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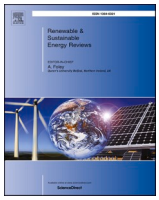

Productive uses of energy: A solution for promoting energy justice in rural areas in West Africa

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ABSTRACT

The rural populations of West Africa are victims of energy injustice, for most of them do not have access to electricity and use very inefficient cooking systems that negatively impact their health and the environment. This study aims to investigate the status of access to energy in rural areas in three West African countries and to identify productive activities that could be developed based on available and accessible energy resources. Thus, surveys were conducted among 2291 rural households, including 640 in Benin, 1001 in Senegal and 650 in Togo. The information was collected using CSPro 6.3 software, cleaned with STATA software and analyzed using Microsoft Office EXCEL 2013 software. The analysis of the findings of the surveys was enriched by typical examples of rural energy enterprises in Mali, Senegal and Nigeria. The findings of the surveys showed that the main source of electricity in rural areas is the non-rechargeable dry cell battery for almost 50% of households and 25% are connected to the grid. The available energy resources reported are solar (89.3%), biomass (73.5%) and agricultural residues (39.5%). The economic activities carried out by households in rural West Africa are essentially agricultural, pastoralism (53.7%) and trade (18.0%). Typical examples of rural enterprises as part of electrification activities which integrate the development of productive activities are presented. This approach allows the populations to have income and cover their electricity consumption bills. This work will continue with the simulation of rural enterprises envisioned in the agriculture and livestock sector in West Africa.

1. Introduction

The Economic Community of West African States (ECOWAS) comprises fifteen countries and represents more than 300 million inhabitants; about one-third of the population of sub-Saharan Africa [1]. Although these countries are endowed with enormous energy resources [2], they face the critical challenge of access to energy with strong inequalities between urban and rural areas in terms of energy prices and income [3]. From 2010 to 2019, access to clean fuels and technologies was stagnant in rural West Africa while in urban areas it improved. In 2019, people without access to electricity in sub-Saharan are in the proportion of one urban resident to five rural residents [4]. Without aggressive public policy and substantial investments, millions of rural inhabitants in West Africa will still be denied access to energy by 2030. Nevertheless, rural areas have not attracted private investments because of their low capacity of consumption of electricity (limited willingness to pay and high costs of power generation) [2]. It is therefore necessary to find new and innovative ways to reduce discrepancies between urban and rural dwellers to ensure energy access for all. Hence, ECOWAS countries are participating in the "Sustainable Energy for All" initiative which aims at achieving universal access to energy by 2030. West African sub-regional institutions such as ECOWAS and the West African Economic and Monetary Union (WAEMU) are developing electrification plans and projects to achieve energy access to all by 2030. In addition, many state level programs are put in place to foster energy access. These projects combine all technological options including the extension of the interconnected grid and off-grid technologies.

The objective of energy justice is to ensure that all individuals in all sectors have access to safe, affordable, adequate, reliable and sustainable energy. Furthermore, it has the goal to protect all individuals from supporting disproportionate shares of energy costs as well as preventing them from negative impacts associated with the construction, operation and maintenance of electric power generation, transmission and distribution systems; and to ensure equitable access to the benefits of each individual [5]. McCauley et al. [6] attempted an initial definition of the energy justice framework based on three principles: distributive justice, procedural justice and recognition justice. Distributive justice implies a

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List of abbreviations

ECOWAS	Economic Community of West African States
EJF	Energy Justice Framework
ERMAP	Research Team on Agricultural Mechanization and Process Engineering
ESA	Ecole Supérieure d'Agronomie
ESMAP	Energy Sector Management Assistance Program
FAO	Food and Agriculture Organization
IDRC	International Development Research Centre
kWh	kilowatt-hour
MDG	Millennium Development Goal
NGO	Non-Gouvernemental Organisation
PERACOD	Programme pour la promotion des énergies renouvelables, de l'électrification rurale et l'approvisionnement durable en combustibles domestiques
PV	Photovoltaic
RBF	Results Based Financing
UL	University of Lomé
US$	United State Dollar
WAEMU	West African Economic and Monetary Union

fair distribution of risks and opportunities related to energy systems; procedural justice implies fair procedures that take into account all people in a non-discriminatory manner, access to decision-making power, and recognition justice implies the respect of all people and their points of view [7]. Sovacool et al. [8] presented a conceptual framework of energy justice by proposing ten descriptive principles, detailed in Table 1. The Energy Justice Framework is a research tool to identify where injustice occurs, who is affected and how, and what solutions exist to correct the injustices [7].

The first rural electrification experiments in Sub-Saharan Africa, carried out mainly through the extension of the interconnected grid, have been carried out by governments with the support of international institutions. Nevertheless, public investment alone cannot achieve the desired outcomes. Therefore, there has been a paradigm shift in energy policies in recent years with the adoption of off-grid technologies and the creation of an enabling environment for private sector participation. Furthermore, private investment in rural electrification through public-private partnership is more desirable [9,10]. Rehman et al. [11] strengthened this idea by pointing out the shortcomings of public-only or private-only sectors initiatives while proposing a hybrid model of public-private partnership to increase energy access in developing countries.

Table 1
Energy Justice Framework (EJF) by Sovacool et al. [8].

Principle	Description
Availability	People deserve sufficient energy resources of high quality (suitable to meet their end uses)
Affordability	All people, including the poor, should pay no more than 10% of their income for energy services
Due process	Countries should respect due process and human rights in their production and use of energy
Transparency and accountability	All people should have access to high quality information about energy and the environment and fair, transparent, and accountable forms of energy decision-making
Sustainability	Energy resources should be depleted with consideration for savings, community development, and precaution
Intragenerational equity	All people have a right to fairly access energy services
Intergenerational equity	Future generations have a right to enjoy a good life undisturbed by the damage our energy systems inflict on the world today
Responsibility	All actors have a responsibility to protect the natural environment and minimize energy-related environmental threats
Resistance	Energy injustices must be actively, deliberately opposed
Intersectionnality	Expanding the idea of recognitional justice to encapsulate new and evolving identities in modern societies, as well as acknowledging how the realization of energy justice is linked to other forms of justice e.g. socio-economic, political and environmental

Research has shown that socio-economic development in rural areas following the implementation of an electricity access project is not automatic [12] and it is often described as a "very passive attitude" [13]. Johnson & Bryden [14] by studying energy supply in rural Mali founds that domestic energy needs accounts for 93% of energy demand, meaning that only 7% of the rural energy is used for productive activities. Therefore, providing access to energy is not sufficient to bring rural populations out of poverty. It may be also necessary to take complementary measures to enable the poor to use modern energy for the development of income-generating activities [15]. Terrapon-Pfaff et al. [16] have confirmed this by stating that access to energy does not automatically lead to the development of profitable activities and energy is only one of the important factors to trigger socio-economic development. The development of productive uses of energy in rural areas thus appears in recent literature as a solution to support electrification projects in order to make these projects more profitable and economically sustainable [17,18]. Bastakoti [19] reinforces this idea by affirming that bringing development to rural areas, requires that the consumption of electricity power by local companies adds value to local resources.

While analyzing 120 rural electrification projects in Latin America and Sub-Saharan Africa, the Independent Evaluation Group of the World Bank [20] concluded, among other things, that: (1) Electricity is mainly used by rural households for lighting and for powering TV sets; (2) The lack of productive use of electricity on a large scale remains a constraint for the financial sustainability of rural electrification programs. Pueyo et al. (2019) [21] in their literature review on gender and the productive uses of energy argue that when electricity is productively used, it helps improve the consumer's ability to purchase energy, thus triggering a virtuous circle where energy becomes more affordable to the consumer and improves the financial sustainability of the energy supplier. Battacharyya and Debajit [22] made recommendations for universal electrification by 2030 in South Asia. These recommendations include the need to adapt electrification projects to the socio-economic context, resource potential and institutional arrangement of the beneficiaries. It will also involve linking electrification projects with rural development activities to create opportunities for the advancement of the local economy.

Given the unavailability of literature on West African off-grid rural electrification projects and the development of its productive use, this research aims to address several questions: i) What are the conditions of access to energy in rural areas in West African countries? ii) What are the potentials of productive use of energy that could be developed in order to make rural electrification activities more sustainable and profitable? iii) What are typical examples of successful rural enterprises in the West Africa sub-region that could be scaled up?

The remainder of the paper is organized as follows: Section 2 describes the material and methods used to answer research questions; Section 3 presents and discusses the results obtained and Section 4 concludes with some recommendations for policy makers and proposes paths for future research.

2. Materials and methods

2.1. Materials

The material used is essentially a questionnaire administered during the surveys from February to April 2019. The questions asked are

developed based on the multi-tier energy access measurement framework of the World Bank's ESMAP program [23] and a literature review [11,24–27] on entrepreneurial initiatives related to energy access and the identification of energy resources available year-round in the areas under survey. As part of the research work on rural enterprise setup in Togo, the surveys took into account the potential added value of electricity as well as products and services that are imported from other surrounding localities due to lack of electricity. The survey questionnaire was administered with tablets.

2.2. Survey methodology

Surveys were carried out in rural West Africa, particularly in three countries: Benin, Senegal and Togo. These surveys were carried out according to a two-stage stratified random sampling design with proportional representation at the first stage where departments and villages in Benin, districts in Senegal and enumeration areas in Togo were selected. At the second stage, the households to be surveyed were selected from each first stage stratum. The survey sample is made up of 2291 rural households: 640 in Benin, 1001 in Senegal and 650 in Togo, as shown in Table 2.

2.3. Processing of collected information

The collected information was recorded using CSPro 6.3 software and cleaned using STATA software. Thereafter, Microsoft Office EXCEL 2013 software was used to analyze and process the collected data. CSPro 6.3 was used because of its adaptability to tablets and of budget constraints.

Questions related to the setup of small businesses and economic wealth in rural areas were left open-ended. It is therefore important to define a framework for analyzing them on a quantitative level. For this reason, the classification framework for economic activities in rural areas developed by the Food and Agriculture Organization (FAO) [28] was adopted for the analysis of the information collected. Table 3 presents the groups of activities as well as the different activities comprise within them.

Similarly, questions on goods and services imported by rural populations from bordering communities remained open-ended and an analytical framework, presented in Table 4, was created, based on the repetition of certain answers.

The analysis of the survey results was enriched by typical examples of rural enterprises based on productive use of energy.

3. Results and discussions

3.1. Energy justice and the status of energy in West Africa

Populations in rural areas in West Africa have limited access to electricity and modern cooking energy, which has negative impacts on health status and the environment. They also pay higher prices for poor quality energy services. Similarly, these predominantly agricultural populations are facing the adverse effects of climate change which reduces their agricultural productivity and consequently their income, thus making them more vulnerable. Women and children are constrained to spend long hours during the day for water supply and gathering firewood for cooking. The lack of access to the mechanical power for processing agricultural products subjected women to manual work. In 2006, the ECOWAS Heads of State and Government adopted the White Paper for a regional policy on access to energy services for rural and peri-urban populations in order to achieve the Millennium Development Goals (MDGs) [29]. This policy set, among other goals, to achieve universal access to a modern cooking service and a rural electrification rate of 36% by 2015. The policy failed to reach its set targets. Fig. 1, built with data from the World Bank's Global Electrification Database [30], shows the variation in the rural electrification rate in ten ECOWAS countries from 2009 to 2018. In most of the countries, rural electrification rates in 2018 have not really evolved and are still below 35%. There is therefore a need to promote energy justice in West Africa in favor of rural areas.

The promotion of energy justice in a sustainable manner in rural areas in West Africa will therefore require a change in the paradigm used so far for rural electrification by developing off-grid solutions (mini-grid and solar home system) with the promotion of the productive uses of energy. In this new approach, electrification will connect households and more especially economic activities (Fig. 2).

The productive use of energy by households could generate additional income for both the household and the electricity supplier and therefore lead to a sustainable electricity access by households. The suggested concept addresses the following attributes of energy justice in rural West Africa:

Table 2
Distribution of rural households surveyed by country.

Item	Benin	Senegal	Togo
First stage selection	3 zones/12 departments/60 villages	14 regions/100 districts	5 regions/50 zones
Second stage selection	10 households per villages.	10 households per district	13 households per zones
Total number of households	640	1001	650

Table 3
Framework for the classification of economic activities in rural areas by FAO [28].

Activity groups	Activities
Agricultural production activities	Crop production (cereals, cash crops, market gardening), livestock (large and small livestock, poultry, rabbits, pigs), beekeeping, fish farming
Processing activities	Milling (mill, mills, …), hulling, canning (cold and drying, juice, jams), bread-making, processing equipment
Para-agricultural and non-agricultural activities	Manufacture of agricultural equipment, rural constructions, wood and metal carpentry workshops, masonry, mechanized welding, machine repairs, etc.
Craft activities	Weaving, dyeing, basketry, embroidery, shoemaking, sewing, etc.
Commercial activities	Sale of essential goods, purchase and sale of agricultural and handicrafts products, sale of various inputs, purchase and sale of agricultural and para-agricultural materials and equipment, cereal stores and banks, village pharmacies, import and export, etc.

Table 4
Framework for analysis of goods and services imported by rural populations.

Activity groups	Activities
Chilled products	Frozen fish, frozen meat, cold drinks (juice, water, drinks, etc.)
Agricultural production	Sorghum, corn, millet, yam, rice, beans, market gardening products, condiments, etc.
Health care services	Health center, pharmacy, veterinary products, vaccines
Telecommunications and office automation products	Recharging, sale, and repair of mobile phones, rental of sound equipment, battery charging, office automation (photocopying, printing, word processing)
Services	Sewing, primary commodities, canned foods, etc.
Processed agricultural products	Gari, oil, flour, soy products, etc.
Processing equipment	Mills for cereals, welding, rice husker, etc.
Others	Anything that is not included in the groups already declined.

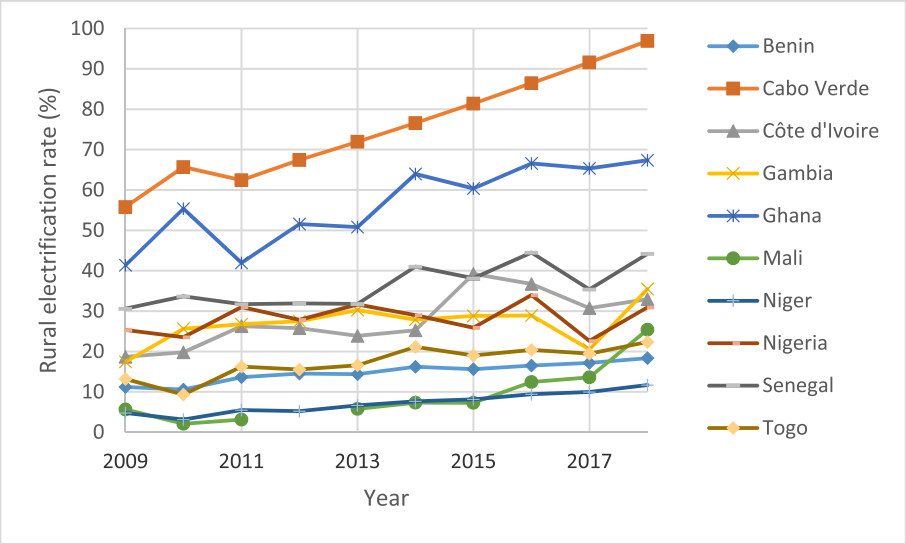

Fig. 1. Change in the rural electrification rate in selected ECOWAS countries from 2009 to 2018.

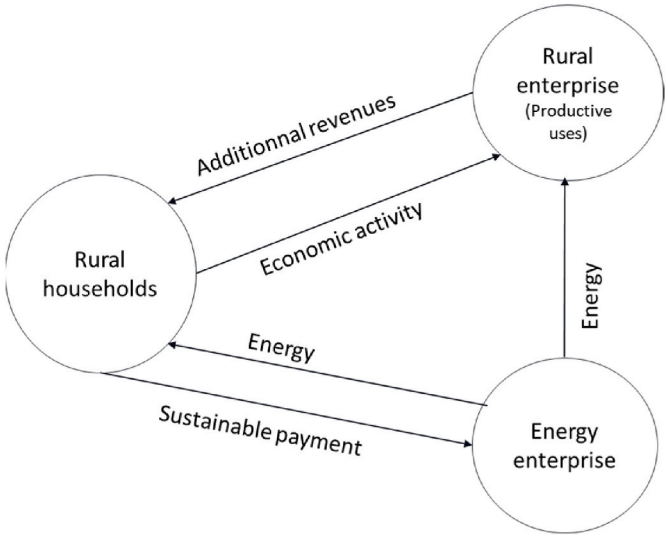

Fig. 2. Electrification model based on the promotion of productive uses of energy.

- Availability: increase energy access to households;
- Affordability: increase capacity to pay of rural population;
- Sustainability: sustainable rural electrification outcomes;
- Intra-generational equity: more energy justice for rural households;
- Inter-generational equity: use of available renewable energy resources.

The other criteria of the energy justice framework such as due process, transparency and accountability, responsibility, resistance, and intersectionality are of social dimensions and notoriously more difficult to measure as mentioned by Jodoin [31] in an attempt to operationalize the energy justice framework in Guinea.

3.2. Main sources of electricity in rural area households in West Africa

Table 5 shows that at the sub-regional level, about 25% of households have access to the electricity with grid connection and about 20% of households are connected by isolated systems (mini-grid and individual solar home system). As a result, slightly more than half of the households do not have access to electricity and rely mainly on non-rechargeable dry cell batteries. The principle of availability of the EJF requiring for sufficient energy resources of high quality is thus not respected for surveyed countries rural dwellers.

Table 5
Main sources of electricity in rural area households in the countries surveyed.

Source of electricity	Benin	Senegal	Togo	All
Grid (%)	20.8	32.1	17.8	24.9
Mini-grid (%)	7.3	3.0	0.0	3.4
Solar home system (%)	21.3	18.0	9.1	16.4
Dry cells (%)	44.8	39.8	68.9	49.5
Rechargeable Battery (%)	2.2	5.0	0.8	3.0
Generator (%)	0.8	0.0	0.0	0.2
Others (%)	2.8	2.1	3.4	2.7

Based on the multi-tier framework for energy access for productive uses defined by the World Bank [23] and presented in Table 6, rural households in West Africa have varying degrees of access to electricity for profitable activities.

Nevertheless, the EJF as well as the literature [32,33] insists on the availability of quality and sufficient energy as an important condition for the development of productive activities in rural areas. It is therefore important to develop the available energy resources to provide access to energy to rural populations that could help them carry out profitable activities.

3.3. Available energy resources identified in rural areas

Solar energy is the most familiar energy source for communities in rural areas in West Africa, followed by wood (Table 7). This result can be explained by a wider adoption of solar equipment in rural areas and the use of wood as the main energy source for cooking by rural households. However, the type of energy resource to develop must be the least cost option in order to meet the affordability criteria of the EJF. For example, there is a tendency in Sub-Saharan Africa to systematically develop solar energy for off-grid electricity but research has shown that micro-grid configuration incorporating solar photovoltaics (PV), batteries and diesel is the lowest-cost option when compared to diesel or solar PV alone [34]. It is then recommended for energy planners to base their energy resources development on detailed techno-economic analysis with appropriate modeling.

Table 6
Tier capacity of electricity supply for productive purposes [23].

Capacity	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Minimum power (W)		3	50	200	800	2000
Minimum daily consumption (kWh)		0.012	0.20	1.00	3.40	8.20
Typical technology		Solar lantern	Solar home system	Generator or mini-grid	Generator or grid	Grid

Table 7
Available energy sources in rural areas identified by rural households.

Energy resource	Benin	Senegal	Togo	All
Solar (%)	89.5	94.7	81.1	89.4
Hydroelectricity (%)	34.4	14.0	47.2	29.1
Wood (%)	90.9	65.2	69.1	73.5
Agricultural waste (%)	90.9	3.4	44.5	39.5
Others (%)	0.0	3.4	0.0	1.5

3.4. Economic activities carried out by rural households surveyed

Table 8 shows that agriculture and production of livestock are the main economic activities carried out by rural households in the three countries. Trade (small business management) is the second most important economic activity and small-scale handicrafts are less developed.

These results call for greater attention from policy-makers to the primary sector, mainly agriculture and livestock, in the framework of rural electrification initiatives in rural areas in West Africa to enable socio-economic development. Anriquez & Stamloulis [35] confirmed these findings by stating that in developing countries agriculture remains the starting point for rural development.

In addition, small scale industries that could add value to the products of the primary sector are missing. However, rural small scale industries are reputed to provide employment, income and basic needs of the population; to contribute to the increase of agricultural productivity as well as to fight against migration [36]. Kyriakaros et al. [37] have then proposed a new electrification model for sub-Saharan African countries in which agricultural products processing becomes the main economic activity around which surrounding communities have access to electricity. In this approach, the cost of electricity to households could be mitigated by the income of electricity generated through agricultural products processing. The cross-subsidization of residential electricity tariff by the small scale industry will contribute to the sustainability of electricity access in West Africa rural areas.

Fig. 3 shows the demand for energy along the main links of the agricultural value chains from inputs to the processing of agricultural products [38]. These needs require different forms of energy: mechanical, electrical and thermal. Energy needs related to transport, logistics and market access in the regions are not taken into account.

It is therefore important to set up energy production systems in rural areas on the basis of the identified available energy resources. The energy produced could be used by electrical equipment to meet the energy demands of the populations and bring value to economic activities. As an example, in Nigeria, a study on the stimulation of productive uses of energy in farming has been carried out in the framework of rural electrification by mini-grids [39]. The study involved the analysis of the value chain of twelve agricultural products including cassava, maize, rice, aquaculture, cocoa, milk, cashew nuts, cowpeas, soybeans, sorghum, cotton and shea nuts. For each of the products, the applicable types of value-adding processing such as mechanical threshing, grating, milling, drying and cool storage in a cold room were studied. Grating of cassava, milling of rice, and milling of grains proved to be the most promising as energy-producing activities with mini-grids in Nigeria. Likewise, Borgstein et al. [40], analyzing the synergy between rural electrification and six agricultural value chains in Ethiopia, found that electrification can generate about US$4 billion in business over five years. They then concluded by advocating for the establishment of a national productive use program that should follow the national electrification plan.

Table 8
Importance of economic activities carried out by rural households in the countries surveyed.

Economic activity	Benin	Senegal	Togo	All
Agriculture/Livestock (%)	60.8	41.7	65.2	53.7
Trade (%)	19.7	17.6	16.9	18.0
Handicrafts (%)	9.7	6.0	7.4	7.4
Non-remunerated activity (%)	1.1	7.6	3.5	4.6
Employee (%)	5.8	8.7	2.8	6.2
Civil servant (%)	1.1	0.9	1.1	1.0
Study (%)	0.8	0.2	0.8	0.5
Other activity (%)	1.1	17.4	2.3	8.6

This new approach to electrification through the development of economic activities and access to energy in households would be a sustainable response to the precarious situation of energy access in West African countries. Therefore, to identify business models that could be developed, the impact of the introduction of electrical equipment in economic activity, the potential for economic wealth and imported products due to lack of access to electricity are studies based on the data collected from rural Togo. The results obtained are complemented by case studies of successful rural businesses models in Senegal, Mali and Nigeria.

3.5. Impact of the introduction of electrical equipment in rural economic activity in Togo

Fig. 4 shows the impact of the introduction of electrical equipment on economic activity in rural Togo.

Productivity improvement is the first impact mentioned in more than 41% of responses, followed by sales increase by 24%, quality improvement and production cost reduction. It can be concluded that there is a need for the introduction of electrical equipment in rural areas in Togo to improve the productivity of economic activities and the income of rural households. Fig. 5 shows some of the equipment needed in agricultural value chains, excluding transport, logistics and market access.

The National Multifunctional Platform Development Program [41] allows the dissemination in rural areas of equipment for processing agricultural products such as mills, graters, presses, grinders, dough mixers and shelling machines. However, the optimization of energy supply and consumption by the platforms would still be a relevant issue. Similarly, the Promotion of Productive Solar Equipment Project [42] intends to disseminate solar powered pumps and solar powered refrigerators in rural areas based on the concept of Results Based Financing (RBF).

3.6. Economic wealth in rural areas in Togo

Table 9 presents the relative importance of economic wealth by region based on a total of 534 responses expressed by rural populations and analyzed using the FAO Rural Economic Activity Classification Framework. It can be noted that agricultural activities including farming and livestock production are mentioned as the first economic wealth in all economic regions of Togo.

These results indicate that the agriculture and livestock sector should

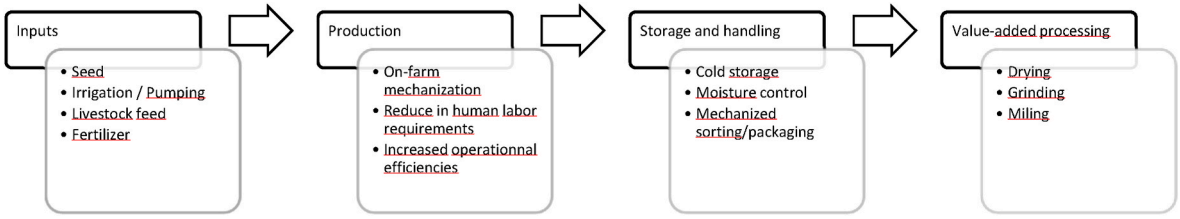

Fig. 3. Energy demands on agricultural value chains [38].

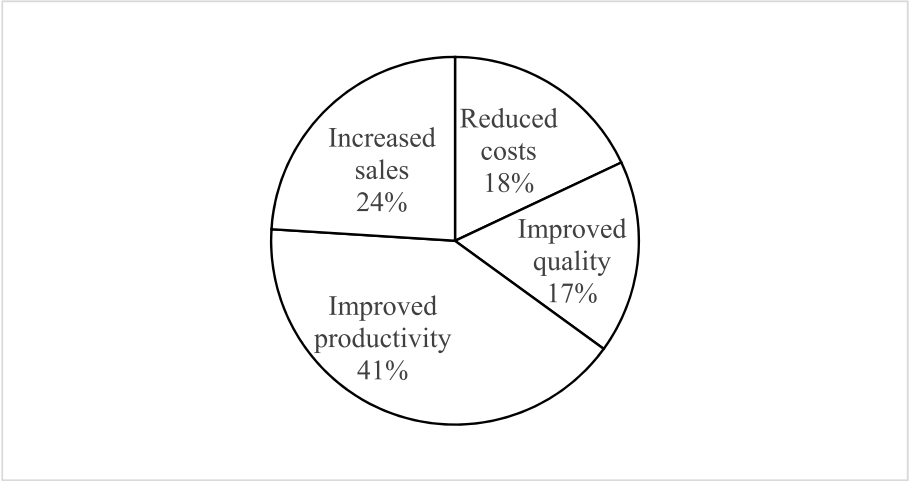

Fig. 4. Impact of the use of electrical equipment on economic activity in rural Togo.

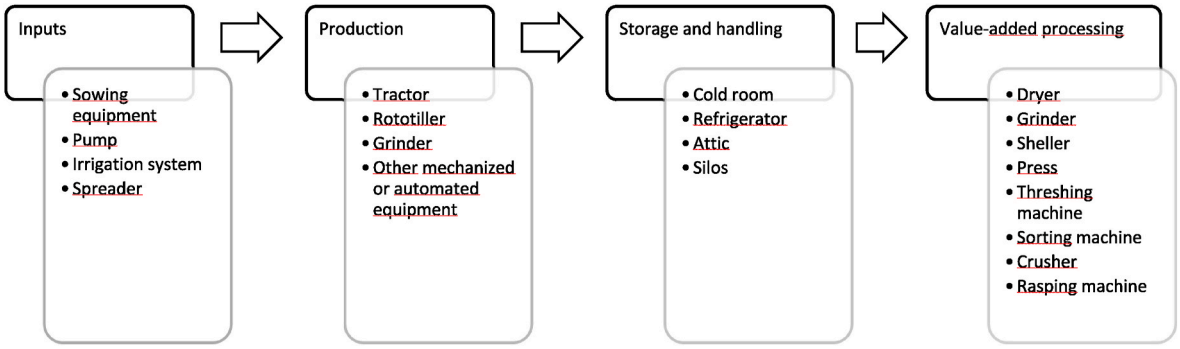

Fig. 5. Energy equipment needed in the agricultural value chain.

Table 9
Importance of economic wealth by economic region in rural areas of Togo.

Economic region	Agricultural production activities (%)	Processing activities (%)	Commercial activities (%)	Para-agricultural and non-agricultural activities (%)	Craft activities (%)
Maritime	5.8	1.3	0.4	1.1	0.7
Plateaux	31.5	2.1	0.7	0.7	1.1
Central	7.3	1.7	0.4	1.9	0.0
Kara	14.4	1.7	3.0	0.6	0.0
Savannah	15.0	3.2	2.4	2.6	0.4
Total by activity	74.0	9.9	6.9	6.9	2.2

be given policy attention concerning projects for the development led by the energy sector. In addition, processing activities adding values to agricultural projects has to be fostered to provide enough demand on the local power network. This will have the advantage to reduce power generation costs and make electricity more affordable for households.

3.7. Products imported from other regions by rural areas in Togo

Table 10 shows that the products imported into rural areas in Togo due to lack of access to energy are mainly chilled products, chilled beverages and refrigerated food, which represents 46.2% of the approximately 639 needs identified. Telecommunication products (cell

Table 10
Products imported by rural areas according to the economic regions of Togo.

Imported product	Maritime	Plateaux	Central	Kara	Savannah	Total
Chilled and frozen products (%)	8.6	8.8	3.8	3.6	21.4	46.2
Telecommunication products (%)	3.1	9.1	1.9	0.0	1.4	15.5
Agricultural products (%)	0.3	9.4	0.5	2.8	0.2	13.1
Processing equipment (%)	1.9	2.7	1.9	0.9	1.9	9.2
Processed agricultural products (%)	0.0	4.7	1.4	0.3	0.6	7.0
Services (%)	0.2	2.0	1.6	0.3	1.1	5.2
Healtcare services (%)	0.0	1.6	0.0	0.0	1.1	2.7
Others (%)	0.0	1.1	0.0	0.0	0.0	1.1

phone and office recharge) and agricultural products are imported needs with significant relative weights.

An analysis of the data by region in Togo leads to the following conclusions:

- Chilled products are the most important need in almost all regions and more pronounced in the Savannah region;
- Chilled products, telecommunication products and processing equipment are the needs mainly imported in the Maritime region;
- The needs are a little more diversified in the Plateau region with chilled products, agricultural products and telecommunication products being the most important;
- In the Central region, there is no really clear trend, all needs have practically the same weight, except for agricultural products and health care which are less in demand;
- In the Kara region, the main needs expressed are chilled products, agricultural products and manufacturing equipment.

Successful examples are presented to illustrate the productive uses of energy by rural enterprises that could be developed within the framework of energy access projects in West Africa.

3.8. Typical examples of successful rural enterprises in West Africa

Typical examples of successful rural enterprises in West Africa include a rural enterprise in Senegal run by women [43], electrified activity zones in Mali [44], and a cooling enterprise in Nigeria [45].

As part of a pilot project to develop the productive uses of energy in Senegal, GIZ, through its PERACOD program, in collaboration with the Senegalese Rural Electrification Agency, supported a group of women from Félane in setting up a multifunctional platform powered entirely by solar energy for the development of fishing and market gardening activities. Indeed, the women of Félane work in the processing of fishing products, agriculture and livestock but are struggling to develop their activities due to lack of access to energy. The PERACOD made it possible to install a solar system that supplies an ice factory with a production capacity of 375 kg/day and a water pumping system. The ice factory enabled women to trade fresh fish products, which was once limited to men, and to increase their income. The water pumping system helps women in gardening and providing water for the ice factory unit [43].

Two communes in Mali, Konségéla in 2015 and Koury in 2019, were financed by the development NGO GERES to set up their electrified activity zones. The latter gathers about ten different economic activities under a single bioclimatic construction, powered by a sustainable and quality energy source, a hybrid solar and generator unit that runs on Jathropha oil. The economic activities that are developing in the electrified activity zones include catering, baking, embroidery, welding, production of Jathropha vegetable oil and sale of refrigerated products. In addition, GERES assists businesses in the electrified activity zones in providing entrepreneurial support and facilitating access to financing. In the locality of Koury, the power generation system has been connected to the mini-grid serving households for greater reliability in the electricity supply [44].

The Coldhubs company in Nigeria provides rural populations with the solar power cold storage for the conservation of perishable foodstuffs. The freezer units, powered by photovoltaic solar energy, are designed to operate continuously throughout the day. Perishable foodstuffs including vegetables and fruits stored in the freezers installed in markets and fields are kept for at least twenty-one days instead of two days. To preserve their products, farmers transfer them to dedicated crates and pay a daily standard fee to Coldhubs. By doing so, Coldhubs contributes to the reduction of post-harvest losses while allowing farmers to avoid discounting their agricultural products and to increase their income [45].

4. Conclusion and policy recommendations

The principles of energy justice are not respected in West African countries because of the very unequal access to energy, especially between rural and urban areas. In recent years, there has been a change of approach in rural electrification projects with the adoption of off-grid technologies, including mini-grids and individual systems. However, experience has shown that off-grid electrification that only takes into account the energy demand within the households is not sustainable. The development of productive activities has emerged in the literature as a solution to promote energy justice that enables households to have access to energy and to have sustainable means to pay for their energy consumption. This research has involved surveys to assess the level of access to energy and to identify the available energy sources, the economic activities carried out and the potential for promoting the productive use of energy in three West African countries, namely Benin, Senegal and Togo. The surveys showed that dry cell batteries are still the means of access to electricity for more than 50% of the rural population despite the availability of several energy sources including solar, biomass and hydroelectricity. Livestock and agriculture, and to a lesser extent trade, are the main economic activities of rural West Africans and provide opportunities for the development of productive uses. The productive uses of energy was illustrated by typical examples of successful rural enterprises in three West African countries: Senegal, Mali and Nigeria. Based on these findings, the following recommendations are formulated to policy makers for more energy justice for rural population in West Africa:

- Be pursuant of energy justice in favor of rural populations who are deprived of safe, affordable, adequate, reliable and sustainable energy;
- Develop productive uses of energy as an integral part of any rural electrification program or project. Criteria to consider include available energy resources to generate energy at the least cost and economic potential to which energy could add value;
- Prioritize, agriculture and livestock as well as small scale industries (agro-processing units) while planning the development of productive uses in rural areas.

Future research will involve simulation of rural enterprises envisioned in the agriculture and livestock sector in West Africa that could serve as models of productive uses of energy in the current context of off-grid rural electrification.

Credit author statement

Kossivi M. S. DOMEGNI: Data curation, Writing – original draft preparation and Editing. Yaovi Ouézou AZOUMA: Supervision, Writing-Reviewing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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