



OPEN Linking energy service access and human capabilities to assess energy justice in the rural Sahel

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The Sahel covers more than 3 M km² across eleven countries and accounts for only one-tenth of the world's per capita energy consumption, yet it remains largely unexplored in the energy justice

access and assessing corresponding public policies. However related infrastructures (e.g., electric grid, roads, telecommunications network) requires to go beyond access to new energy carriers. We thus propose to enrich the energy justice framework by considering (1) access to energy services

observations and interviews in rural

remain unevenly distributed: though opening up rural areas and providing local populations with new e.g., semi-nomadic, low-income) are often left aside; (2) social

tensions may arise locally due to resource management, as new or more productive energy services become available. We conclude that energy policies should not only focus on infrastructures (regional energy access), but also consider the corresponding end-use equipment (local energy service access),

policies on other sectors.

Keywords Sahel, Energy justice, Energy services, Human well-being, Energy access, Rural areas

According to the former Secretary-General of the United Nations, energy is the thread that connects economic growth, social equity, and a healthy environment¹. Ensuring access to affordable, reliable, sustainable and modern energy services for all (UN SDG 7) is a priority for policymakers and development agencies at both international and national levels. The unequal distribution of the benefits and negative impacts of the global energy system can be perceived as a form of injustice for developing countries, especially in the Sahelian strip where energy access remains particularly low and where populations are especially vulnerable to climate change and insecurity².

Injustices can also be observed at a lower scale within a country, for instance those related to accessibility by gender³ or discrimination in access to medium- and large-scale energy infrastructure^{4–6}. Much of the literature on energy justice in Sub-Saharan Africa has focused on the disparities of energy access between rural and urban areas, for instance showing how decentralized electrification affects isolated communities⁶. Despite the large number of such isolated communities in the Sahel, studies on social and geographical aspects of energy (in)justice issues in the region are still very limited.

Typically, Akrofi et al.⁷ recently performed a systematic review of publications on energy justice in Africa: out of the 26 studies they found, only one actually focused on a country in the Sahelian region, Burkina Faso. Essentially, recent publications have emphasized distributive justice issues in the southern part of West Africa^{3,8}, where it is mostly analyzed in terms of access to energy for given areas or communities. In the one publication on the Sahelian region (i.e. Burkina Faso) the authors analyzed energy justice issues through the lens of energy distribution, national electrification strategies, and renewable energy programs, concluding that large-scale, centralized on-grid facilities might be inadequate to achieve full electricity access⁹. Furthermore, the literature in the field of energy justice in Africa mainly focuses on (in)justice issues in terms of energy access for vulnerable communities^{4,5,10}. In this paper, we instead propose to assess energy (in)justice issues by analyzing access to

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energy services. Accordingly, our contributions are twofold: we (1) bring energy justice insights from the Sahelian region, and (2) focus on access to energy services for improving living conditions.

In the framework of energy justice, energy is seen as a means to promote well-being, freedom, and equity while respecting decision-making processes for both producers and consumers¹¹. Energy's transformative capacity to improve quality of life has led some researchers¹² to establish links between the deployment of energy infrastructures and capability-based approaches¹³. However, the energy justice literature usually considers inequalities based on the availability of specific energy carriers, e.g. electricity^{5,8}. Instead, looking at the perceived benefits of energy in terms of user capabilities helps contextualize the concept and eventually gives a better understanding of the relation between energy and people's well-being¹⁴. Accordingly, it is essential to evaluate the effectiveness of energy access policies and programs not only through a measure of access to clean energy carriers, but also in terms of their contributions to the daily lives and well-being of rural populations, and the tangible benefits and opportunities they generate.

According to Bilgiç et al.¹⁵, energy access can be defined as access to (1) new energy carriers, i.e., FFE (fossil fuels and electricity), (2) a minimum level of electricity, and (3) sustainable and safer cooking fuels and stoves. Current energy policies and programs actually focus on increasing access to cooking energy and electricity (e.g., "Desert to Power"¹⁶, "Energy4Sahel"¹⁷, Alliance for the Sahel¹⁸, while the scope of the energy justice literature in Sub-Saharan Africa remains confined to specific energy carriers (e.g. bioenergy, electricity)¹⁴. The actual framework (academic and developmental) regards energy access as the way to promote energy justice and well-being in Sub-Saharan Africa. However, this definition might be too narrow. For instance, the literature on energy access and most energy programs have left out mobility aspects, whereas the transportation sector is closely linked to FFE access. We believe that there is a need to bring a more holistic understanding of energy access.

This is where the concept of *energy services* can enlarge the spectrum of the capability-based approach when assessing how energy affects the well-being of users. Energy services stand for the "functions performed using energy which are means to obtain or facilitate desired end services or states"^{16,18}. Energy services go beyond the energy sources or carriers by focusing on the benefits and opportunities that energy provides in terms of capabilities, either locally to human beings¹⁹, or globally to human development²⁰. For instance, Whiting et al.²¹ have recently conducted a comparative analysis of the level of illumination between urban Ancient Romans and inhabitants of 1820s London (the Georgians). They showed how the Romans, though using much more fuel (i.e., lower energy efficiency), experienced more artificial lighting than the Georgians, leading to the inference that Romans' capabilities and quality of life were higher than their Georgian counterparts during hours of darkness or in dark spaces. Note that the conclusion would likely be different if the authors had only assessed energy access for both periods, i.e., the availability of energy sources and carriers. Access to energy services rather than sole energy access therefore seems better suited to understanding what actually gives people opportunities and capacities to seize them.

In this paper, we argue that full energy access does not necessarily give access to energy services for all, leading to energy (in)justice issues. In order to illustrate this assertion, we propose an in-depth analysis of the qualitative data we collected from various stakeholders involved in or benefiting from energy access programs in rural areas of the Sahel. In fact, empirical observations in the field show that most of the corresponding populations do not derive significant benefits from existing infrastructures or FFE, even though they are increasingly available in the region.

Given this observation, what are the real benefits of current energy access policies for rural populations in the Sahel? We try to answer this question by using the concept of energy justice as an analytical tool that we enrich with perspectives from the concepts of energy services and capabilities (cf. Section 2). Our study is based on qualitative data we collected in two rural regions of Senegal: the Ferlo and the Sine, which we present in Sect. 3. Section 4 details our results on how capabilities are enhanced through FFE and new infrastructures (4.1), how local inequalities emerge from their development (4.2), and finally how transformations in the management of energy resources unfold (4.3). Policy recommendations and research perspectives are given in the conclusion.

Combining energy justice, energy services and capabilities

Energy justice as an analytical tool

In this work, we emphasize that there are different approaches to addressing energy justice. It is important to note that the question of energy justice permeates various aspects, from energy conversion to distribution, commercialization, and use¹¹. Energy justice is based on the concept of environmental justice, which can be defined as the distribution of environmental externalities and access to natural resources, equal protection against burdens, constant involvement in decision-making, and equitable treatment in accessing benefits²². It seeks to identify where injustices arise, which societal groups are excluded or overlooked, and the means to address these situations and reduce injustices. It begins by questioning how benefits and burdens are distributed, remediated, and how victims (e.g., of climate change) are recognized²³. This includes considerations of costs (dangers and externalities caused to a community), benefits (inequalities in access to FFE), and procedures (exclusionary decision-making processes for energy projects)¹¹.

Energy justice is multiscale, i.e., includes both societal level, referring to the proper functioning of society, and individual level, understood as a fair and equitable treatment of their interactions. It is organized around 3 tenets, with both evaluative and normative objectives²³: (i) distributive justice, which looks at the unequal distribution of benefits, resources, and environmental externalities; (ii) procedural justice, which examines how decisions are made to achieve social goals, as well as the stakeholders involved and influential in decision-making processes; and (iii) recognition-based justice, which focuses on domination, non-recognition, and lack of respect toward a community²⁴. Essentially, energy justice provides insights about (in)justice issues in a given energy system^{5,8,16}.

Energy justice can be conceived as a decision-making tool that makes the various stakeholders, including decision-makers, policymakers, regulators, investors, and consumers, accountable for access to energy resources¹¹. The energy justice framework raises the following questions: Is a certain segment of the population denied access to one or several energy resources? How are these energy resources managed and regulated? Are there communities that have not been considered in the development of energy access policies? In seeking answers to these questions, the concept of energy justice helps identify certain elements in our observations that might otherwise have gone unnoticed. In this way, the concept of energy justice can also be considered a tool to evaluate public energy policies and the governance of energy systems. The present study is based on this approach, which we enriched by mobilizing the concepts of energy services and capabilities to better account for the link between energy supply and individual well-being.

Access to energy services for human needs and capabilities

Human well-being can be defined and evaluated in many different ways. A first approach is to rely on introspective assessments of individual well-being. Other approaches have tried to define more objective assessments through the definition and classification of human needs (e.g., physical health, autonomy), and the means to satisfy them (e.g., Max-Neef “satisfiers”)^{25,26}. Among these different theories of human well-being and needs, the capability approach developed by Sen and Nussbaum has been a successful tool to analyze questions related to energy justice¹³. The capability theory can be defined as the access to opportunities and freedom of choice for individuals or communities. When applied in the energy context, it emphasizes the opportunities that energy provides, as a material precondition, to empower individuals through ensuring essential capabilities for well-being and a decent quality of life^{20,27}. Though well-being encompasses broader aspects and is more complex to evaluate, satisfying those essential capabilities is a fundamental step toward human well-being²⁸.

Most studies in this context consider living conditions or energy poverty and examine how access to specific energy carriers can improve quality of life^{20,29,30}. However, Day et al.²⁰ have shown how measuring energy poverty – defined as any direct or indirect inability to meet a need or “essential capability” – through access to energy carriers only may not be adapted to the context in which it is applied, especially in the Global South³¹. This indicator would be better contextualized by accounting for other ways to achieve these capabilities²⁰. Instead of focusing on the energy carriers, it underlines “the benefits that energy carriers provide for human well-being”³², namely energy services. Whether in the residential, agricultural, rural, or urban sectors, energy services refer to the functions or activities performed or facilitated by the use of energy in order to obtain end states or services (e.g., lighting, cooking, heating, transport, refrigeration, etc.)³³.

The analytical framework we defined for this work is thus based on 3 concepts: energy justice, energy services and capabilities. Energy justice can be analyzed through access to energy services^{11,23} that increase people’s capabilities and improve human well-being. Our aim is not to look at inequalities in people’s access to electricity or gas, or any other energy carrier, but rather to question whether human beings can freely cook their meals, move or travel, get information and communicate, etc. In this way, our study goes beyond the presence or absence of FFE in communities or villages, and focuses on the real opportunities these energy carriers provide to populations and individuals. Accordingly, it encompasses issues linked to the use of infrastructures on one hand and access to the necessary end-use equipment associated with them on the other.

Methods and study areas

In the following, we examine how energy justice can be applied to the issue of addressing specific energy services in the rural Sahel. Our results are mainly based on a fieldwork carried out in November 2024 in two regions of Senegal: the Ferlo and the Sine (cf. Figure 1). In both regions, the climate is hot and semi-arid, marked by a short, intense rainy season, as in most parts of the Sahelian strip. Note that we visited these regions just after the end of the wet season (June to October), which may partially affect our results. The Sine region belongs to the groundnut basin and is mainly dedicated to agro-pastoral activities (poly- or monoculture of groundnut, niébé, hibiscus, millet, sorghum, and watermelons). The main activity in the Ferlo is livestock farming (sheep, goats, and zebus), while some forestry products (jujube, and gum) are also collected for sale. The Ferlo region is essentially populated by the Fulani ethnic group with a semi-nomadic lifestyle linked to the transhumance of their herds, sometimes leading to conflicts with agropastoralists people from the groundnut basin, who mainly belong to the Serer and wolof ethnic groups³⁴. In each municipality visited, the population is divided between a more or less dense “center” and numerous small, scattered villages. These villages are much further apart in the Ferlo than in the Sine region, hence the much lower population density in the Ferlo (cf. Table 1). The distribution of the roads and households is much denser in the Sine than in the Ferlo. We sought to visit highly contrasting contexts in terms of mobility (tarmac roads, laterite tracks, or sand paths) and electricity access (on-grid, off-grid mini-grids, or no access).

The Ferlo region has long remained an isolated and marginalized area³⁵, a situation reflected in its limited access to public infrastructure. The *Programme d’Urgence pour le Développement Communautaire* (PUDC, Emergency Program for Community Development), launched by the Senegalese government in 2015, has become the leading initiative for the construction of road, water, and energy infrastructures in rural areas. However, new roads and energy infrastructures appear to be largely insufficient or unevenly distributed, creating “infrastructure gaps” where pastoral communities and some remote rural settlements are marginalized³⁶ and remain out of reach for specific essential services. Some of these services are provided by private stakeholders. In rural electrification policy, Senegal has implemented a concession-based system whereby private companies are granted concessions to distribute electricity in specific areas³⁷. Concessions are supervised by the *Agence Sénégalaise d’Électrification Rurale* (ASER, Senegalese Agency for Rural Electrification), which acts as an arbiter in village selection among various stakeholders involved in implementing electricity infrastructures, including certain state-led projects (e.g., PUDC). The concession covering the northern regions of the country is managed

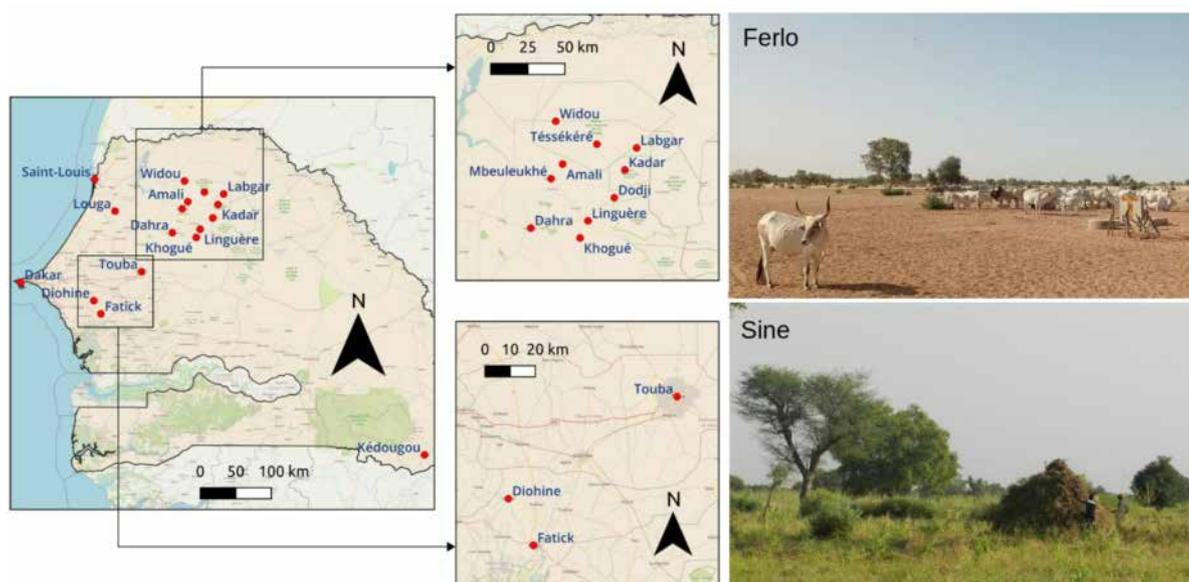


Fig. 1. Map of the main visited locations (left). Pictures taken on the field close to Widou (Ferlo, top right) and Dioghine (Sine, bottom right). Source from authors. Map generated by QGIS 3.40 Bratislava; Background image Openstreetmap CC BY-SA 2.0, Data : OSM + author GPS data.

	Diohine	Widou	Labgar
Commune	Ngayokhème	Tessekere	Labgar
Population of the commune [hab]	29 808	11 691	10 547
Population density of the commune [hab/km ²]	269.7	7.1	10.5
Population of the commune "center" [hab]	2037	713	3237
Number of neighborhoods, villages and arrondissements	62	105	84

Table 1. Demographic characteristics of the main visited locations (from the 2023 National census³⁹). "Center" corresponds to the place where the town hall is located; the size of its population is approximated, as the delimitations of the villages are not available.

by the *Compagnie Marocco-Sénégalaise d'électricité* (COMASEL, Moroccan-Senegalese Electricity Company), which operates the rural network facilities.

Regarding access to infrastructures, pastoralist populations remain the least well-served, particularly in terms of energy and road infrastructures. This disparity is largely due to their mobility and the spatial dispersion of pastoral settlements compared to agricultural villages. In contrast, the Sine region is significantly better equipped with infrastructure, reflecting an unbalanced model of territorial development between western regions and the rest of the country, as highlighted in the literature³⁸.

Data were collected from different sources and through different methodologies:

- Focus-groups: Two were conducted, one in Dioghine (Sine) and one in Labgar (Ferlo), gathering about ten people, including young people and women; the main topic was the link between energy and agriculture; each session lasted around two hours.
- Semi-directed family interviews: Four were conducted in the Ferlo (close to Labgar, Amali, and Widou) and one in Dioghine, gathering family members from different generations and genders; the aim was to understand domestic daily life and its links with energy use; each interview lasted between one and three hours.
- Individual interviews: Six interviews were conducted with local institutions (Regional Development Agencies of Fatick and Louga, COMASEL of Louga et Dahra, Enda Epopop in Louga, Water and Forestry Offices in Widou) and around twenty interviews with people encountered during focus-groups, observations, or on-site visits (boreholes, farms, dairy unit, mini-grids); each interview lasted between twenty minutes and over one hour.
- Landscape observations: Conducted along the roads between towns and villages we visited, as well as in their outskirts.

Interviews were conducted in French, Pulaar, Wolof and Serer. Except for the latter language, where some interviewees translated the words of others, the main author conducted the interviews and translated for co-authors when necessary.

An interview grid was developed as a survey tool to shed light on the lived experiences related to past, present and future (in their view) processes of various energy services in the residential, agricultural, and other economic sectors. This analysis is based on cross-referencing various pieces of information gathered from different stakeholders within the energy system, including agency directors of electricity companies, electrical technicians, public officials, project managers, merchants, managers of agricultural processing units, and end users in the study areas. We mobilized these materials to gain insights into the evolution and dynamics of the *socio-energy* system, as well as to understand the conditions of energy access and the ways energy is used locally. This work *does not aim* at providing a quantitative analysis of energy access and use in the areas under study. Rather, it aims at drawing attention to several aspects that could later be explored in greater depth, for example through appropriate surveys among representative population samples.

Results and discussion

In the pastoral rural areas of northern Senegal, access to electricity is relatively recent, dating back to no more than five years. Often located far from the national grid, some villages are supplied with electricity by small solar power plants (e.g., Widou, Khogué, Kadar), which have fluctuating and very limited daily production capacities. These small solar power systems were deployed by COMASEL, which is responsible for the management and operation of solar mini-grids. In contrast, electricity supply in Diohine was achieved about 20 years ago through connection to the national grid and is administered by the *Société Nationale d'électricité du Sénégal* (Senelec, Senegalese national company). Grid connection has provided inhabitants with access to new domestic energy services (electric lighting, cooling and preservation, information and communication), social services (schools, healthcare, water wells), and community services (mills, metal welding, entertainment halls). The diversity of available energy services in the village has generated economic opportunities for local communities, attracting residents from neighboring villages. In particular, women have developed economic activities based on operating small food processing units, which has supported the development of local agricultural production in return.

Locally, FFE availability has been increasing through the creation, extension, or enhancement of network infrastructures at the country scale. Accordingly, people's capabilities have been improved in two different ways: by simplifying existing activities or by providing new energy services that were not available. On one hand, the use of electricity or diesel-powered machines in processing agricultural products (e.g., millet flour, peanut flour, oil, and paste) has significantly mitigated both the physical effort and time previously required to manually pound the same products with mortars and pestles (cf. Figure 2). Motorized vehicles (cars, motorbikes, trucks) have also strongly reduced travel times and eased the mobility of passengers and goods (e.g., baker's delivery rounds in Labgar with a motorbike). As traditional cooking habits involve long preparation times in large families, the use of gas for cooking meals remains limited. When people can afford it, gas allows faster heating of tea or breakfast preparation, or can be used for income-generating food processing (e.g., peanut roasting, milk pasteurization).

FFE as "satisfiers" for the development of various capabilities is well documented^{14,20,33}. In the Ferlo and the Sine, we similarly observed that FFE has increased productivity and reduced the time and effort involved in certain activities. For instance, we noticed a large adoption of telecommunication means (mobile phones), and media (TVs) to a lesser extent, now supplied by electricity from mini-grids or solar home systems. Electrification via the national grid has also extended the diversity of craft activities (e.g., welding) and allowed cooling (freezing), though it remains very costly. Cooling has increased economic revenues – through starting business activities based on short-term conservation of perishable products, or the sale of ice, ice-cream, and fresh juice – or enhanced domestic comfort (e.g., cold drinks). Diesel-powered boreholes have multiplied in the Ferlo, funded

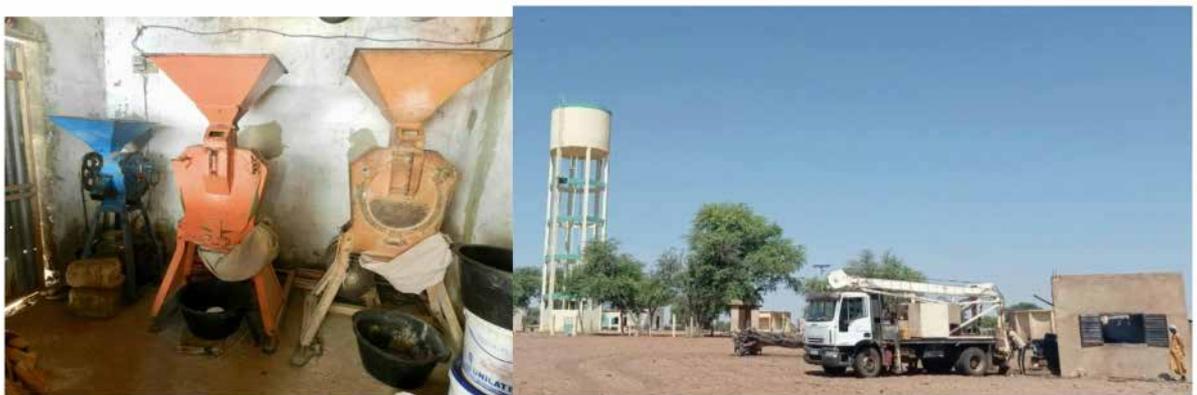


Fig. 2. Left: Electric mills rented by a woman who launched her activity of millet and peanut processing in Diohine (Sine). Right: Diesel-powered borehole being fixed in Amali (Ferlo); the truck came by the laterite road. Pictures from the authors.

by the PUDC program, in order to provide access to deeper water resources that were previously unreachable (cf. Figure 2). Tarmac and laterite roads close to Diohine now enable the supply of goods by trucks, including some of the FFE and new materials (e.g., cement and sand for building) that were hardly accessible before. Note that villages located along the laterite road between Diohine and the main asphalt road are electrified, unlike settlements located a few kilometers away (e.g. Toukar), suggesting that policy- and decision-makers tend to prioritize electrical infrastructures in visible areas (e.g., solar street lights).

In fact, the extension of the road network and telecommunication infrastructures has opened up these rural areas to new markets. Local communities can now access goods from other regions (e.g., fresh fish from St Louis and palm oil from Kedougou on the market of Mbeulekhe) and send their own goods to cities like Touba or Dakar. This was made possible by the new road infrastructure that now interconnects formerly remote rural areas. This is the main factor that has eased the development of transport services and the exchange of different products between rural and urban areas. The paved road now allows agricultural products coming from the southern part of the country, as well as fishery products from coastal cities, or manufactured goods, to reach these rural populations. For instance, in the remote village of Mbeuleukhe, the laterite road connecting the village to the city of Dahra, which was under transformation towards a paved road at the time of our visit, has facilitated the transport of goods and supported the development of local businesses. Typically, we met women there selling food products in the local market: one woman selling fresh fish sent from Dakar by her brother's son who lives there, and another selling palm oil brought from Kedougou by one of her cousins. Therefore, products and goods are now transferable through a combination of existing informal social networks, new road infrastructure, and related daily transports from the village to big cities (e.g. Dakar, Touba). The same applies to Labgar and Kadar, where a new laterite road was recently constructed.

Travel to neighboring regions has also been made simpler through the use of collective transports called “horaires”, for instance, to do shopping or send children to schools in bigger cities located in or near the Ferlo area. Some young people have high hopes for the development of road infrastructures: “Within 10 years, asphalt will connect Labgar and Linguere. Labgar is a crossroads for trips to Touba and elsewhere. Labgar's market is becoming more popular than Dodji. Business is booming here, there's a lot of investment, and people here and around are becoming aware of investment, initiatives and opportunities.” (young man in Labgar, translated from French). Access to telecommunications has also had a major impact on the integration of the villages with the rest of the country and abroad. Mobile phones have eased communication and money transfer with family members, especially with those who live abroad (e.g., United States, France, Italy). Telecoms have also improved access to information and entertainment: a Fulani herder told us that “no information escapes him [sic]”, he gets his information mainly from Youtube on his phone, with videos in Wolof or sometimes in French, which he understands but does not speak. His “phone, it's both [his] radio and TV”, while elders only listened to the Sen National radio, he told us. His brother owns a TV, especially to watch soccer, but his family also watches documentaries and TV shows. From an energy justice perspective, these infrastructures improve the integration of rural peoples into their national community and, more broadly, into the world, though this also requires individual efforts to acquire and use information and communication tools (e.g. smartphone, tv). One case in particular is illustrative. In 2023, a man bought a small solar panel. He uses it to charge a small battery, which he then employs to recharge his phone, power a small TV, or supply a lamp in his hut.

Regarding FFE, road infrastructure and related services, Sine's population enjoys better access. In the Ferlo, such infrastructures are relatively recent and not yet available to all, some of which were still under construction at the time of our visit. This disparity is reflected in the living conditions of the populations, particularly with regard to transportation and the provision of electric services.

Inequalities in access to energy services among rural communities

FFE has increased the range of available energy sources and services, but these benefits remain unevenly distributed. In the Ferlo, because of vast municipalities and low-density settlements, the deployment of mini-grids (cf. Figure 3) or telecommunication antennas may not cover all households. According to some residents' feedback, political affinities of local representatives might determine which villages will benefit from this equipment. In contrast, a COMASEL representative stated that electrification is not affected by local policymakers, but rather by techno-economic aspects (population density, distance to the network, etc.), even though some officials might have taken credit for having electrified a village in the end. Essentially, many scattered settlements in the Ferlo do not feel they are involved in infrastructure development (telecoms, electricity, roads), emphasizing potential spatial/geographical as well as procedural (in)justice issues⁴⁰.

In the Ferlo, the people living in scattered households are often livestock breeders who spend part of the year under transhumance. This lifestyle keeps their local energy consumption low throughout the year, which explains COMASEL's lack of interest in these populations: “It's too expensive to bring electricity to Fulani people who live far away with only 2 or 3 houses [sic]. What's more, our Fulani relatives only live here for 3 months of the year...” (translated from French). If extending the grid or installing a mini-grid is not feasible, alternative solutions or policies to enhance access to FFE could be developed. The question of energy access for pastoral communities, who are mainly transhumant populations, is often absent from policies as well as from research on energy access in the Sahelian strip^{41,42}.

On the other hand, the development of infrastructures (power grid, road network) is not sufficient to ensure universal use of electricity or motorized mobility. Both the equipment and FFE associated with it (e.g. mills, refrigerators, cars) remain (very) expensive for many households and are sometimes not available locally. Thus, new tarmac roads do not necessarily bring rapid development of motorized mobility over longer distances in rural areas. In fact, most people continue to use carts (cf. Figure 3), raising questions about the effectiveness of the infrastructure policy on local well-being and capabilities. Just as solar PV has addressed the need for lighting



Fig. 3. Left: A cart traveling on a tarmac road. This is an example of the existing contrast between new infrastructures and populations' typical equipment. Apart from highways where carts are prohibited, there is currently no regulation policy governing how tarmac roads should be shared between carts and motorized vehicles. Right: ini-grid operated by COMASEL in Kadar, supplying lights, phone charging and one refrigerator. Pictures from the authors.

and mobile phone charging in rural areas, rural mobility will also require new policy schemes to facilitate travel for these populations.

The concept of energy justice leads to questioning how the benefits of new energy infrastructures and/or FFE are eventually distributed. The people who benefit from these infrastructures are often those who can afford the associated equipment, i.e., by investing capital in machines, cars or other materials. As credit remains less accessible to rural households⁴³, only people who previously worked and saved money in the capital or abroad, or with relatives who can send money from Dakar or abroad, will find the necessary capital. Some may also benefit from development programs to obtain machines and start a business, in which case the equipment may be shared within a cooperative of several people. Recovering the costs of purchasing and maintaining equipment or FFE therefore requires earning money by charging for a product or a service. Many services that were not previously monetized are now becoming so (cooking, agricultural processing, access to water from boreholes, mobility), yet the majority of the population does not receive any regular income to access those services. The monetization of resources and services is also accompanied by a desire among some people to increase their income, either by moving to bigger cities to build up capital or by investing locally in activities with greater added value (fish farming and watermelon cultivation in Diohine, fattening broiler chickens in Labgar, etc.).

Fish farming represents a particular case of the diversification of production activities in areas where agriculture has traditionally been the main livelihood. Changes in the dietary habits of rural communities, characterized by the growing consumption of rice and fish (a popular Senegalese meal), have created new opportunities for fish farming, as fish is often sourced from distant locations. However, the complexity of such installations (including water quality management and fish feed) requires proper training. We found that personnel training, installation, and operating costs are very high, and these expenses are generally covered by wealthy family members living in Dakar or abroad, along with financial support from the government. In another case, watermelon cultivation appears as the best option for increasing household income, both in terms of capital and know-how. Farmers can harvest twice in a 5-month period, while other crops (such as peanuts or millet) are not yet ready for harvesting. Furthermore, both the laterite road and the proximity to big cities such as Dakar and Mbour have made it easier for farmers to sell their products at attractive prices. As a result, watermelon cultivation is partly transforming local agricultural practices.

Transformation in the management of energy sources

Monetizing FFE or the services they provide can also be seen as energy resource management. Setting prices for grid connection and electricity use, or for pumping water from diesel-powered boreholes, can limit resource consumption. In theory, since the daily energy supplied by a mini-grid is limited by its capacity, an operator could introduce overpricing policies in order to avoid blackouts (i.e., when consumption is higher than the energy produced). As this approach goes against the desire to provide the whole country with an equivalent electricity service, the Senegalese government introduced harmonized electricity tariffs for both the national grid and mini-grids in 2018. In practice, our visits to several villages supplied by mini-grids revealed that every day, electricity supply is cut off in the evening due to a lack of available energy. This results in the shutdown of street lighting and freezers, preventing income-generating activities such as ice production and food preservation. These blackouts have several causes, among them the lack of upper limits on energy consumption, the State's legal obligation to connect every household requesting connection, or undersized mini-grids²⁹. Different processes for allocating electrical resources could be imagined, such that essential services are maintained at the community level. Through planning of the daily available energy, users could collectively decide to limit electricity use during the day (procedural justice) in order to keep freezers operating throughout the night and

maintain access to refrigeration in the village. The recent development of FFE and associated infrastructures has not yet been followed by the establishment of collective organizations for managing conflicts of use. Another example is the absence of regulation policies on how roads should eventually be shared between carts and motorized vehicles, except on highways where cart use is prohibited.

Local regulation of these new resources could benefit from research focusing on the procedural aspect of energy justice, as well as from former self-management systems that once existed in many communities for certain resources (wood, water, land)^{30,44}. It is still possible to observe examples of self-management systems in the Ferlo, in particular for wood collection and grazing areas through the use of fenced plots. Pastoral units (PU) are land tenure tools used to manage pastoral resources within municipalities. With support from local development projects and the Great Green Wall initiative, small plots have been installed within PUs for soil restoration and forest regeneration through controlled grazing. Pastoral resource management is carried out at the PU scale, i.e., beyond individual plots, by local communities. Self-management of these plots has enabled several families to access pastures while limiting pressure on the environment: “And we can see the success of the project, vegetation is much more diverse within the plot than outside. [...] Today, the people inside the plots identify strongly with the project and never stop reminding us of its benefits.” (Forestry officer). In practice, not all the plots work equally well, and maintaining them creates conflicts with people who were unable to join the program when it was established in the 1980s. Families outside the plot system cannot graze or harvest wood in these plots, while those with access can benefit from resources outside as well.

Wood remains the main energy source for cooking in rural areas of both the Ferlo and the Sine. However, wood is increasingly scarce due to population growth and legal restrictions on wood harvesting. In the Ferlo, wood is still available but must be collected from further away, and conflicts may arise between wood for construction and wood for cooking. On the other hand, in some communities near Diohine, women cannot fetch wood due to the ban of wood cutting by the forestry services and land owners. As a result, they have turned to new cooking fuels: a mixture of agricultural residues (millet bran) and livestock manure. This new usage sometimes leads to conflicts with farmers who have been using the same manure to fertilize their fields. Since women are responsible for harvesting cooking fuels, they are the ones most affected by these conflicts. In this agropastoral zone, herders and farmers have long been providing each other with complementary services involving livestock manure through informal agreements. Typically, farmers trade soil fertilization against the possibility for herders to let their livestock graze during the post-harvest period. This long-standing synergy between livestock and farming has been disrupted by the new use of manure as a cooking fuel. While in the past wood was sufficiently accessible, today the “first-come, first-served” rule prevails, meaning that some families struggle to access cooking energy.

This example illustrates the existing tensions between energy access and environmental issues at the community level. More indirectly, the use of FFE can increase pressure on other resources and lead to conflicts over access to other essential services. For example, access to electricity or diesel for boreholes has increased water availability for herds, while enhanced mobility through tarmac extension and access to motorized vehicles has multiplied livestock marketplaces (e.g., Labgar’s market). Access to fossil fuels, made possible by road infrastructure, has accelerated borehole development. Their density has increased from one borehole every 20–30 km to one every less than 10 km in the last decade⁴⁵. As a result, herds have grown even larger, increasing pressure on local grazing lands and in other regions of Senegal, as many herders are now forced to migrate further and/or for longer periods to feed their herds.

Both demographic pressure and fuelwood demand for cooking in the Sine region pose major challenges. We observe conflicts of interest and procedural energy injustices in how women must manage access to cooking energy. This contrasts with the situation in the Ferlo, where fuelwood for cooking remains readily available. The main issue lies in limited access to electricity and related services, while the use of FFE (for transport and boreholes) has increased pressure on pastoral resources.

Sahelian strip

In rural areas of Sahelian Senegal, the benefits brought by energy, road, and hydraulic infrastructures, as well as access to FFE, have not yet enabled equitable access to energy services among rural populations. For specific services such as cooking, pressures on fuelwood resources have led to the emergence of authority-centered management forms. From an energy justice perspective, existing measures reveal procedural injustices, i.e., the absence of certain affected stakeholders in decision-making processes. Both wood scarcity and related regulation have resulted in the collection of cow dung and crop residues as cooking fuels, generating conflicts between women – who rely on these materials for cooking – and farmers who use them as fertilizers. Access to energy services in the Sahelian strip remains a major challenge and requires new management strategies for local resources, whether pastoral or agricultural.

Another distinctiveness of the Sahelian region [in Senegal] lies in its pastoral mobility and infrastructural exclusion. The transhumant lifestyle, characterized by seasonal herd movements and low-density settlements, makes energy infrastructures (e.g., national grid and solar mini-grids) rather poorly adapted to pastoral contexts. Spatial inequalities, such as disparities between off-road and on-road villages, are potentially exacerbated by the lack of tailored policies for transhumant groups. The contrast between transhumant areas and sedentary regions, where energy access is more established and stable, underlines distributive & recognition justice issues. Though enhanced access to FFE and laterite roads might open up pastoral communities to new markets and services, economic opportunities remain constrained by the fluctuating supply capacities of existing energy infrastructures (e.g., daily blackouts in mini-grids).

Finally, tensions between access to energy services and preservation of local resources require particular attention in the region. For instance, the existing scarcity of water resources in Sahelian Senegal has been mitigated through local management strategies driven by energy access. On one hand, FFE associated with

hydraulic infrastructures have enabled the extraction of water from deeper groundwater tables. This has contributed to (1) increasing monetization of the water access service, and (2) overgrazing due to the resulting expansion of herds. On the other hand, fuelwood resources of Sahelian Senegal (Ferlo) are now under growing pressure due to population growth. Accordingly, some mechanisms have been locally implemented, such as “pastoral units” which aim at improving the management of local pastoral resources. Yet those few examples show how tensions between energy access, the new services it provides, and preservation of local resources are likely to increase in the near future.

Conclusion

Energy access policies implemented in Senegal, and in many other Sahelian countries, can be analyzed through the three tenets of energy justice (distributive, procedural, recognition). Regarding distributive justice, the development of infrastructures opens up rural communities and provides populations with access to a greater diversity of energy carriers. On a national scale, these public policies help reduce inequalities in access to energy, particularly between urban and rural populations. However, by extending justice assessment beyond access to energy carriers, we showed that, at an individual level, the benefits in terms of access to energy services and capability enhancement are less straightforward. Most of the population cannot afford the end-use equipment relying on these infrastructures, or the costs of FFE. Our analysis highlights how the spatial scale (e.g., national vs. communal scale) used to design and assess the development of energy infrastructures may hide injustices within the population. We emphasize that current infrastructure development could be more focused on improving real access to energy services for each individual and community (local scale) rather than on regional interconnection (national scale).

The analysis of these policies through recognition justice reveals that some villages of Fulani herders are not really considered in electrification plans and related studies due to their *semi-nomadic* lifestyle. Similarly, infrastructures are mainly designed for people who have access to economic capital or regular income, leaving out families whose access to monetary resources is limited. These reflections should enrich future research, in particular in the field of technical sciences – for example, on how social aspects could be taken into account in energy models or on the necessary innovations to meet the specific needs of marginalized populations and reinforce their social inclusion. It also advocates for considering the diversity of populations’ practices, lifestyles and income levels when designing public policies.

Looking at resource allocation and conflict management (procedural justice), we found that, among communities, national regulations and individualistic modes of governance have taken precedence over collective modes of self-management. This trend may result from new infrastructures with their own management methods (e.g., mini-grids) or from changes in resource use and availability (e.g., wood). By increasing productivity or enabling the extraction of new resources, energy policies may affect local agriculture, forestry, breeding, etc. Quantifying the flows and stocks of energy and other resources (soil, biomass, water) in rural areas may help identify the relevant governance levels for these different resources. In addition, it could support policy-makers in the decartmentalization of sectoral policies, which seems key to the sustainable management of ecosystems and the well-being of local populations.

This work introduces a novel contribution to the literature on energy access by focusing specifically on access to energy services in the Sahel. Now more than ever, the region’s particular characteristics (climate, economic activities, mobility patterns, and settlement structures) necessitates innovative approaches that provide energy services tailored to the specific needs and activities of Sahelian populations, while adapting to their lifestyles. Energy justice enables the integration of such approaches into processes ranging from decision-making to the operation of energy infrastructures, and ultimately aims at reducing inequalities in long-marginalized areas and communities.

Data availability

The datasets used and/or analyzed in this study are available from the corresponding author upon reasonable request.

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Author contributions

****M.K.**** : Writing the whole manuscript text – review & editing, Conceptualization, Investigation, Validation, Methodology, Collected Data, Data Investigation and Compilation; ****T.C.**** : Writing the whole manuscript text – review & editing, Conceptualization, Investigation, Validation, Methodology, Collected Data, Data investigation and Compilation; ****M.L.**** : Review, Investigation, conceptualization, validation, Methodology, Collected Data, Data investigation and Compilation; ****A.N.**** : Reformulation and reviewed; ****B.P.**** : Writing – review & editing, Conceptualization, Investigation, Validation and Funding.

Declarations

Competing interests

The authors declare no competing interests.

Ethical approbation

This study does not require approval from the ethics committee, as it does not fall within the scope of Law No. 2009-17 of March 9, 2009, which establishes the Code of Ethics for Health Research and to which this committee is subject. According to Article 3 of this law, its application is limited to health research, which includes: epidemiological research, biomedical research, research in traditional medicine, research on health systems, and research in social and human sciences. Article 4 further specifies that research in social and human sciences pertains to the study of social and human factors influencing the health status of individuals and societies. Moreover, Article 8 states that the ethical and scientific approval of the National Ethics Committee for Health Research (CNER) is a prerequisite for conducting any research within these categories. Finally, based on Article 2 of Decree No. 2009–729 of August 3, 2009, which defines the missions and responsibilities of CNER, we consider that this study does not fall within the scope of research requiring ethics committee approval. We did not collect data on humans in the strict sense, nor any data directly linked to individuals. However, we gathered factual information about processes and services provided to communities of stakeholders. The data used and analyzed are not publicly available but can be provided upon request.

Data collection and participant consent

Data collection was based on a protocol established by the authors in accordance with the French GDPR (General Data Protection Regulation) guidelines and IRD (French Research Institute for Development) directives and regulations. Informed consent was obtained from all participants and by their legal representatives.

Additional information

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