655.40	2,150,750.29	0.1924
5	871,655.40	1,570,952.18	0.1405
2	871,655.40	1,223,073.32	0.1094
MS			
O&M (%/yr)	Investment (US$)	NPC (US$)	LCOE (US$/kWh)
10	378,553.80	943,315.17	0.1785
5	378,553.80	691,512.93	0.1309
2	378,553.80	540,431.59	0.1023
CS			
O&M (%/yr)	Investment (US$)	NPC (US$)	LCOE (US$/kWh)
10	303,336.00	754,670.97	0.1785
5	303,336.00	552,901.29	0.1308
2	303,336.00	431,839.47	0.1021

Table 11 includes O&M costs at 10%, 5% and 2% of the investment per year. The willingness to pay as defined in the methods section can be found in Table *12*. As with the LCOE, the WTP presents positive changes when the operation and maintenance costs are reduced. With Table *12* the effects of collaborative consumption can be seen in the WTP increase within the same O&M category. The effects of collaborative consumption and community ownership in the WTP within the same O&M category can be seen in Table 12. When the community owns the system, the overall costs of electricity supply will decrease leading to the increase in WTP by the community members. If the community owned the generation system and then managed the operation and maintenance of the plant on its own, the O&M costs could decrease substantially. It would ultimately lead to increase the interest of the community to learn on how to operate such a system properly, and how to keep it in good condition to ensure the operational sustainability.

Table 12: WTP per scenario

O&M (%/yr)	Scenario	Monthly costs (US$/month)	WTP (%)
10	IS	23.90	17%
	MS	10.48	50%
	OS	8.39	59%
5	IS	17.46	29%
	MS	7.68	62%
	OS	6.14	71%
2	IS	13.59	39%
	MS	6.00	72%
	OS	4.80	81%

In the early stage of implementation of such projects, rural villages might not have the technical expertise to maintain the generation equipment properly. Therefore, to keep the system functional, the operations and maintenance cost need to be higher (10% in Table 12). As the community gets more acquainted with the equipment, they can start performing some of the maintenance tasks, reducing the O&M costs (5% in Table 12). Once the population benefiting from the system acquires the full set of knowledge needed to maintain the equipment, they can perform the most, if not all, of the tasks to keep the generation system operating. This could drive the O&M costs even further down (2% in Table 12). Each subsequent change in the O&M costs produces a change in the WTP, ranging from 17% to 39% on individual ownership scenario. With the application of community ownership and collaborative consumption, the WTP sees a more drastic change, i. e. ranging from 17% to 59%, even before the community starts to perform some of the O&M activities (IS, MS and OS within 10% O&M in Table 12). When both scenarios are combined, the changes to WTP seem to be very high, i.e. from 17% (IS within 10% O&M in Table 12) to 81% (OS within 2% O&M in Table 12). In order to ensure a successful implementation of such a project, where the population is willing and able to pay, awareness campaigns and training programs would be needed. Therefore, stakeholder workshops need to be organized from the planning phase.

For the case of an individual ownership scenario and stand-alone systems, the cost would be 26.93 US$/month when including the O&M costs in the calculations and 11.32 US$/month when O&M costs are not included. This would mean a WTP of 8.04% when considering O&M costs, and 43.82% when O&M costs are not considered. For the mixed ownership and community ownership scenarios, equivalent stand-alone systems have not been considered because having standalone systems on communal and mixed scenarios would imply that no collaborative consumption is used.

Although the systems used for the calculations are theoretical, the positive effects of the community ownership model are undeniable. For rural villages, where the national grid does not reach, using such models could prove to be an affordable variable to achieve broader electrification. To use models like the proposed ones, the residents of the village would require, not only being willing to pay for the electricity appliances, but also be willing to participate in collaborative consumption and community ownership and willing to both regulate and follow the regulations, self-established or otherwise, for the proper use of the system. Because of the monthly cost reduction, the use of collaborative consumption and community ownership would enable the poorest members of rural populations to enjoy the benefits electricity supply brings. Although the high costs in the initial investment is still a barrier to surpass.

It is clear that renewable energy technologies, solar PV in this case, could solve the electrification needs of the residential sector in rural areas. It is also clear that the initial investment required is something scary to the people living in rural areas. Through the implementation of demand-side management, the power need can be influenced to accommodate off-grid renewable generation. With concepts such as community ownership and collaborative consumption, the overall energy demand could be reduced from the conceptual planning of electrification projects to achieve more affordable prices of electrification systems. Furthermore, integration of the income generating activities that require power could also help to repay the capital investment, besides the uplifting the rural socio-economic situation.

4. Conclusions

This study introduced the concepts of collaborative consumption and community ownership approaches in the field of rural electrification in a rural setting in Niger. It aimed to identify if more people were willing to pay for electricity services provided by renewable sources when the usual individual ownership schemes are replaced. The analysis showed that the application of these concepts, in tandem with empowering the population to properly use and maintain the generation equipment, seems promising in increasing the willingness to pay among the inhabitants of studied village. It could be observed that:

- When the villagers themselves undertake the maintenance of the off-grid solar PV system, the willingness to pay increases by more than twice.
- If the population practices collaborative consumption and community ownership, the willingness to pay increases by a factor of almost 3.5.
- When the villagers use the introduced concepts, and properly maintain the systems on their own, the willingness to pay increases by a factor of 4.7.

In order to obtain these results in practice, there is a need for a shift from the individual (conventional) way of electrical equipment use to the communal use. This could be quite challenging in the beginning. In order to smoothen the shift, stakeholder workshops need to be organized from the project planning stages thorough the implementation phase of communal power generation and electrical appliances use.

Sub-Saharan Africa is blessed with abundant solar energy; but also suffers from low electricity access in rural areas. Because the population in rural Africa is generally of scarce financial resources, the willingness to pay for electricity generation systems is also low. Given the results of this study, the application of the concepts of collaborative consumption and community ownership could help the electrification of rural Africa up to some extent.

However, there is a need of further research to study the emerging issues that would arise from using collaborative consumption and community ownership, user behaviour among others. Implementation of pilot projects could help in providing data on system performance and population acceptance as well as it could help in the analysis of user satisfaction during the use phase.

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Nomenclature

Chrg. Cntrl.	Charge controller
IS	Individual ownership scenario
MS	Mixed ownership scenario
CS	Community ownership scenario
LCOE	Livelized Cost of Electricity
NPC	Net Present Cost
O&M	Operation and maintenance
PV	Photovoltaic
Tmax	Maximum temperature
Tmean	Average temperature
Tmin	Min temperature
WTP	Willingness to pay

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Highlights

- For a case study site in Niger, a field research combined with survey was carried out
- Novel approach of collaborative consumption and ownership model was applied
- A possible reduction of about 80% of the monthly energy costs can be achieved
- The WTP in collaborative consumption operational model increased from 17% to 81%
- Through demand side management, off grid renewables can be accommodated