Electricity Autonomy and Power Grids in Africa: From Rural Experiments to Urban Hybridizations

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13.1. Introduction

Will the electricity revolution in Africa come from the deployment of decentralized solutions? By contributing to decarbonizing the energy mix and relying on off-grid systems now available everywhere on the continent, is the exploitation of local renewable resources able to meet the demand of some 600 million Africans that dominant industrial systems have failed to serve, and under what conditions? This is the challenge that policies arising from a late realization of energy deficiencies and their role in the (poor) development of the continent[1], and which are now priorities for Agenda 2063[2] and the African Development Bank (ADB 2017), intend to address.

Beyond the promises of this new electrification model, this chapter looks at the modes and places of the announced sociotechnical transition by examining the

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1 "Africa's energy infrastructure deficit is a major obstacle to economic growth": statement by ADB Group President, Donald Kaberuka, at the World Energy Congress (September 12–16, 2010, Montreal). https://www.afdb.org/fr/news-and-events/afdb-at-world-energy-congress-energy-is-key-to-africas-development-7075/.

2 Plan for the structural transformation of Africa adopted in May 2013 at the Golden Jubilee of the African Union.

relationship between large networks and decentralized solutions, defined here as "autonomous" modes of access to electricity[3].

From renewable and/or fossil energy sources combined in various ways, three main families of decentralized solutions can be identified in sub-Saharan Africa: mini-grids[4] powered by power plants, most often hybrid, supplying electricity to end customers (households and craft businesses); energy kiosks offering community services; and individual systems (solar torches, lanterns and kits) for basic lighting and electronic device charging (Berthélemy and Béguerie 2016). Most often proposed by external actors, in terms of supply or even commercial opportunism, these solutions are part of an autonomy model which, far from expressing a challenge to the network, legitimizes "by default" self-sufficiency imaginaries. In this sense, the interpretative registers here are very different from those prevailing in the analysis of alternative energy scenes in Europe (Christen and Hamman 2015). Since African configurations are recent, however, the dynamics and modalities of autonomization are likely to evolve and a processual definition of autonomy is preferred here to qualify relations to the grid, which may also vary depending on whether one considers physical infrastructure, socioeconomic mechanisms or the political logic of decentralized solutions (Bridge *et al.* 2013). It is, therefore, a question of understanding when and where electrical autonomy is appropriate; by which collective dynamics (ephemeral or sustainable) it is supported; in which project it is part of, as an end in itself or as a step in a long-term process integrating coordination modes between centralized and decentralized access to electricity.

The chapter first seeks to clarify the link between electricity shortages and the recent expansion of international discourses, initiatives and intervention frameworks to facilitate the large-scale deployment of decentralized solutions from renewable energy (Africa Progress Panel 2017). It shows that the diffusion of decentralized solutions takes two main paths. One, institutionalized and mediatized, takes the form of off-grid projects included in international programs (Bloomberg NEF and Lighting Global 2016). These projects, which we propose to consider as electrical experiments (Hamman 2016), primarily concern rural areas outside the territories served by network operators. The other channel of diffusion, commercial and often

3 When electrification is carried out by means of an off-grid device, it is primarily the local production of electricity that defines autonomy. It should be noted, however, that this technical definition of decentralization does not take into account the organization of the electricity sector, since the same centralized operator can operate technically independent local systems.

4 Depending on the number of users and the power available on the grid, they are sometimes referred to as nano-grid, micro-grid or mini-grid. In this text, we will use the generic term mini-grid.

informal, is through import channels (particularly Chinese solar equipment[5]), local traders in new and second-hand equipment, and purchasing practices based on customers' economic opportunities and the information they have at their disposal. It is developing wherever there is demand, taking advantage of the dynamics and places of "inconspicuous globalization" (Choplin and Pliez 2015). In other words, off-grid electrification devices, designed for rural autonomy, are partially "diverted"[6] to various urban autonomy practices. There are two main reasons for this. The first is that the city/countryside division has only a limited operational scope in the face of increasingly diffuse African urbanization. The second is that grid/off-grid specialization does not offer satisfactory answers to the poor quality of conventional urban electricity service. Although designed as a rural pre-electrification solution[7], off-grid projects are also a response to the significant latent demand in urban spaces.

This misappropriation of place and objective is a little-known result of experiments in electrical autonomy, whose use is being reinvented by the population. It invites us to take an interest in the grid/off-grid interfaces, thus created in cities, and leads us to an examination of the places and types of friction resulting from urban practices for assembling the available technical devices. What respective places do the centralized network and the autonomous devices occupy in the emergence of new arrangements, both spatial and functional? Do they herald more permanent electrical hybridizations? These questions open up a largely unexplored field of research. Institutional actors and experts stress the impossibility of making reliable projections due to the lack of data and hindsight. All are therefore operating today in a context of great uncertainty, between the hope of a boom in the off-grid solutions market and fear of a collapse due to the lack of a sustainable economic model (Payen *et al.* 2016; PwC 2017a). Indeed, despite the profusion of commitments, rhetoric and initiatives in support of decentralized electrification solutions, the true scale of achievements remains limited and, above all, very poorly documented.

In addition, the analysis of documents on decentralized rural electrification solutions faces two pitfalls: imperfectly defined, "rural" is used to describe very diverse spaces, including diffuse urbanization (town, peri-urban, sprawl along major roads); sources, many of which are in the gray literature (project sheets and documents, sites of various organizations), anticipate or exaggerate the impact of

5 The vast majority of low-cost equipment comes from China (Bloomberg NEF and Lighting Global 2016).

6 In the sense proposed by Olivier de Sardan in his analysis of development projects (Olivier de Sardan 1995).

7 Understood as a preliminary step to electrification: "Unlike electrification, end-users are not connected to a grid or are not energy self-producer" (Tavernier and Rakotoniaina 2016: 68).

interventions that are not yet implemented or only in the start-up phase. It is therefore difficult to establish the real state of deployment of these systems, their appropriation, the uses made of them, the degree of satisfaction among inhabitants, etc. The "facts" on which to base the reflection are quite few and rely on a limited number of examples cited on a recurring basis. These also offer only tenuous indications in relation to our hypotheses on interface hybridizations, which must be sought among the "problems" encountered by rural projects: unfair competition from urban traders, markets flooded with imported products, circulation of non-branded and second-hand equipment, etc. are all dynamics in which urban drivers are most often ignored. The purpose of this paper is, therefore, to establish a "state of knowledge" on urban electric hybridization based on available sources and the landscape that emerges from them[8]. The focus is on sub-Saharan Africa excluding South Africa, whose electricity indicators and development are exceptional in every respect on the continent (Jaglin and Dubresson 2016).

Section 13.2 presents the context of off-grid projects, justified by the "crisis" of centralized systems in a continental context of power shortage, and their expected contribution to the electrification of the continent. Section 13.3 shows that the future of the grid/off-grid pair is not sealed: while their economic models have yet to be invented in rural areas, decentralized solutions, circulating according to long and short-range market channels, are already part of urban dwellers' daily lives. The conclusion returns to the singularity of an African physiognomy of electrical autonomy and the prospects for hybridization in urban areas connected to the grid.

13.2. From the "crisis" to electrical experiments

With more than 600 million people without access to electricity out of a population of a billion, sub-Saharan Africa is the region of the world with the worst indicators in this sector[9]: generation and distribution capacities are very insufficient and average per capita consumption is among the lowest in the world (UNEP 2017).

Many projects seek to remedy this "crisis". Some of them aim to strengthen and complement national infrastructures by building new centralized production capacities from fossil and renewable energies, extending network infrastructures and

8 The approach is part of the Hybridelec project, (ANR 2017 Challenge 2). Scientific leader: E. Verdeil (Sciences Po Paris). Co-coordinator: S. Jaglin (Latts, UPEM).

9 Due to the lack of access to modern energy, traditional biomass (wood transformed or not transformed into coal) remains the main source of energy in sub-Saharan Africa (80% of consumption). Its use, coupled with the use of candles and kerosene in cities, causes problems such as air pollution in homes, the severity of which is the subject of late awareness (Muindi and Mberu 2017).

modernizing them to facilitate the integration of intermittent energies. These interventions represent the bulk of the amounts to be invested for the coming decades and are presented as essential for the construction of the continental infrastructure backbone (ICA 2017; Eberhard 2015). This vision of electricity development is capital-intensive and in line with the internal expertise of major financial institutions. It has long been exclusive, but it is now partially in competition with another, based on an approach that values decentralized or off-grid solutions, community ownership and endogenous local development (Berthélemy and Béguerie 2016). Encouraged by the recognition of access to electricity as a major development issue[10], this second approach benefits from international initiatives that encourage greater commitment from governments and private industrial actors, and benefits from innovations and "disruptive technologies" that would now have the capacity to "unleash Africa's energy future" (Africa Progress Panel 2017).

13.2.1. *Electric disasters and riots*

The electricity shortage situation is primarily due to insufficient production and distribution capacities. The installed capacity of sub-Saharan African countries was 90 GW in 2014 and, without South Africa, it fell to 40 GW. The undersizing and obsolescence of distribution networks also aggravate the electricity deficit, with some countries having even experienced grid contractions during the 1990s due to wars or lack of infrastructure maintenance (Eberhard *et al.* 2011; Eberhard 2015).

In 2015, the average rate of access to electricity service in urban areas was 60% and electricity infrastructure served on average 20% of localities. According to international standards, the amount of electricity needed to meet the basic needs of a household of five people (lighting, ventilation, communication: mobile phone, radio and/or television) would be around 250 kWh per year for a rural household and 500 kWh for an urban household (Desarnaud 2016). The available data estimate the average consumption of an African household (excluding South Africa) at 181 kWh per year (ADB 2017) and indicate that, even in cities that appear to be well served by the grid, electricity service is provided only for a few hours a day, on an irregular basis and with varying voltages, increasing dependency on generators.

The infrastructural backlog of the continent and electricity poverty must also be seen in the context of rapidly changing societies. Two major forces of change thus

10 The issue of access to electricity has recently been linked to development and poverty alleviation issues. Thus, it was not part of the Millennium Development Goals defined in 2000 and it was not until the RIO+20 conference in 2012 and the Sustainable Development Goals (2015 – 2030) that an ambition for universal access to electricity formulated in Goal 7 ("Access to clean energy at an affordable cost") was clearly stated at international level.

have a major impact on electricity demand. First, sustained average population growth (+2.6%/year): even though catching up is in itself a considerable challenge, it is made even more difficult by the prospect of a tripling of the urban population by 2030[11]. Then, the growth of middle classes in the South (Desjeux 2011) is accompanied by an increase in purchasing power and consumer spending, particularly on energy, as well as increased demands on governments. While uneven, this process is noticeable in many African cities, which are regularly affected by electricity shortages caused by persistent – or even increasing – mismatches between supply and demand. These shortages have significant economic and political costs ("power riots") and the priority of public authorities is to increase and secure electricity supply, particularly in cities.

Senegal is an illustration of this: the 2011 electricity crisis, linked to a drop in production itself caused by the catastrophic financial situation of the national company Senelec, resulted, in a context of sustained population growth (+2.7%/year from 2000 to 2016), in a wave of cuts over more than a year. Exasperated, people expressed their anger on the streets and violent protest movements were reported across the country and in the capital city. The government's short-term policy response focused on maintenance work to improve the rate of capacity utilization. In the current medium term, it combines the construction of new coal-fired power plants, which were the only ones capable, under current conditions, of producing cheap electricity, with the development of solar energy (Taccoen 2017). Nigeria, Africa's largest oil producer, is also seeking rapid solutions in a context where the domestic terminal at Lagos International Airport was plunged into darkness in February 2016 and University of Lagos students blocked access roads to their main campus in April to protest against "an epileptic (sic) electricity supply" (Taccoen 2016: 4 – 5).

13.2.2. *Huge investment needs*

To remedy this catastrophic deficit, the traditional approach has been based on massive investments in new centralized production capacities and in the extension of national electricity grids. It aims to modernize electricity systems to meet a high level of consumption and service from the outset and relies on private investors to provide financial and technical capital in the form of public–private partnerships (Eberhard *et al*. 2016). However, this option has so far faced many obstacles.

The main reason for the chronic undersizing of electricity infrastructure is, according to many reports, the financial vulnerability of companies in the sector:

11 The average annual urban growth rate is 3.4% according to United Nations estimates, more than the growth rates of conventional electrification.

"the main cause of the slow progress in access expansion in SSA is the poor financial viability of electricity utilities" (Trimble *et al.* 2016: 7). While these companies cannot borrow at affordable rates, most African governments are unable to finance projects, and public development aid has and will only partially fill this gap. Two other sources of financing have certainly emerged in recent years: independent private financing (67 projects in sub-Saharan Africa excluding South Africa since 1990), which nevertheless remains concentrated in a small number of countries[12], and Chinese investments (30 projects between 1990 and 2014 in 16 countries, although with a predominance of large-scale hydropower projects[13]) (Eberhard 2015). It is interesting to note here that these Chinese investors favor the financing of large energy infrastructure as part of explicit policies to expand centralized systems (OECD/IEA, 2016), in response to the request of many governments. With more than ten new hydropower plants by 2020, the expansion of the low-voltage grid and the construction of interconnection networks with neighboring countries, the Ethiopian Electric Power Corporation's (EEPCo) strategic plan adopted in 2010 is emblematic of these ambitions (Gascon 2015). For the time being, however, despite these powerful network dynamics, access to the necessary financing to improve the national electricity sector remains insufficient in most countries.

The amounts of capital required are colossal, difficult to estimate and even more difficult to secure in an unstable political and economic environment. Comparing existing studies, some of which include all the countries on the continent while others cover only those in sub-Saharan Africa, shows the difficulty of correctly estimating needs (Trimble *et al*. 2016). In the fog of projection figures, the data probably closest to the objectives set are provided by Africa Energy Outlook 2040 for the implementation of the energy component of PIDA (Programme for Infrastructure Development in Africa): for the four power pools in sub-Saharan Africa, they estimate that US$ 45.6 billion/year will be needed between 2014 and 2040 to achieve an average electrification rate of 65% (ADB/African Union/NEPAD 2011).

While the assessment of the amounts to be invested is complicated, their breakdown by type of project is no less so. The amounts posted most often concern new projects without taking into account the need to renovate or replace the existing infrastructure, although it is partly obsolete: when the service exists, it is very expensive (twice as expensive as in Latin America, three times as expensive as in South-East Asia: Eberhard *et al.* 2011), often rationed and of poor quality. In theory, energy efficiency policies could be an alternative solution by freeing up capacity to

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12 Mainly Nigeria, Kenya, Uganda and, more marginally, Côte d'Ivoire and Ghana (Eberhard 2015).

13 77% of projects.

connect unserved households while improving the service of those already electrified. According to the example provided by Desarnaud (2016), a 40 W solar panel can power a 25 W incandescent lamp for 5 h or, with more efficient devices, two LEDs for 5 h as well as a television, a fan, a mobile phone charger and a radio for 3 h. However, the author also points out that the technical conditions for such a development are often not met in African countries where the most efficient electronic products and household appliances are absent from local markets or too expensive for a majority of households.

The objective of electrification via conventional electricity systems therefore seems unrealistic in the short to medium term and is no longer considered in the scenarios of the main international energy initiatives. While most experts affirm the need to launch large-scale energy projects quickly, more and more of them are thinking of an electricity development also based on decentralized solutions that are faster to implement and less costly (Africa Progress Panel 2017; ADB 2017; PwC 2017a).

As envisaged today, African electricity development could thus combine the consolidation of national systems, based on an energy mix that depends on available resources and financing opportunities, and decentralized electrification solutions using a mix of diesel and renewable energy sources. The former are designed to support economic growth, the latter to promote the development of territories, officially in isolated areas or scattered rural settlements. They embody a gradual electrification scheme in which the first few kilo watt hours, accessible with a minimum level of service, are considered decisive in terms of socioeconomic development.

In the documents, there is no reference to a possible redefinition of the electrical model and the conditions for its transformation, but rather the implicit wager of an advantageous combination between these two electrification paths, with a separation of territories and the social functions of electricity.

13.2.3. *Renewables and decentralized systems: a third way for sub-Saharan Africa?*

The context is favorable to the massive development of renewable energies in Africa. The continent has abundant resources and the potential for installed production capacities is estimated at 10 TW for solar, 350 GW for hydro, 110 GW for wind and 15 GW for geothermal (UNEP 2017). Even if comparisons are difficult and controversial, studies anticipate that renewables will quickly become competitive. For example, a 2011 European Union report calculated that decentralized solutions based on renewable energies (solar and hydro), combined with the extension of the existing grid or generators, would make it possible to electrify the entire continent at a cost per kilowatt hour of less than €0.30 (Monforti 2011).

In fact, technological advances and the fall in the price of certain equipment, particularly solar equipment (down 80% for photovoltaic modules since 2009) make it possible to deploy competitive decentralized electricity production from renewable energies (IRENA 2016). Off-grid technologies are also fast to deploy: sales of solar-powered pico-solar energy in Africa have increased from 500,000 in 2011 to 11.3 million in 2015 (Africa Progress Panel 2017). They have the advantage of diversifying resources in a flexible, evolving and scalable way: individual system, isolated or interconnected mini-grid and national grid. Modular, solar technologies also allow the combination of several devices to create a system that corresponds to the needs and financing capacities of the consumer–producer: the PV panel can supply both connected and autonomous decentralized systems; in the latter, it can be used alone "over the sun", coupled with a storage system and/or integrated into a hybrid system that most often includes a generator (Pillot 2014).

For many analysts, the African electricity future would therefore be part of a triple transformation movement: low-cost fossil energy production to respond quickly to the impatience of urban consumers, development of renewable energies in centralized installations connected to the grid (geothermal, large-size wind and solar farms, hydroelectricity) and mobilizing advanced technical and economic engineering, accelerated deployment of small capacity decentralized and rural solutions, partly powered by renewable energies, adjustable to the purchasing power of households and the limited capacities of local public and private actors. However, this neat vision says little about the processes and results of "bottom-up" transitions, about the forms of autonomy actually practiced by urban dwellers, and about local energy mixes.

13.3. Electrical hybridizations between pragmatic autonomy and new dependencies

There are indeed contrasts between prospective visions and feedback from the field. On the one hand, project deployment is slow and many projects do not go beyond the study stage (Buchsenschutz 2016). On the other hand, the heterogeneity of technologies and energy sources (renewable and fossil), the geographies of their diffusion and the multiplicity of decentralized solutions, including in the presence of the network, show an apparent disorder far from the logic and intentions displayed. What are the reasons for this "dissipation"? An approach in terms of electrical experimentation provides insights into the processes at work.

Referring “both to the development of temporary projects and their implementation on small scales” (Hamman 2016: 2), the notion of experimentation is inspired here by the work of socioanthropology development (Lavigne Delville 2011; Olivier de Sardan 1995) and suggests analyzing off-grid electrification projects both as systems of action and as territories–laboratories for sociotechnical solutions to be tested. In countries under an “aid regime”, it invites us to examine the forms of intermediation between the project universe and the local space, the intertwining of project reappropriations and reinterpretations, the modes of articulation – or disarticulation – between projects and public policies (Baron and Lavigne Delville 2015). At its peak, the electrical experimentation should make it possible to identify the conditions for achieving three related objectives: testing technological solutions in different environments; identifying promising markets and the conditions for developing commercial solutions for target customers and territories; and advancing electrifying. It therefore aims to promote localized learning processes, on the one hand, and to improve knowledge of the value chain of decentralized electrical solutions that depend on disparate and dispersed resources (equipment suppliers, service managers, mobile phone operators, application developers, etc.), on the other hand.

Thought and understood as “outdoor” laboratory tests, electrical experiments are carried out in reception areas but, like any development project, they can experience overspill[14] (Jacob and Lavigne Delville 2016) and are exposed to forms of appropriation involving disarticulation, selection and “diversion” (Olivier de Sardan 1995). Their effects, promising or undesirable, can fuel more subversive, informal and undisciplined experimental dynamics, shaping in their own way electrical autonomies that escape projects, for example in urban areas.

In this second part, we question these differences by shifting the gaze and looking at the “displaced” effects of the experiments. The aim is to explore the social dynamics by which project design can be subverted to the point that solutions of rural autonomy lead to urban electric hybridizations.

13.3.1. *Rural experiments....*

In rural areas, individual solutions – from lanterns to SHS kits (solar home systems) – have been very successful. First tested in pilot projects in East Africa, they are at the heart of market building strategies in 11 African countries, the main

14 With reference to Callon’s work on the sociology of translation, Jacob and Lavigne Delville define overspill as a process of questioning the problematization (how to pose and respond to the problem to be addressed) of a development project that tests the strength of the network of associated actors (Jacob and Lavigne Delville 2016).

ones being Ethiopia, Kenya, Tanzania, followed by Nigeria, Uganda, the Democratic Republic of Congo and Rwanda, where they are deployed by many companies, start-ups and giants in the sector (Engie, EDF[15], Schneider Electric, Total, Philips, Orange, etc.), particularly as part of the World Bank Group's Lighting Africa program, which would have equipped around 11 million households (Bloomberg NEF and Lighting Global 2016). The projects are based on relatively similar combinations of ingredients. First, a technical offer (Azuri Technologies' SHS Indigo Duo, which has been broadcast in Rwanda since 2013 with USAID support, includes, for example, a unit connected to a 2.5 W solar panel, equipped with a phosphate-iron-lithium battery, two light points using LEDs and adapters for charging a telephone). Second, a local marketing network based on "last mile" distributors, strategic for the entire value chain, who must be trained and then supported in their activity. Finally, financing mechanisms, which are diverse and can be based on microcredit, as proposed by the *Fondation Energies pour le Monde* in Burkina Faso, or on pay-as-you-go (PAYG)[16], facilitated by the use of "mobile money" platforms, as in the Light Lwengo offers in Uganda, the Mahazava start-up in Madagascar or the Bright Light project in Benin. The latter, which was tested in 2016, is based on a partnership between a national supplier of solar lamps (ARESS) and a mobile telephone operator (MTN Benin), whose agents distribute the equipment and whose network allows the use of the Easy Buy payment tool[17].

Behind this first front, informal circuits for the sale and repair of appliances proliferate on local markets and increase the penetration of these devices in response to households' needs for lighting, telephone charging and even radio and television operation, as shown, for example, by a study in Burkina Faso (Bensch *et al.* 2016) and observations in Lower Casamance in Senegal (Francius *et al.* 2017). According

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15 At the end of 2016, in partnership with the American company Off-Grid Electric, EDF created ZECI to supply off-grid solar energy in Côte d'Ivoire. In 2018, EDF, Off-Grid Electric and a Ghanaian industrial company launched ZEGHA and an *off-grid* solar kit offer in Ghana. At the end of 2017, Engie acquired Fenix International, a specialist in domestic solar installations in rural and peri-urban areas in Uganda and Zambia, and announced its intention to reach a market of 20 million people (*Le Monde de l'énergie* [online], March 5, 2018, http://www.lemondedelenergie.com/edf-afrique/2018/03/05/).

16 A leasing system that allows, after the initial payment of a modest sum for the purchase of a solar kit, use before becoming owner by means of regular payments of a small amount. The system is equipped with a locking mechanism in the event of non-payment. Among the leaders in this market in sub-Saharan Africa: M-KOPA (Kenya, Tanzania, Uganda), Azuri (Rwanda), Off-grid Electric (Tanzania, Rwanda), Mobisol (Tanzania), Nova Lumos (Nigeria) (Bloomberg NEF and Lighting Global 2016).

17 See the project sheet on the GSMA website: https://www.gsma.com/mobilefordevelopment/programme/m4dutilities/bright-lights-for-benin-market-introduction-of-pay-as-you-go-solar.

to a study conducted in seven African countries, these informal networks for the sale of non-branded equipment have a decisive role in the “silent transition of lighting” from the most used fuels (lamp oil and candles) to LED torches powered by dry cells, now sold in almost all shops (Bensch *et al.* 2015). Although in principle aimed at rural customers, these commercial networks are concentrated in cities, where the supply chains originate (Bloomberg NEF and Lighting Global 2016).

In villages and towns, particularly along the main traffic routes, collective solutions – kiosks and autonomous mini-grids – seem *a priori* more appropriate. The kiosks offer electrical services for charging, printing, Internet access, refrigeration, television/cinema, etc., often coupled with a commodity trade. They currently exist in several African countries[18], but their development is hampered by a fragile business model, as studies in Togo (Galichon and Payen 2017) and Madagascar (Tavernier and Rakotoniaina 2016) show. In the latter country, HERi Madagascar, a social enterprise created in 2011, is developing a model of franchised kiosks for female entrepreneurs (44 in January 2016). Each kiosk is powered by six solar panels (total capacity of approximately 1 kW) and equipped with two batteries, a charge regulator and a 450 W inverter to connect devices running on alternating current. If the operation of a kiosk seems to be able to find a financial balance after two years, on the other hand, HERi Madagascar’s initial investment and operation depend, for the moment, on external contributions (*idem*).

Halfway between individual options and connection to the national grid, the mini-grid producing and distributing electricity locally to end users is a possible solution in more densely populated areas: in addition to the domestic needs of households, they aim to meet the operating needs of public facilities and those of small economic activities. In the cotton-growing regions of southern Mali, the NGO GERES promotes an “Electrified Activities Zone” model, in which a hybrid solar/agrofuel plant supplies electricity to a group of very small interconnected companies (hairdresser, baker, welding company, etc.)[19], sometimes in addition to a mini-grid serving households (Béguerie and Pallière 2016). The oldest models of mini-grids[20], such as in Mauritania (Munnich 2016), operate with diesel generators; the most recent ones use renewable energies, mainly solar, such as in northern Burkina Faso (Fondem 2016), or a solar-diesel hybrid to overcome intermittency problems (now the major choice in Mali). They can be deployed and managed by the national incumbent operators, but the principle of private management by

18 In particular Ethiopia, Kenya, Madagascar at the initiative of some actors (EnDev, HERi Madagascar, KPLC, Solarkiosk, Schneider, etc.). For a detailed study of the model, see: Hartl 2014.

19 See the GERES website: http://www.geres.eu/fr/nos-actions/par-pays/afrique-de-l-ouest/geres-mali.

20 On the history of this model, see: GVEP (2011).

licensed operators or concession holders (companies or cooperatives) is now favored. In Kenya, the national company KPLC's diesel-powered mini-grids are gradually being replaced by hybrid systems and, since the 2016 legal and regulatory review creating permits (<3 MW) and licenses (>3 MW), entrusted to private distributors (electricity is then purchased in bulk from KPLC) or to independent producers/distributors. In Mali and Senegal, an SSD (*Société de services décentralisés*[21]) model has been developed, with an electrification concession for a renewable period of 15–25 years (Heuraux and Houssou 2015). Created in 2001, the SSD Yeelen Kura has thus obtained from the Malian Agency for the Development of Domestic Energy and Rural Electrification (AMADER) an operating permit in 23 municipalities in the cotton zone for a renewable period of 15 years. Access, another Malian SSD, operates 12 mini-grids providing domestic electricity and street lighting, mainly in rural areas, but is also developing an urban project to complete the national grid with solar installations (GSMA 2017). Mini-grids powered by micro hydropower plants also exist in Zimbabwe, Malawi and Zambia and many observers agree that mini-grids represent "a significant market". However, their current deployment remains hampered by the lack of a clear regulatory framework, insufficient operating revenues, a general lack of capacity and, above all, a lack of investment in the face of risks perceived as too high (Payen *et al.* 2016).

13.3.2. ... and urban hybridizations

With a few exceptions, none of these three decentralized solutions is officially designed for cities, although their future is partly urban for at least two reasons. First, it must be stressed that the political-administrative organizations of many countries lead by convention to classify as "rural" many villages and towns that are primarily concerned by decentralized electrification projects. Then, in the (larger) cities themselves, population growth and urban sprawl, the sharp increase in electricity demand, particularly from the middle and wealthy classes, the insufficient capacity and stability of existing networks and, more generally, the poor quality of service, also require innovative solutions. Finally, urban dwellers constitute an attractive "market" for the products and technical kits that projects are finding it difficult to sell in rural areas because of poverty even more than because of implementation risks (Allet 2016). This is reflected in the emergence of local markets for non-branded solar products, which institutional actors consider to be unfair and inefficient competition for companies in the sector[22] (PwC 2017a) but which are also, for many rural households, "wise investments" (Grimm and Peters

21 A decentralized services company.

22 "The market for cheap, non-branded pico-solar products – unbranded items or copies of branded ones – is at least as big as the brand-quality market in number of units sold" (Bloomberg NEF and Lighting Global 2016: 2).

2016). Thus, in Burkina Faso: "We find that the adoption rate of a non-branded SHS [Solar Home System] is considerably higher at 36 percent compared to eight percent for a branded SHS. [...] We show that non-branded SHSs provide a similar service level as branded solar, in that they do not fall behind in terms of consumer satisfaction and durability, and that non-branded products are more cost-effective" (Bensch *et al*. 2016: 3).

The presence of solar panels and solar kits in shops and urban markets shows that individual solutions are also penetrating cities, where product ranges seem to be more extensive (from non-branded low-cost low-tech equipment from informal retailers to branded products from approved suppliers) and in more diverse associations (generators, solar equipment, batteries). Accompanying the "lighting transition" (Bensch *et al*. 2015) and the need to recharge mobile phones in rural areas, the use of decentralized solutions is, in cities, a response to the growth and diversification of demands but also a city parade against network failures (Bloomberg NEF and Lighting Global 2016). There are many strategies for use: saving on electricity bills (solar water heaters, solar panels), securing supplies in addition to inconsistent and poor-quality service (generators, batteries, Nigerian inverters[23]), self-generation of electricity in the absence of a grid (unconnected solar panels). This calls into question the very idea that decentralized solutions are restricted to the pre-electrification of isolated rural populations, as confirmed by the experience of solar equipment vendors: demand is high for equipment that is on average more powerful and more expensive, from connected urban households that are confronted with intermittent service (Bloomberg NEF and Lighting Global 2016). In these urban contexts, autonomous systems are first and foremost a palliative of the network and a means of rapidly increasing the satisfaction of growing needs.

Through urban practices, off-grid systems are thus *de facto* confronted with coexistence with the grid: "It is not difficult to imagine how solar kits could become an integral part of the daily experience of this population, if local grids fail to meet power demand. Some manufacturers and distributors are already reporting that they target sales in urban areas, even of portable lights. These are most likely used as back-up lights during power outages" (*idem*: 44). This has two consequences for urban electrical services: a stacking of devices and practices in response to uncertainty and a long-lasting hybridization of electrification configurations (Jaglin 2017). However, these configurations are poorly understood, both by assessments of rural experiments (Galichon and Payen 2017; Payen *et al*. 2016; Pillot 2014) and by urban studies, focusing on "palliative delivery" modes (Mpiana Tshitenge 2015) and "incremental infrastructures" (Silver 2014). With a few exceptions (Andreasen and

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23 Variable power modules composed of one or more batteries and an inverter, generally connected to the grid and possibly to solar panels to stabilize and secure the electricity supply.

Møller-Jensen 2016; Tenenbaum *et al.* 2015; Smits 2012), coevolutions of decentralized solutions and the network are poorly articulated, even though the compartmentalized geography of modes of access to electricity does not stand up to empirical examination.

13.3.3. *Off-grid under constraints*

The democratization of off-grid systems and infrastructure consolidation must therefore be considered together, since the future of electrical autonomy is not so much outside the grid as in interaction with it. This leads to new configurations that rebuild inertia and dependencies.

In the majority of African countries, the dynamics of technological innovation and use are now focused on solar kits, solar panels and batteries. Components are most often imported, software is developed by NGOs or start-ups with external support and project structures are financed by international aid. Major research and development efforts remain necessary to take it to the next level: electrical engineering to make mini-grids and individual devices more reliable, but also business models for supply must be invented in countries where technical, socioeconomic and political factors are unstable, especially at local levels. Capital and expertise will hopefully come, but the urgency must be met: African urban dwellers are now seeking a more systematic use of electricity for uses that correspond to their vision of modern urban life. They are therefore turning to a proven solution: the power generator, whose market is growing rapidly. Rightly criticized for their pollution (air and noise pollution) and operating costs (depending on a diesel fuel that is often imported), they also have unequalled advantages: of all sizes and variable power, they can be purchased in stores or created from old engines using DIY, and they are flexible and can respond to occasional interruptions as well as compensate for a structurally insufficient supply. In many cities, they are an essential auxiliary to electricity supply: the growth of their market in Africa is estimated at more than 10%/year (Douet and Coulibaly 2015) and their number is estimated at 60 million in Nigeria (Taccoen 2016).

However, the overall situation is not well known. On the one hand, there are signs of market maturation with improved equipment (quieter and more fuel-efficient units, even “clean” units with gas recovery, or associated with solar panels in hybrid solutions) and, on the other hand, uncertainty factors related in particular to diesel supply conditions and equipment maintenance problems[24]. The

24 The cost of which depends in particular on national subsidy policies for petroleum products, which are now disputed, while the transport of fuel remains problematic due to the lack of road infrastructure.

ability of national policies to offer credible solutions to electricity demand, whether grid or off-grid, remains the main variable in this market and, according to Aggreko, the world leader in temporary power solutions managing more than 2,000 MW in 34 countries across the continent, “contained power generators” of all sizes have a bright future ahead.

A variety of factors, beyond the lack of capital, also determine the success – or failure – of decentralized solutions and receive too little attention.

First, the organization of a facilitating environment requires appropriate national measures. This observation is widely shared, but concrete measures have barely been drafted in many countries, where government voluntarism is insufficient to adapt policy, regulatory and tariff frameworks (Africa Progress Panel 2017). Political intervention is also necessary to organize markets. Structural reforms have been undertaken to partially deregulate the vertical monopoly of national utilities in some countries (Ghana, Nigeria, Uganda, Kenya). But technical (Tenenbaum *et al*. 2016) and commercial (Beaurain and Amoussou 2016) sectoral regulation is lagging behind while the emergence of new markets attracts greed: “Many importers, installers and retailers have started in the field but, due to the lack of rules and controls, counterfeit equipment is available alongside very good equipment and unscrupulous players are more numerous than very well-trained installers. For local populations, who are generally illiterate and poorly informed, the purchase of equipment is like a game of chance”[25]. For Beaurain and Amoussou (2016), the development of the sector must be supervised to protect young companies and businesses issuing certified equipment from the “unfair” practices of informal competitors (smuggling products, unauthorized equipment, etc.). It must also be done to build household confidence by marketing cheap and sufficiently efficient equipment that is adapted to climatic and environmental conditions (heat, dust, humidity), and that is robust and repairable by local craftsmen. However, the role of labeled branded materials in this process is a matter of debate (Bensch *et al.* 2016; Grimm and Peters 2016).

Second, the technical and economic difficulties should not be underestimated. Studying the potential of solar energy in Djibouti, Pillot points out that the most widely used and best-known systems in the world today are decentralized grid-connected systems in the context of universal electrification; however, these configurations offer little appropriate feedback for autonomous photovoltaic devices in sub-Saharan Africa (Pillot 2014). The fact that individual autonomous systems are already widely used is only part of the answer to the problem because their effectiveness is quite relative, according to the author, who suggests that

25 *Le Monde de l’énergie* [online], September 5, 2017, http://www.lemondedelenergie.com/afrique-paiement-usage-solaire-individuel/2017/09/05/.

experimentation efforts should focus on storage solutions coupled with intermittent sources under real conditions of autonomous systems operation.

It is also often argued that the spread of decentralized power solutions in sub-Saharan Africa benefits from leveraging effects of the mobile ecosystem, as claimed by the GSMA[26]: mobile operators need electricity for their often isolated towers and can in turn provide a reliable source of revenue while helping to collect electricity bills through mobile applications. More generally, electronics and mobile services are transforming business management (smart meters, prepaid, mobile money) and have the potential to significantly expand the customer base by adapting electrical services to people without bank accounts at the "bottom of the market". In Mali, where 26% of the population have access to electricity but 90% are thought to be covered by mobile networks, a study suggests that the use of mobile money and GSM M2M technology[27] would increase the profitability and quality of mini-grids and solar home installations managed by SSDs in southern regions (GSMA 2017).

However, these promising solutions have yet to be tested and evaluated. Failing this, the lack of technical adaptation to local configurations results in the early failure of many decentralized solutions[28] and only partial control of the conditions for successful different models (Galichon and Payen 2017; Payen *et al.* 2016). It also manifests itself in discrepancies between the supply and the consumption needs both of households (misuse of kits with too many devices connected to them has been noted in some projects[29]) and of craftsmen (whose machines require more power and reliability). GERES "Electrified Activities Zone" is thus a response to the limitations observed in the mini-grids operated by the SSD Yeelen Kura, whose service offer, from 4 pm to midnight, severely limits the activities of small businesses during the day, even though this latent demand represents an untapped commercial potential for the SSD[30]. More systematic feedback is also needed to compare solutions. For example, the hire-purchase model dominates in East Africa while West African SSDs favor the sale of electricity services, arguing that this is more likely to ensure sufficient use in the long term (GSMA 2017). A rigorous comparison of the respective effects of these systems on household inclusion and the

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26 International association of operators, manufacturers and industrialists in the mobile telephony sector. See the website of the "Mobile for Development Utilities" program. www.gsma.com/mobilefordevelopment/m4dutilities.

27 Machine-to-machine: communication between devices.

28 According to AMADER, Mali has 200 mini-grids, only half of which were in working order in 2017 (GSMA 2017).

29 J. Daniélou (ENGIE Lab), personal communication, February 2017.

30 See the project sheet on the GERES website: http://www.geres.eu/images/fiches/fiche-projet-mali-pep-fr-v2.pdf.

sustainability of their access to electricity should be carried out to inform electrification choices and assess the challenges of variable geometry autonomy.

Finally, a third set of factors, of a political–institutional nature, deserves attention. In this area, obstacles do not only come from "above", from the lack of governments' political will or the resistance of national electricity companies. The deployment of decentralized solutions also comes up against obstacles "from below" due to the weakness of local initiatives, public actors' lack of capacity, and resistance from interest groups (for example, those, importing generators and fuel in Nigeria). Like elsewhere (Nadaï *et al*. 2015; Christen and Hamman 2015), the mobilization of territorial resources is decisive in the genesis and success of local energy transition projects in Africa (Beaurain and Amoussou 2016). However, the transactional nature (Hamman 2016) of empowerment processes and the representations inspired by off-grid solutions are rarely questioned. On the one hand, electrification projects assume that renewable energies and decentralized solutions, by making it possible, fulfill a desire for electrical autonomy while many households dream of a connection to the grid. Although local renewable energy sources are raising, along with hopes for rapid electrification, a "new" question of autonomy, little is known about how this influences the geographically and socially situated representations of grid and off-grid systems. On the other hand, electrification projects tend to "freeze" the demand of local communities whose social, political and economic dynamisms cannot be reduced to a stable and objectifiable whole. Despite appearances, electrical autonomy devices do not arrive on greenfield land and are part of existing offers and practices, particularly in urban areas. Whether total or partial, substitution involves a change or even a displacement of social norms; it disrupts power relations and can generate tensions and resistance. A project does not easily and immediately fit into its host environment and society, usually based on different interests, capacities, visions, temporalities (Jacob and Lavigne Delville 2016).

In other words, the territorialization of electrical autonomy resists the standardization of electrical experiments: "Mini-grids require a mode of governance, for what is a local public good, that is appropriate to the context and enables collective maintenance management and conflict resolution in the event of disputes about how this common resource is to be shared" (Berthélémy and Béguerie 2016: 8). Where collectives are poorly structured, too conflictual or too heterogeneous, an autonomous mini-grid is unlikely to function on a sustainable basis; where the initial conditions seem more favorable, the sustainability of a mini-grid often depends on how it has been designed, sized and organized to facilitate learning and enhance its profitability (Payen *et al*. 2016). Everywhere, the rise of decentralized electrification solutions depends on the modes of appropriation and their effects on emerging sociabilities, for example around new electrical services (shared refrigerator spaces, collective television-video, telephone charging in stores, etc.).

13.4. Conclusion

Despite the territorial compartmentalization of electrification policies distinguishing reticulated cities from off-grid countryside, hybridization processes are under way. All you have to do is walk around African cities to see that social practices, straddling urban and rural worlds, contribute to the technical and geographical spillover effects of electrical experiments and contribute to the introduction of decentralized solutions into the grid's territories. In this context, the autonomy promoted by electrical experiments seems both fragile in its foundations and poorly understood in its implications.

First, since cities are absent from projects both as spaces and as actors, reflection on future transformations deprives itself of particularly dynamic observatories and promising laboratories. It also deprives itself of a political barometer, as the failures of the major electricity networks feed social impatience in real urban cauldrons (Jaglin and Verdeil 2017).

Second, this reflection is ill-equipped to anticipate the way in which decentralized electrical solutions contribute to a profound remodeling of the nature of the service offered, far from the monopolistic public electricity systems that have dominated until now but also very different from the autonomy thought for the rural world. On the contrary, it seems crucial to compare the expectations of electrical experiments with their real results and to deepen, through field research, the understanding of their effects on the transformation of electrical systems and the redefinition of the respective roles of grid and off-grid.

Finally, considering stand-alone solutions in an exclusive pre-electrification scheme rather than in co-supply configurations with the grid reduces the power to re-imagine what the electric city of tomorrow could be. In *Africa 3.0 l'autre Eldorado technologique*, PwC unveils its vision of a radical transformation of the African continent through solar and digital electricity (PwC 2017b). What autonomy can this revolution lead to? That of isolated territories with stagnant trajectories or that of societies with increased "capacities", combining the resources of chosen electrical autonomy, ever-increasing connectivity and controlled dependency on the grid(s)? Where, if not in cities, is this second scenario the most likely? In other contexts, Daniélou and Ménard formulate the hypothesis that "giving a district temporary energy autonomy through a high density of solar panels, as is the case in some projects, becomes a condition for the survival of the electricity distribution network" (Daniélou and Ménard 2014: 4). The idea is not without relevance for sub-Saharan Africa. Flexible, less costly and risky than national electrification policies based on large networked infrastructures, autonomous electrification systems provide (elements of) answers to the necessary economic and human development of a continent where population growth poses considerable challenges to spatial planning. They also propose (elements of) responses to the need to redesign modes of action in the context of financial scarcity and the gap between a predefined, designed and planned "top-down" offer and heterogeneous urban demands. Paradoxically, rural electricity experiments are thus inspiring new solutions for cities, where networks are undercapacity, but by democratizing autonomous devices, they also promote a crypto-hybridization of centralized electricity systems. Recognizing these crypto-hybridizations as part of sustainable solutions, by rethinking the relationships between networks and autonomy in urbanized spaces, would open up new possibilities.

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