Off-grid Electricity in sub-Saharan Africa: from rural experiments to urban hybridisations

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1. Introduction

Will the electricity revolution in Africa come from the deployment of decentralised solutions? With their capacity to decarbonise the energy mix and to use off-grid solutions now available everywhere on the continent, are local renewable resources capable of meeting demand from some 600 million Africans that the dominant industrial systems have failed to meet, and if so under what conditions? That is the challenge targeted by policies developed in response to the delayed awareness of energy gaps and their role in the (mis)-development of the continent,[2] which are now priorities for Agenda 2063 and for the African Development Bank (AfDB 2017).[3]

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[2] "Africa's energy infrastructure gap is a key constraint on the continent's economic growth potential.": Declaration of the President of the AfDB Group, Donald Kaberuka, to the World Energy Congress (12-16 September 2010, Montréal). URL: https://www.afdb.org/fr/news-and-events/afdb-at-world-energy-congress-energy-is-key-to-africas-development-7075/

[3] Agenda 2063 is a plan for the structural transformation of Africa adopted in May 2013 at the African Union's Golden Jubilee.

Beyond the promises of this new model of electrification, this research paper will examine the forms and whereabouts of the proposed sociotechnical transition by exploring the relations between large power grids and decentralised solutions, defined here as "autonomous" modes of access to electricity.[4]

Out of a variety of combinations of renewable and/or fossil energy sources, three main families of decentralised solutions can be identified in sub-Saharan Africa: mini-grids supplied by power stations,[5] usually hybrid, which supply electricity to end-users (households and small businesses); energy kiosks that provide community services; individual systems (solar torches, lanterns and kits) that fulfil basic needs such as lighting and phone charging (Berthélemy and Béguerie 2016). Usually distributed commercially – and sometimes opportunistically – by outside actors, these solutions constitute a model of autonomy which, far from expressing opposition to the grid, gives "default" legitimacy to a vision of self-sufficiency. In this sense, the interpretative registers here are very different from those that prevail in the analysis of alternative energy scenarios in Europe (Christen and Hamman 2015). Since the configurations that can be observed in Africa are recent, however, the dynamics and characteristics of autonomisation are likely to form new combinations. We therefore favour a processual definition of autonomy to describe relations to the grid that can also vary depending whether the emphasis is placed on the material infrastructures, the socio-economic mechanism or the political rationales of decentralised solutions (Bridge et al. 2013). The aim is hence to understand when and where electrical autonomy is adopted; what collective dynamics (temporary or long-term) drive it; and which projects incorporate it, either as an end in itself or as a stage in a long-term process that includes modes of coordination between centralised and decentralised access to electricity.

The paper first seeks to clarify the link between electricity shortage and the recent proliferation of international rhetoric, initiatives and frameworks promoting the large-scale deployment of decentralised solutions using renewable resources (Africa Progress Panel 2017). It shows that the spread of decentralised solutions follows two main pathways. One of them, institutionalised and well publicised in the media, takes the form of off-grid projects that are themselves part of international programmes (Bloomberg NEF and Lighting Global 2016). These projects, which we propose to

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[4] When electrification is accomplished using an off-grid system, it is primarily local power production that defines autonomy. It should be noted, however, that this technical definition of decentralisation ignores the organisation of the electricity sector, since a single centralised operator can run technically independent local systems.

[5] Depending on the number of users and the power available on the network, they are sometimes described as nano-grids, micro-grids or mini-grids. In this text, we will use the generic term mini-grid.

treat as electricity experiments (Hamman 2016), are primarily directed to rural locations outside the areas served by the grid. The other pathway, commercial and often informal, operates through import chains (particularly Chinese solar equipment),[6] through local sellers of new and used equipment, and through purchasing practices that depend on the economic opportunities and information available to customers. It develops wherever demand exists, and above all in cities, where the end segments of the "discreet" value chains of globalisation prosper (Choplin and Pliez 2018). In other words, off-grid electrification systems, earmarked for rural energy autonomy, are partially "diverted" to serve a variety of urban autonomy practices.[7] There are two main reasons for this. The first is that the divide between city and country has only limited operational relevance in the light of Africa's increasingly diffuse urbanisation. The second is that the distinction between on-grid and off-grid provides no satisfactory response to the sorry quality of the conventional urban electricity supply. Although conceived as a solution for rural pre-electrification,[8] off-grid projects are also a response to significant latent demand in urban areas, a fact that influences their electricity future.

This redirection of both location and use is an unexpected and insufficiently recognised outcome of experiments in electricity autonomy, as it uses are reinvented by urban populations. It is an invitation to explore the interfaces that then emerge between on-grid and off-grid solutions in cities and to examine the locus and nature of the frictions that arise from the technical combinations implemented in urban conditions. What respective roles do the grid and autonomous systems play in the emergence of entirely novel spatial and functional arrangements? Do these offer a foretaste of more lasting forms of electrical hybridisation? These questions open up a largely unexplored territory of research. Both institutions and experts stress the impossibility of making reliable projections in the absence of data and history. This means that everyone is currently operating in conditions of great uncertainty, between hopes of a takeoff in the market for off-grid solutions and fear of its collapse for lack of a sustainable economic model (Payen et al. 2016; PwC 2017a). In fact, despite the profusion of commitments, rhetoric and initiatives in favour of decentralised electrification solutions, the real scale of implementation remains limited and, above all, very poorly documented.

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

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

[8] Understood as a stage preliminary to electrification: "Unlike electrification, end-users are not connected to a grid or are not energy self-producers" (Tavernier and Rakotoniaina 2016 : 68).

In addition, the analysis of the literature on decentralised rural electrification solutions comes up against two obstacles: imperfectly defined, the term “rural” is used to describe very disparate spaces, including areas of diffuse urbanisation (villages, suburbs, roadside population corridors); the sources, many of which are found in the grey literature (project descriptions and documents, different organisational websites), anticipate – not to say exaggerate – the impact of operations that have not yet been implemented or are only in their infancy. It is therefore difficult to establish the real status of these projects, the degree of adoption, the forms of use, the level of satisfaction in their target populations… The “facts” on which any analysis can be based are fairly few in number and drawn from a small and frequently quoted set of examples. Moreover, these provide only tenuous indications regarding our hypotheses on hybrid interfaces, which are cited among the “problems” encountered by rural projects: unfair competition from urban sellers, markets flooded with imported products, distribution of unbranded and used equipment… all dynamics in which the urban drivers are usually ignored. The aim here is therefore to establish “what is known” about urban electrical hybridisation, based on the available sources and the landscape that emerges from them. The focus is on sub-Saharan Africa, excluding South Africa, whose electrical indicators and development are exceptional on the continent in every respect (Jaglin and Dubresson 2016).

Section 2 presents the background to off-grid projects – justified by the “crisis” of centralised systems in a continent-wide context of electricity shortage – and their expected contribution to the electrification of the continent. The next section shows that the future of the grid/off-grid pairing is not sealed: while rural business models have yet to be invented, decentralised solutions – spreading through long and short range commercial pathways – are already part of the day-to-day experience of city populations. The conclusion re-examines the distinctiveness of the African physiognomy of electricity autonomy and the prospects for hybridisation in urban areas connected to the grid.

2. From the “crisis” to electricity experiments

With more than 600 million people lacking access to electricity out of a population of a billion, sub-Saharan Africa is the world region with the worst indicators in this sector:[9] production and distribution capacities are very inadequate and average per capita electricity consumption is among the lowest in the world (UNEP 2017).

[9] In the absence of access to modern energy, traditional biomass (wood, either raw or converted to charcoal) remains the main energy source in sub-Saharan Africa (80% of consumption). Its use, combined in urban environments with candles and kerosene, causes problems such as air

There are numerous projects that seek to resolve this “crisis”. Some propose to reinforce and supplement national infrastructures by building new centralised production capacity fuelled by fossil and renewable resources, and by extending and modernising grid infrastructures to facilitate the integration of intermittent energy sources. These operations account for most of the investment planned over the coming decades and are presented as essential to the construction of the continent’s infrastructural skeleton (ICA 2017; Eberhard 2015). This vision of electricity development as a capital intensive process, reflecting the internal expertise of the big financial institutions, was for a long time the only game in town. However, it is now partially in competition with another vision, founded on an approach that emphasises decentralised or off-grid solutions, embeddedness in local communities 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 is a beneficiary of international initiatives that are prompting increased involvement by governments and private industrial actors, and is exploiting innovations and “disruptive technologies” that now claim to have the capacity to “unlock Africa’s energy future” (Africa Progress Panel 2017).

2.1. *Electricity shortages and riots*

The first reason for Sub-Saharan Africa’s electricity shortage is the inadequacy of its production and distribution capacities. Installed power in the countries of sub-Saharan Africa stood at 90 GW in 2014, and 40 GW without South Africa. Moreover, the deficit is exacerbated by the inadequate scale and the age of the distribution infrastructures, some of which even underwent contraction in the 1990s as a result of war or lack of maintenance (Eberhard et al. 2011; Eberhard 2015).

In 2015, the average rate of access to a power supply in cities was 60%, and electricity infrastructures served an average of 20% of localities. According to international standards, the quantity of electricity needed to meet the basic needs of a five-person household (lighting, ventilation, communication: mobile phone, radio and/or television) is around 250 kWh per year for a rural household and 500 kWh for an urban household (Desarnaud 2016). The available data put the average consumption of an African household (outside South Africa) at 181 kWh per year

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pollution in homes, which presents dangers that for a long time went unrecognised (Muindi and Mberu 2017).

[10] The question of access to electricity was only recently connected with issues of development and poverty reduction. It was therefore not among the Millennium Development Goals set in 2000 and it was not until the RIO+20 Conference in 2012 and the Sustainable Development Goals (2015-2030) that the international objective of universal access to electricity was clearly set out in Goal 7 (“Access to clean and affordable energy”).

(AfDB 2017) and indicate that, even in cities with an apparently adequate grid, the power supply is irregular, limited to a few hours a day, and subject to fluctuations, increasing the dependency on generators.

The continent's infrastructural lag and energy poverty need also to be situated within the context of rapid societal change. Two major forces of change have a major impact on electricity demand. First, sustained demographic growth (2.6% per year): whereas simply catching up will be a considerable challenge, the prospect of a tripling of the urban population by 2013 makes it an even tougher task.[11] Then, the ebb and flow of the world's middle classes (Desjeux 2011) is accompanied in the southern hemisphere by growing purchasing power and consumer spending, in particular on energy, together with increased expectations of governments. While uneven, this process is apparent in many African cities, which are regularly impacted by electricity shortages caused by persistent – not to say growing – mismatches between supply and demand. These shortages have big economic and political costs ("electricity riots") and providing an adequate and secure electricity supply, particularly in cities, is a priority for governments.

Senegal is an illustration of this process: the electricity crisis of 2011, linked with a fall in production itself caused by the catastrophic financial situation of the national power company Senelec, and against a background of sustained demographic growth (2.7% per year from 2000 to 2016), led to a wave of power outages lasting more than a year. Exasperated, people took to the streets and there were violent protest movements across the country and in the capital. The government's short-term political response was to focus on maintenance work to improve the use of existing capacity. In the medium-term, it is building new coal-fired power stations – in current conditions the only way to produce cheap electricity – and developing solar energy (LGE No 74-2017). Nigeria, though Africa's premier oil producer, is also looking for rapid solutions in circumstances where the domestic terminal at Lagos International airport was plunged into darkness in February 2016 and students at the University of Lagos blocked the access roads to their main campus in April to protest against an "epileptic [sic] electricity supply" (LGE No 62-2016: 4-5).

2.2. *Colossal investment needs*

To resolve this catastrophic deficit, the traditional approach has been based on massive investment in new centralised production capacity and in extending national power grids. The goal is to modernise electricity networks in order to achieve a high

[11] The average annual rate of urban population growth is 3.4% according to UN estimates, i.e. more than the pace of progress of conventional electrification.

and immediate level of consumption and service, relying on private investors to provide the financial and technical capital in the form of public-private partnerships (Eberhard et al. 2016). However, this tactic has so far encountered numerous obstacles.

According to many analyses, the main reason for the chronic undercapacity of the power infrastructures is the financial vulnerability of the operators: “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 firms are unable to borrow at affordable rates, most African governments cannot fund the projects, and public development aid has only partially been able to fill the gap, a situation that is unlikely to change. Two other sources of funding have emerged in recent years: independent private finance (67 projects in sub-Saharan Africa excluding South Africa since 1990), which is concentrated in a small number of countries;[12] and Chinese investment (30 projects between 1990 and 2014 in 16 countries, predominantly large-scale hydroelectric schemes)[13] (Eberhard 2015). It is worth noting here that these Chinese investors prefer to finance big energy infrastructures within the context of explicit policies for the expansion of centralised networks (OECD, IEA, 2016), reflecting in this respect the wishes of many governments. With more than ten new hydroelectric plants set to come on stream by 2020, extension to its low-voltage supply network and the construction of interconnecting networks with neighbouring countries, the Ethiopian Electric Power Corporation’s (EEPCo) strategic plan, adopted in 2010, is typical of these ambitions (Gascon 2015). For the moment, however, despite these powerful network dynamics, access to the finance needed to improve the national electricity sector is still insufficient in most countries.

The amounts of capital needed are colossal, difficult to estimate and even more difficult to secure in an unstable political and economic climate. A comparison between studies, some of which cover all the countries on the continent, others only those of sub-Saharan Africa, shows the difficulty of estimating the needs accurately (Trimble et al. 2016). In the fog of projection figures, the data that probably most closely match the objectives come from *Africa Energy Outlook 2040* for the implementation of the energy PIDA (Programme for Infrastructure Development in Africa): for the four power pools in sub-Saharan Africa, they set a figure of €45.6 billion a year between 2014 and 2040 for the investment needed to arrive at an average electrification rate of 65% (AfDB, African Union, NEPAD 2011).

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[12] Mainly Nigeria, Kenya, Uganda and, to a lesser degree, Ivory Coast and Ghana (Eberhard 2015).

[13] 77% of the projects.

Complicated as it is to assess the amounts of investment needed, breaking them down by project type is no less complicated. The headline figures usually relate to new projects, without considering the need for the renovation or replacement of existing infrastructures. Yet some of the physical fabric of Africa's electricity systems is obsolete: when service exists, it is very expensive (twice as costly as in Latin America, three times more than in Southeast Asia: Eberhard et al. 2011), often rationed and mediocre in quality. In theory, energy efficiency policies could offer an alternative solution by releasing capacity to connect non-electrified households, while improving service for those already connected. According to the example given by Desarnaud (2016), a 40 W solar panel can power a 25 W standard light bulb for five hours or, with more efficient devices, two LED lamps for five hours as well as a television, a fan, a mobile phone charger and a radio for three hours. However, the author also stresses that the technical conditions for such development are often not present in African countries, where the most efficient electronic devices and household appliances are frequently not available on the market or are too expensive for most households.

The goal of electrification with conventional systems therefore seems unrealistic in the short and medium term, and in fact is no longer included in the scenarios considered in the main international energy initiatives. While most experts talk about the need for the speedy launch of large-scale energy projects, increasing numbers are also looking at electrical development based on decentralised solutions, which are quicker to implement and less costly (Africa Progress Panel 2017; AfDB 2017; PwC 2017a).

As currently conceived, African electrical development could therefore follow a combined path: consolidation of national systems with an energy mix based on available resources and funding opportunities, alongside decentralised electrification solutions usually with a mix of diesel and renewables. The first component is seen as supporting economic growth, the second as fostering territorial development, officially in isolated areas or lightly populated rural zones. Here, they embody a vision of gradual electrification, in which the first few kWh, accessible with a minimum level of service, are considered to be decisive in terms of socio-economic development.

Nowhere in the documents do we find any reference to the possibility of redefining the model or to the possibility of a change. Instead there is the implicit commitment to an advantageous combination of these two avenues of electrification, with a sharing of the territories and social functions of electricity.

2.3. *Renewables and decentralised systems: a third way for sub-Saharan Africa?*

The conditions are favourable for the large-scale development of renewable energy in Africa. The continent possesses abundant resources and the potential for installed production capacity is estimated at 10 TW for solar, 350 GW for hydroelectric, 110 GW for wind, and 15 GW for geothermal (UNEP 2017). Although comparisons are difficult and controversial, studies suggest that renewables would quickly become competitive. A 2011 European Union report calculates, for example, that decentralised solutions based on renewables (solar and hydroelectric), occasionally in combination with extensions to existing grids or with generators, could electrify the entire continent at a cost per kilowatt-hour of less than €0.30 (Monforti 2011).

In fact, with technological advances and the fall in the prices of certain materials, in particular solar (80% drop in the cost of photovoltaic modules since 2009), the deployment of renewables-based decentralised electricity production is now a competitive option (IRENA 2016). Moreover, off-grid technologies can spread quickly: for example, sales of pico-solar devices in Africa rose from 500,000 in 2011 to 11.3 million in 2015 (Africa Progress Panel 2017). They have the advantage of achieving resource diversification in a way that is flexible, evolving and scalable: individual system, isolated or interconnected mini-grid, national grid. Moreover, solar technologies are modular, which means that several units can be combined to form a system consonant with the needs and financial capacity of the consumer-producer: the PV panel can supply power to both connected and autonomous decentralised systems; in autonomous systems, it can be used on its own "while the sun shines", be linked to a storage system and/or incorporated into a hybrid system, usually with a generator (Pillot 2014).

For many analysts, therefore, Africa's energy future lies in a threefold transformation: low-cost production using fossil fuels to respond quickly to the needs of urban consumers; development of renewable energy in centralised facilities connected to the grid (geothermal energy, large-scale wind and solar farms, hydroelectricity) and using cutting-edge techno-economic engineering; rapid implementation of low-capacity decentralised and rustic solutions, partly fuelled by renewables, and adjustable both to household purchasing power and to the limited capacities of local public and private actors. However, this pretty schema says little about the processes and outcomes of "bottom-up" transitions, about the forms of autonomy that are in fact practised by citydwellers, and about local energy mixes.

3. Electrical hybridisations: between pragmatic autonomy and new dependencies

There is something of a contrast between the coherence of these forward-looking scenarios and the reality on the ground. First, project implementation is slow and many projects never get beyond the drawing board (Buchsenschutz 2016). Second, the heterogeneity of the technologies and energy resources (renewable and fossil), the geographies of their dissemination, the proliferation of decentralised solutions, including those linked to a grid, reveal a disorder that is a long way from the rationales and intentions. What are the reasons for this "dissipation"? Approaching the question from the perspective of electrical experimentation casts light on the processes at work.

Referring "both to the development of temporary projects and to their small-scale implementation" (Hamman 2016: 2), the notion of experimentation here is inspired by work in the social anthropology of development (Lavigne Delville 2011; Olivier de Sardan 1995) and applied to the examination of off-grid electrification projects both as systems of action and as territories-laboratories for the testing of sociotechnical solutions. Applied to countries "under an aid regime", it prompts us to examine the forms of intermediation between the world of the project and local space, the interplay of project reappropriations and reinterpretations, and the forms of connection – or disconnection – between the project and public policies (Baron and Lavigne Delville 2015). Ultimately, electricity experimentation should help us to identify the conditions needed to achieve three linked objectives: testing technological solutions in different environments; identifying promising markets and the conditions needed to develop commercial solutions for end-users and territories; pursuing electrification. The aim, therefore, is both to foster localised learning processes and to gain a better understanding of the value chain of decentralised electricity solutions, which depends on links that are disparate and dispersed (equipment suppliers, service operators, mobile phone companies, app developers, etc.).

Conceived and understood as "open-air" laboratory tests, electrical experimentation is embedded in specific spaces but, as with any development project, can experience overspill (Jacob and Lavigne Delville 2016),[14] and undergo forms of adoption that entail disconnection, selection and "redirection" (Olivier de Sardan 1995). Their effects, whether promising or undesirable, can drive dynamics of

[14] In reference to the works of Callon on the sociology of translation, Jacob and Lavigne Delville define overspill as a process that questions the problematisation (the way of stating the problem to be tackled and responding to it) of a development project, which challenges the solidity of the network of actors involved (Jacob and Lavigne Delville 2016).

experiment that are more subversive, informal or undisciplined, shaping forms of electricity autonomy outside the perimeter of the project, for example in urban areas.

In this second section, we examine these deviations by shifting the focus and looking for the "displaced" effects of experimentation. The aim is to explore the social dynamics whereby the design of projects can be subverted to the point that solutions designed to foster rural electricity autonomy lead to hybrid urban power solutions.

3.1. *Rural experiments…*

In rural areas, individual solutions – from lamps to SHS (solar home systems) – are an undisputed success. First trialled in pilot projects in East Africa, they are at the centre of market-building strategies in 11 African countries, principally Ethiopia, Kenya and Tanzania, followed by Nigeria, Uganda, Democratic Republic of Congo and Rwanda, where they are distributed by numerous companies, from start-ups to the sector's big players (Engie, EDF,[15] Schneider Electric, Total, Philips, Orange…), notably within the framework of the World Bank Group's Lighting Africa programme, which has supplied some 11 million households (Bloomberg NEF and Lighting Global 2016). The projects are based on fairly similar combinations of components. First, a technical component (for example, the Azuri Technologies Indigo Duo SHS distributed in Rwanda since 2013 with the support of USAID, consists of a unit connected to a 2.5 W solar panel, fitted with a lithium iron phosphate battery, two LED light points and adapters that can be used to charge a mobile phone). Next, a local marketing network dependent on "last mile" distributors, who are crucial to the entire value chain and must be trained and then supported in their activity. Finally, funding mechanisms, which are diverse and can be based on microcredit, as provided by the World Energy Foundation in Burkina Faso, or on PAYG (pay-as-you-go),[16] facilitated by the use of "mobile money" platforms such as the Light Lwengo

[15] At the end of 2016, in partnership with the US firm Off-Grid Electric, EDF set up the company ZECI to supply off-grid solar energy in Ivory Coast. In 2018, EDF, Off-Grid Electric and a Ghanaian company launched the company ZEGHA and a range of off-grid solar kits in Ghana. At the end of 2017, Engie took over Fenix International, a firm specialising in domestic solar installations in rural and periurban areas in Uganda and Zambia, and announced its intention of reaching a market of 20 million people (*Le Monde de l'énergie* [online], 5 March 2018, URL : http://www.lemondedelenergie.com/edf-afrique/2018/03/05/).

[16] A hire purchase system in which, after a modest initial payment to acquire a solar kit, the purchaser is able to use it and ultimately become its owner through regular small payments. The kit has a locking mechanism in the event of payment default. The market leaders in sub-Saharan Africa include: M-KOPA (Kenya, Tanzania, Uganda), Azuri (Rwanda), Off-grid

system in Uganda, the Mahazava start-up in Madagascar, or the Bright Light project in Benin. The latter, which was in its trial phase in 2016, is based on a partnership between a national importer and supplier of solar lights (ARESS) and a mobile phone operator (MTN Bénin), which uses its employees to distribute the equipment and its network to run the Easy Buy payment app.[17]

Behind this first front, informal circuits for the sale and repair of devices are proliferating on local markets and driving the penetration of these devices, which meet household needs for lighting, phone recharging, or indeed for radios and televisions, as shown, for example, by a study in Burkina Faso (Bensch et al. 2016) and observations in Basse Casamance in Senegal (Francius et al. 2017). According to a study conducted in seven African countries, the unbranded equipment sold in these informal networks plays a decisive role in the "silent lighting transition" from the most common methods (kerosene and candles) to LED lanterns powered by dry batteries, now sold on virtually every market stall (Bensch et al. 2015). Although aimed in principle at rural customers, these networks are concentrated in the cities, which is where the supply chains originate (Bloomberg NEF and Lighting Global 2016).

In villages and small towns, in particular those located along main road arteries, collective solutions – kiosks and stand-alone mini-grids – are in principle more appropriate. The kiosks supply services such as recharging, printing, Internet access, refrigeration, television/films… often alongside a range of basic products. They currently exist in several African countries,[18] but their development is limited by the fragility of their business model, as has been shown by studies in Togo (Galichon and Payen 2017) and in Madagascar (Tavernier and Rakotoniaina 2016). In the latter country, HERi Madagascar, a social enterprise set up in 2011, is developing a model based on the granting of kiosk franchises to female entrepreneurs (44 in January 2016). Each kiosk is powered by 6 photovoltaic panels (total capacity around 1 kW) and equipped with two batteries, a charge controller and a 450 W inverter for connecting AC devices. While it would seem that a kiosk can become financially

Electric (Tanzania, Rwanda), Mobisol (Tanzania), Nova Lumos (Nigeria) (Bloomberg NEF and Lighting Global 2016).

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

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

viable after two years, HERi Madagascar's initial investment and operation depend, for the moment, on external funding (*idem*).

Halfway between individual options and connection to the national grid, the mini-grid that produces and distributes electricity locally to end-users is a possible solution in more densely populated centres: apart from domestic household needs, such mini-grids are designed to meet the operating needs of community facilities and small businesses. In the cotton regions in southern Mali, the NGO GERES promotes an "Electrified Activities Zone" model, where a hybrid solar/agrofuel plant supplies electricity to a group of very small interconnected enterprises (hairdresser, bakery, welder, etc.), [19] sometimes supplementing a mini-grid that supplies power to households (Béguerie and Pallière 2016). The oldest mini-grid models,[20] for example in Mauritania (Munnich 2016), rely on diesel-fuelled generators; the most recent types – for example in northern Burkina Faso (Fondem 2016) – use solar energy or a mix of solar and diesel to avoid intermittency problems (now also the most common option in Mali). They can be distributed and run by the big historical operators, but private management exercised by licensed operators or contracted out to concession holders (companies or cooperatives) is now the preferred model. In Kenya, for example, the mini-grids fed by diesel-fuelled generators belonging to the national utility KPLC are gradually being replaced by hybrid systems and – since the creation of permits (<3MW) and licences (>3MW) following the legal and regulatory review of 2016 – being allocated to private distributors (in which case the electricity is bought wholesale from KPLC) or to independent producers/distributors. The model developed in Mali and Senegal is the Decentralised Services Company (SSD), an entity which is awarded an electrification licence for an extendable period of 15 to 25 years (Heuraux and Houssou 2015). The Malian Agency for Domestic Energy Development and Rural Electrification (AMADER) thus awarded the Yeelen Kura SSD, set up in 2001, an operating licence in 23 localities in the cotton region for a renewable period of 15 years. Access, another Malian SSD, operates 12 mini-grids supplying domestic electricity and public lighting, mainly in rural areas, but is also developing an urban project to supplement the national grid with solar installations (GSMA 2017). There are also mini-grids fed by hydroelectric micro-plants in Zimbabwe, Malawi and Zambia, and many observers agree that mini-grids represent "a considerable market". At present, however, their deployment continues to be hampered by the absence of a clear regulatory framework, by insufficient operating

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

[20] For the history of this model, see: GVEP 2011.

revenues, a general lack of capacity, and above all by lack of investment in a sector perceived as high-risk (Payen et al. 2016).

3.2. … and urban hybridisations

With very few exceptions, none of the three decentralised solutions is officially designed for cities, but this is nevertheless where their future partly lies. First, it needs to be stressed that political and administrative organisation in many countries means that villages and small towns are conventionally classified as rural, and are therefore primary targets of these decentralised electrification projects. Then, in the (biggest) cities themselves, demographic growth and urban sprawl, the steady rise in electricity demand, especially among the middle and wealthy classes, the undercapacity and unreliability of the existing systems and, more generally, the mediocre quality of service, also demand innovative solutions. Finally, citydwellers constitute an attractive "market" for technical products and kits that the projects are hard put to distribute in rural environments, more because of poverty than because of the vagaries of implementation (Allet 2016).[21] This is evidenced by the emergence of local markets for unbranded solar products, perceived by the institutional players as unfair and inefficient competition for firms in the sector (PwC 2017a),[22] but which for many rural households are also "sensible investments" (Grimm and Peters 2016). In Burkina Faso, for example: "We find that the adoption rate of non-branded SHS [Solar Home System] is considerably higher at 36 percent compared to eight percent for branded SHS. […] We show that non-branded SHSs provide a similar service level as branded solar, 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 photovoltaic panels and solar kits in urban stores and markets shows that individual solutions are also infiltrating the cities, where the product ranges seem more extensive (from the low-cost-tech non-branded equipment sold by informal traders to the branded products distributed by approved suppliers) and more

[21] In Rwanda, Indigo Duo customers belong to the wealthiest segment of rural households, whereas in Uganda, the most dynamic market is for the most comprehensive systems sold without subsidy (see the special issue on "Decentralized electrification and development: initial assessment of recent projects", *Field Actions Science Reports*, second semester 2016. URL: https://factsreports.revues.org/4116). More generally, the research conducted by Grimm and Peters in several African countries shows that the poorest households are not able to make the initial investment needed without subsidy (Grimm and Peters 2016).

[22] "The market for cheap, generic 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).

varied in their combinations (generators, solar equipment, batteries). Accompanying the "lighting transition" (Bensch et al. 2015) and mobile phone charging requirements in the rural world, the use of decentralised solutions in cities is a response to the growth and diversification of demand, but also a reaction by urbanites to the deficiencies of the grids (Bloomberg NEF and Lighting Global 2016). The strategies of use are multiple: savings on electricity bills (solar water heaters, photovoltaic panels), security of supply to offset an unreliable and low-quality service (generator, batteries, Nigerian inverter),[23] electricity production in the absence of a centralised supply (stand-alone photovoltaic panels). This challenges the very idea that decentralised solutions are restricted to the pre-electrification of isolated rural populations, as confirmed by the experience of the sellers of solar devices: there is strong demand – for equipment that on average is more powerful and more costly – from urban households that are connected to the grid but experience intermittent service (Bloomberg NEF and Lighting Global 2016). In these urban environments, autonomous systems are above all a stopgap measure to compensate for the deficiencies of the grid and a quick way to meet rising needs.

In the light of these urban practices, off-grid systems necessarily have to operate in 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 electricity services: an accumulation of systems and practices in response to uncertainty and a long-term hybridisation of electrification configurations (Jaglin 2017). However, these configurations are poorly understood, both in the assessments of rural experiments (Galichon and Payen 2017; Payen et al. 2016; Pillot 2014) and in urban studies, which focus on modes of "palliative relief" (Mpiana Tshitenge 2015) and on "incremental infrastructures" (Silver 2014). With one or two exceptions (Andreasen and Møller-Jensen 2016; Tenenbaum et al. 2015; Smits 2012), few connections are made between the recognition of decentralised solutions and the future of the conventional grid, despite the fact that the compartmentalised geography of modes of access to electricity does not stand up to empirical scrutiny, which instead reveals that the sociotechnical worlds of electricity production, distribution and consumption are closely interwoven.

[23] This is a variable power module consisting of one or more batteries and an inverter, generally connected to the grid and possibly to photovoltaic panels to provide a more stable and secure electricity supply.

3.3. *Off-grid stresses*

The democratisation of off-grid systems and the consolidation of infrastructures need to be examined together, since the future of electricity autonomy lies not so much outside the grid than in interaction with it in reordered configurations of inertia and dependency.

In most African countries today, the dynamics of technological innovation and usage thus centre around solar kits, photovoltaic panels and batteries. The components are usually imported, the software is developed by NGOs or start-ups with external support, the project structures are funded by international aid. Serious research and development efforts are still required to transition to the next stage: electrotechnical R&D is needed to improve the reliability of mini-grids and individual devices, but business models also need to be developed in countries where technical, socio-economic and political factors are unstable, especially at local scale. It may be hoped that capital and expertise will come, but this needs to happen fast: Africa's urban populations aspire, *now*, to more continuous use of electricity for purposes that correspond to their vision of a modern urban life. They are therefore turning to a tried and tested solution, the generator, which is a fast-growing market. Rightly criticised for their environmental impact (air and sound pollution) and their operating costs (the diesel they run on is often imported), generators also have unrivalled advantages: varying widely in size and power, store bought or cobbled together from old engines, they are flexible and offer a solution both to occasional power outages and to a structurally inadequate electricity supply. In every city today, they are an indispensable auxiliary to the power supply: their market in Africa is growing at a rate of more than 10% a year (Douet and Coulibaly 2015) and their number in Nigeria is estimated at 60 million (LGE No 62 2016). However, little is known about the global situation. On one side, signs of market maturation are apparent, with improved equipment (generators that are quieter and more fuel-efficient, or even "clean", with gas recovery or perhaps combined with photovoltaic panels in hybrid solutions) and, on the other side, there are factors of uncertainty relating in particular to diesel supply and equipment maintenance.[24] However, the capacity of national politicians to offer credible solutions to electricity demand, whether on-grid or off-grid, remains the main variable in this market and, according to Aggreko, the world leader in temporary supply solutions with more than 2000 MW under management in 34 countries on the continent, "generators in containers", of all sizes, have a rosy future …

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[24] The cost of which notably depends on national policies regarding subsidies for petroleum products, which are now a matter of controversy, while fuel distribution remains problematic because of the lack of road infrastructures.

Apart from the lack of capital, a range of factors govern the success – or failure – of decentralised solutions and have received insufficient scholarly attention.

First of all, creating a conducive environment requires appropriate national measures. This is widely acknowledged, but concrete measures have scarcely been initiated in many countries, where there is a lack of political will to change the political, regulatory and pricing frameworks (Africa Progress Panel 2017). Political intervention is also needed to organise the markets. Structural reforms have been undertaken to partially deregulate the vertical monopoly of national utilities in some countries (Ghana, Nigeria, Uganda, Kenya) but, focusing on the conventional grid, sectoral regulation, both technical (Tenenbaum et al. 2016) and commercial (Beaurain and Amoussou 2016), is moving slowly. At the same time, the emergence of these new markets has sharpened appetites: "Numerous importers, installers and resellers have entered the market but, in the absence of rules and checks, counterfeit material is available alongside very good equipment and there are more unscrupulous operators than highly trained installers. For local populations, generally illiterate and poorly informed, buying equipment is like tossing a coin."[25] For Beaurain and Amoussou (2016), there is a need for development in the sector to be managed in order to protect new businesses and companies supplying certified equipment from the "unfair" practices of informal competitors (counterfeit products, unlicensed services, etc.). This is also needed to generate customer trust by selling equipment that is appropriately priced and effective, suited to the climatic and environmental conditions (heat, dust, humidity), robust and reparable by local mechanics. However, the role of labelled brand equipment in this process remains a matter of debate (Bensch et al. 2016; Grimm and Peters 2016).

Secondly, the technical and economic difficulties should not be underestimated. Studying the potential of photovoltaic power in Djibouti, for example, Pillot notes that the most used and best-known systems in the world today are decentralised systems connected to the grid in a context of universal electrification; however, these configurations tell us little about autonomous photovoltaic systems in sub-Saharan Africa (Pillot 2014). The fact that individual autonomous systems are already widespread is only part of the answer to the problem, because according to the author their effectiveness is entirely relative, which suggests the need to concentrate experimental efforts on storage solutions connected to intermittent sources in the real-world operating conditions of autonomous systems.

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

It is also often suggested that the spread of decentralised electricity solutions is linked, in sub-Saharan Africa, with the spread of the mobile ecosystem, a process whose leverage effects the GSMA is keen to promote.[26] Mobile phone operators need electricity for their masts, which are often isolated, and can in return provide a reliable source of revenue while helping with the collection of electricity bills through mobile applications. More generally, electronics and mobile services transform the management of sales (smart meters, prepayment, mobile money) and can drive significant increases in customer numbers by adapting electricity 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, one study suggests that the use of mobile money and GSM M2M technology will enhance the viability and quality of mini-grids and domestic solar installations managed by SSD in the southern areas (GSMA 2017).[27]

Nonetheless, these promising solutions have yet to be tested and evaluated. Without testing and evaluation, the lack of technical adaptation to local conditions leads to the premature failure of decentralised solutions[28] and the understanding of the conditions of success of the different models remains far too partial (Galichon and Payen 2017; Payen et al. 2016). It also leads to a mismatch between the service offered and the consumption needs of households (improper use of the kits, with the connection of too many devices, has been seen in certain projects)[29] or tradespeople (whose machines require more power and reliability). The GERES "Electrified Activities Zone" is thus a response to the limitations observed with the mini-grids operated by the Yeelen Kura SSD which, by providing power only from 4 p.m. to midnight, severely limits the daytime activities of the small businesses it supplies, although this latent demand represents unexploited 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, whereas West African SSDs favour the sale of electricity services, arguing that this is more likely to guarantee sufficient long-term usage (GSMA 2017). A rigorous comparison is needed of the respective effects of the systems on household inclusion and the durability of their access to

[26] An international organisation of operators, manufacturers and industries in the mobile phone sector. See the "Mobile for Development Utilities" programme website. URL: www.gsma.com/mobilefordevelopment/m4dutilities

[27] M2M: machine-to-machine, i.e. communication between devices.

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

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

[30] For a description of the project, go to the GERES website. URL: http://www.geres.eu/images/fiches/fiche-projet-mali-pep-fr-v2.pdf

electricity, in order to inform electrification choices and assess the pros and cons of variable-geometry autonomy.

Finally, a third set of factors, politico-institutional in nature, merits attention. In this sphere, obstacles come not only “from above”, from the lack of political will of governments or the resistance of national utilities. The deployment of decentralised solutions also runs up, “at the bottom”, against obstacles relating to the weakness of local initiatives, to the lack of capacity of public actors, to the resistance of interest groups (e.g. generator and fuel importers in Nigeria). As is the case elsewhere (Nadaï et al. 2015; Christen and Hamman 2015), mobilising territorial resources is crucial to the genesis and success of local energy transition projects in Africa (Beaurain and Amoussou 2016). However, the transactional nature (Hamman 2016) of the processes of achieving autonomy and the representations that inspire off-grid solutions receive little scholarly attention. On the one hand, the projects assume that by making electricity autonomy possible, renewables and decentralised solutions give people what they want, whereas many households dream instead of connection to the grid. Of course, as well as arousing hopes for rapid electrification, local sources of renewable energy elicit a “new” question of autonomy, of its conditions and its desirability, but little is known about how this influences the geographically and socially situated representations of off-grid and on-grid systems. On the other hand, electrification projects tend to “fix” the demand in local communities, whose social, political and economic dynamics cannot be reduced to a stable and objective ensemble. Despite appearances, autonomous electricity does not arrive in virgin territory and takes its place among existing offerings and earlier practices, in particular in urban areas. Whether total or partial, the substitution entails a rearrangement or even a displacement of social norms, it disrupts power relations and can generate tensions and resistances. A project does not fit spontaneously into a generic world. On the contrary, the factors involved in the construction of that world, rooted in different interests, capacities, visions and timescales, contribute to its success or failure (Jacob and Lavigne Delville 2016).

In other words, the territorialisation of electricity autonomy resists the standardisation of electrical experiment: “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). In cases where collectives are insufficiently structured, too conflictual or too heterogeneous, an autonomous mini-grid has few chances of functioning in the long-term; where the starting conditions seem more favourable, the permanence of a mini-grid often depends on the way it was designed, scaled and organised to facilitate learning and maintain profitability (Payen et al. 2016). Everywhere, the development of

decentralised electrification solutions depends on how they are adopted and their effects on emerging social relations, for example around new electrical services (shared refrigeration spaces, community television-video, store-based phone charging…).

4. Conclusion

Despite the territorial compartmentalisation of electrification policies, with their distinction between the grid-connected cities and the off-grid countryside, processes of hybridisation are taking place. One needs only to stroll through sub-Saharan African cities to observe that social practices, spanning the urban and rural worlds, are contributing to the technical and geographical overspill of electricity experiments and helping to bring decentralised solutions into the territories of the grid. In these circumstances, the autonomy promised by electricity experiments seems both fragile in its foundations and poorly understood in its implications.

First, with the exclusion of cities from the project as both places and actors, our thinking about the future transformation is deprived of particularly dynamic observatories and promising laboratories. It is also deprived of a political barometer, given that the deficiencies of the big power networks feed social frustration in cities that have become urban cauldrons (Jaglin and Verdeil 2017).

Next, without them our thinking is poorly equipped to anticipate how decentralised electricity solutions contribute to a profound reshaping of the nature of the service provided, a long way from the monopolistic public electricity systems that have so far dominated, but also very different from the autonomy envisaged for the rural world. Indeed, it seems crucial to compare the anticipated results of electricity experiments with their actual outcomes and, through field research, to explore their transformative effects on power systems and how they redefine the respective roles of the grid and the off-grid.

Finally, tackling autonomous solutions from the perspective of pre-electrification alone, rather than in configurations of joint operation with the grid, reduces our capacity to reimagine what the electric city of tomorrow might be. In "Africa 3.0, the other technological eldorado", PwC gives its vision of a radical transformation of the African continent by solar power and digital technology (PwC 2017b). What kind of autonomy might arise out of this revolution? An autonomy of isolated territories with contracting/stagnant/regressive?? trajectories or one of societies with increased "capacities", combining the resources of growing electricity autonomy, ever greater connectivity and managed dependency on the grid(s)? Where, if not in cities, is this second scenario more probable? In other contexts, Daniélou and Ménard argue that

"giving a neighbourhood temporary energy autonomy by means of a dense fabric of photovoltaic panels, as is the case in certain projects, becomes a condition for the survival of the power grid" (2014: 4). The idea is not irrelevant to sub-Saharan Africa. Flexible, less costly and risky than national electrification policies founded on big networked infrastructures, autonomous electrification systems provide (partial) answers to the need for economic and human development on a continent where demographic growth poses considerable challenges to spatial planning. They also provide (partial) answers to the need for an overhaul of practices in conditions of financial penury and of a mismatch between a predefined supply, designed and planned "from the top", and the heterogeneity of urban demand. Paradoxically, therefore, rural electricity experiments are inspiring new solutions for cities, where grid capacity is insufficient, but by democratising autonomous systems, they are also encouraging a hidden urban hybridisation of centralised power systems. Recognising the role of these crypto-hybridisations as an integral part of durable solutions, by rethinking the relations between networks and autonomy in urban environments, would open up new possibilities.

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