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Smart and disruptive infrastructures: Re-building knowledge on the informal city

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Abstract
Smart urbanism is an established research area in geography and the social sciences. We draw on 'worlding-provincialising' strategies identified in an Urban Studies *Special Issue* from February 2021 to explore how smart infrastructures, a form of smart urbanism, disrupt representations of informality and urban development in new and productive ways. Focussing on the disruptive or troublesome implications of smart infrastructures reveals site-level considerations for developing policy and practice, where acknowledging the nuanced context for its use can present opportunities for not only understanding energy transitions in the Global South, but also creates opportunities for cross-learning. Drawing on our collective insights on a solar mini-grid project in Qandu-Qandu, Cape Town, we sketch out three ways the disruptive aspects of solar energy can be helpful for re-building knowledge on the informal city by: (i) re-positioning notions of 'formal' and 'informal' infrastructure(s) in urban planning and policymaking; (ii) highlighting new avenues for citizen autonomy; and (iii) recasting the informal city as a site for continuous innovation and learning.

Keywords
energy, informality, off-grid, smart infrastructure, urban studies

摘要
智慧城市化是地理学和社会科学的一个既定研究领域。我们借鉴2021年2月《城市研究特刊》（Urban Studies Special Issue）中介绍的 "全球化-当地化 "战略，探讨智慧基础设施作为智慧城市化的一种形式，如何以富有成效的新方式颠覆了对非正规性和城市发展的表述。通过重点关注智慧基础设施的颠覆性或棘手的影响，我们揭示了制定政策和实践的现场考虑因素，同时承认其使用的细微背景不仅可以为理解发展中国家的能源转型提供机会，还可以创造相互学习的机会。根据对开普敦Qandu-Qandu太阳能微电网项目的集体洞察，我们概述了太阳能的颠覆性方面可以通过以下三种方式帮助重新建立关于非正规城市的认识：(i) 重新定位城市规划和政策制定中的 "正规 "和 "非正规 "基础设施的概念；(ii) 强调公民自治的新途径；(iii) 将非正规城市重塑为一个持续创新和学习的场所。

关键词
能源、非正规性、离网、智慧基础设施、城市研究

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'Worlding–provincialising–worlding' smart infrastructure in the informal city

'Worlding–provincialising' processes

In a recent Special Issue on Smart Urbanism, the diversity of smart technologies and their embedded power geometries were identified as much-needed avenues for future research in urban studies (Burns et al., 2021). Towards exploring the diversity of smart urbanism, Burns et al. (2021: 461) make the call to consider the 'worlding–provincialising' strategies used by actors, which supports an understanding of how smart urbanism is followed in dynamic and unpredicted ways. While the special issue calls for

the need to provincialise our understanding using case studies, we argue the provincialising–worlding strategies provide a much more insightful interplay for re-building knowledge on infrastructure in the informal city. This is because, in addition to translating global ideas on smart infrastructures on the ground, we demonstrate how it can enable provincialising–worlding outcomes for better understanding the use of smart infrastructures in a wide range of urban settings.

Worlding strategies are global discourses or approaches that encourage the development of society, the environment, and the economy. Strategies include global circulations of culture, capital, and innovation to support technological innovation and sustainability, often resulting in continuous processes of disruption and rebuilding with each 'passing wave' of technology and innovation (Barns, 2018: 11). Worlding processes are often shaped by large technological corporations and governments concerning 'economic development interests', where actors can 'poise themselves' on the global stage (Burns et al., 2021: 462). In some cases, this can include assemblages of corporate and state actors in promoting, circulating, and materialising specific urban strategies and projects in multiple locations (Datta and Odendaal, 2019; Rapoport, 2015; Söderström, 2021). Worlding strategies, therefore, define the use of global ideas at the local level, including specific approaches to urban infrastructures such as renewable energy, which we focus on in this commentary.

Provincialising is the process through which one or more actors engage with, or implement, worlding strategies. One or more actors draw in worlding strategies in ways that are meaningful to them, where they find relevance and value in ideas and/or technologies. Through provincialising strategies, actors valorise urban diversity and decentre dominant Euro-American urban theories often attached to worlding strategies, where global discourses encourage the development of society, the environment, and the economy (Burns et al., 2021: 462). Therefore, provincialising offers an entry point to consider new and/or emergent meanings of infrastructures and the urban. We use this entry point to consider the use of solar energy technologies in Qandu-Qandu, Cape Town, contributing towards an embedded understanding of the splintered ways in which infrastructure develops, adding nuance to the 'infrastructural turn' in the social sciences (Graham and Marvin, 2022), including the way that space can be controlled through infrastructures or technologies (Easterling, 2014). Towards understanding the individual connections that comprise the highly dynamic aspects of urbanism and the use of off-the-grid technologies as outlined by Burns et al. (2021), we argue for the need to take the worlding–provincialising strategy one step further to consider the 'worlding–provincialising–worlding' aspects and what this means for the urban. While a focus on 'worlding–provincialising' strategies enables a closer engagement with how ideas translate in context-specific ways, as indicated by Burns et al. (2021), we assert the value of reflecting on its dynamic and disruptive aspects underpinned by Roy (2011) which can challenge dominant discourses around urban infrastructures in the Global North that tend to frame smart infrastructures as something only good and beneficial. Expanding on the worlding–provincialising interplay, therefore, enables a more focused exploration of how smart and disruptive aspects offer avenues for re-building knowledge on infrastructures in the informal city. It also provides a focused starting point for considering how nuances manifest, splinter, and influence the use of other technologies (see Caprotti et al., 2022).

We draw on our collective experience of using solar mini-grids as smart

infrastructures in Qandu-Qandu, South Africa, to speak to global discourses through its influence on government priorities and funding streams (Rossi, 2016). Through our work, we outline one account of the use of solar energy, a form of smart infrastructure, in an off-grid setting. Drawing on informality and smart scholarship, we consider how the use of solar energy: (i) challenges our notions of 'formal' and 'informal' infrastructure(s) in policy and planning, (ii) highlights avenues for citizen autonomy and engagements with the state, and (iii) frames the informal city as a site for continuous innovation and learning alongside other more 'formal' locations. Our findings offer fresh insights for re-building understandings of urban infrastructures in cities of the Global South, highlighting its contradictions and amenity to policymaking and practice.

Smart infrastructures in the informal city

Smart urbanism is now largely understood to signify the use of capital-intensive and advanced technologies and digital processes with which cities can be governed and regulated in near-real-time (Kitchin, 2014). Smart technologies and processes include anything from sensor networks to Big Data analytics, Artificial Intelligence (AI), and the integration of the Internet of Things (IoT) into the urban matrix, including infrastructural solutions. Infrastructural solutions can range from high-profile projects incorporating smart urban technologies, such as new-build sites like Songdo smart city, South Korea (Kuecker and Hartley, 2020), to redevelopment projects in Camden, New Jersey (Wiig, 2018), to national strategic priorities such as the Smart Dubai initiative (Breslow, 2021), or Singapore's Smart Nation strategy (Ho, 2017). It is also constituted by a range of smaller infrastructural projects, including ad hoc interventions to respond to specific local needs, including iShack, Stellenbosch (Kovacic et al., 2021), Open Data Roadmap, Mozambique (Clemente and Gill Barroca, 2017), or Bájale al Acoso,[1] Ecuador (Usi, 2018).

Specific projects constitute a key moment for exploring the use of smart infrastructures as an embedded and bounded phenomenon (used in time and space). Existing studies such as those by Watson (2015) and Odendaal (2021) implicitly draw on worlding–provincialising strategies to outline the use of smart infrastructures in African cities, where the 'allure' of power and development has driven the use of such smart infrastructures. Current studies in the Global South showcase smart urbanism: projects in South Africa focus on the emancipatory potential of smart urbanism (Odendaal, 2021), smart urban experiments have been investigated in the Philippines (Mouton, 2021), and smart urban narratives have been analysed in the Chilean context (Jirón et al., 2021). However, this work often has a limited focus on informality, which is already an established area in Southern Urbanism scholarship. Indeed, studies of urban informality have focused on the multiple ways in which it exists within, and at the peripheries of, established markets and legal structures (Bouwmeester and Hartmann, 2021; Nogueira, 2019), policy and planning frameworks (Roy, 2005; Watson, 2009), and state and municipal service delivery capabilities. Research has also engaged with the multiple vulnerabilities existing in informal urban contexts, including those that have emerged as a result of climate change (Satterthwait et al., 2020) and the Covid-19 pandemic (Auberbach and Thachil, 2021). Additionally, the concept of informality itself has been unpacked and critiqued, for example in work that seeks to distinguish between informality and practices of temporary appropriation of the built environment (Lara-Hernandez et al., 2020). Furthermore, the scales at and within which

urban informality exists have been problematised in relation to infrastructures: for example, in work that explores how peri-urbanity in sub-Saharan Africa includes not just the continuum between formal and informal, but between rural and urban, agricultural and small-scale industrial, in other words, a fragmented and dynamic landscape of processes and flows (Cantoni et al., 2022). In this paper, we consider urban informality not only in relation to formal structures (of policy, planning, markets and other frameworks), but as spaces and places characterised by dynamic flows of materials, processes and practices of the everyday (Devlin, 2018). Infrastructure can be seen as a bridge between the structural and everyday fluidity, as the networks of materials, technical know-how, needs and presence/absence (of services, delivery, access, and more) intersect in the infrastructural landscapes present in informality. Therefore, this paper broadens the understanding and use of smart infrastructures by proposing the worlding–provincialising–worlding interplay to explore the use of smart urbanism in informal settings and its role in shaping smart infrastructures.

Smart and disruptive infrastructures

Infrastructures and disrupting energy flows

The recent 'infrastructural turn' in social sciences conceptualises urban infrastructures as socio-material artefacts. Called heterogeneous configurations, socio-material artefacts can constitute a diverse range of socio-technical forms (Lawhon et al., 2018). Focussing on how 'overlapping systems' of heterogeneous infrastructures come to exist in specific geographic areas enables a closer analysis of their diversity and the sometimes 'disruptive' ways they come to exist (Truelove and Cornea, 2021: 231). Conceptualising infrastructure in this way marks a shift away from its 'universal' or 'uniform' aspects typically associated with Euro-American approaches to urban development (Koepke et al., 2021; Lawhon et al., 2018: 720). Scholars working on the 'infrastructural turn', therefore, place an explicit focus on the many socio-technical forms of infrastructure that can reveal the 'imperfect' ways residents draw on one or more energy sources as part of their 'socio-electric lives' (Munro, 2020: 428). This is underscored as alternative ways infrastructures are considered and developed outside Euro-American contexts.

Several authors have also identified ways in which residents of informal cities draw on socio-technical systems and how this relates to energy flows. These include studies in Accra (Silver, 2014), Dar es Salaam (Koepke et al., 2021), and Mozambique (Smith, 2023). Energy is accessed via 'informal' and 'smart' means, such as through grid connections (of ranging quality and service), individual installations, and subscriber-retailers, alongside 'less smart' options such as candles, paraffin, gas, and clandestine connections. While a focus on the fragmented options and how they come to exist in the Global South has been identified as an opportunity for the 'deepening and broadening analyses of urban environments and everyday spaces of possibility', the disruptive configurations of infrastructures have been identified as a new and promising avenue for exploring urbanism (Truelove and Cornea, 2021: 242; Caprotti et al., 2022). We highlight how the difficult, disruptive, and complex disjunctures in Qandu-Qandu's energy landscape help to reframe the delivery and use of smart infrastructures in informal settings.

Appearances of informality

There is a tacit assumption that informality cannot be 'smart', as well as a recognition that the interface between informality and

the smart city is negotiated in various ways depending on the specific articulations of the state (Breslow, 2021). As informality does not fit within mainstream discourses of urban 'smartness' as performed by North American, European, and Asian states and technology corporations, informality can disrupt understandings and notions of 'smart' (smart cities, smart infrastructure) in policy and practice. For example, in a review of national, regional, and local policy documents in Brazil and South Africa, Kovacic (2022: 1) found that the appearance of informality is tied to a strong sense of a 'lack of formality'. Other accounts of the informal city have acknowledged it as an 'underdeveloped' part of the city that is rife with 'poverty, environmental toxicity, and disease' (Kovacic, 2022: 1; Sharp, 2022: 5). By implication, informal spaces are not viewed as supporting innovation to address their own or other urban concerns. In contrast, we argue that informality itself can be disruptive to understandings and constructions of what it is to be 'smart' in the city.

Therefore, while the use of 'smart' infrastructures can be presented (via corporate or other celebratory discourses) as something that is considered 'good' and can provide 'solutions' to urban problems (Vanolo, 2014), the use and development of such infrastructures often lie at odds with 'appearance of informality' that are incorporated and perpetuated by actors in policy and practice (Kovacic, 2022: 1; Sharp, 2022: 736). Therefore, the use of smart infrastructures conflicts with notions of uncertainty and uncontrollability, where their use is often only couched in notions of correction (Caprotti et al., 2022; Robinson, 2005; Roy, 2011). While the disruptive aspects of alternative forms of energy have been acknowledged in relation to policy (Kovacic et al., 2021), governance (Baker and Phillips, 2019; Caprotti et al., 2020), and systemic factors such as race and class (Phillips and Petrova, 2021), we highlight a gap around the appearances of informality and how they are challenged through the use of smart infrastructures, which we take forward through our experiences in Qandu-Qandu. Our argument here is that just as informality is in many ways defined by its relationship, marginality and tension vis-à-vis the state, at the same time, the existence of digitally-enabled, 'smart' infrastructures in informal settlements sidesteps and in is tension with the celebratory narratives and disciplinary intent of mainstream smart urbanism (Krivy, 2018), which tends to treat citizens as trackable, disciplined originators of data within formal, established legal, consumption and market structures.

Smart and always 'good' infrastructures

The assumption underpinning the use of smart infrastructures in the informal city is that it can provide 'efficient, technologically advanced, green and inclusive' service to rectify previously 'bad' practices (Vanolo, 2014: 883). That said, while using smart infrastructures often presents a safer and cleaner form of energy, the exact way worlding ideas are provincialised remains unknown. By implication, assuming smart infrastructures will resolve all issues related to the deficiencies of informal settings and all energy needs is not accurate or realistic. To accommodate the lived or real implications and roll-out of such programmes, experimenting and testing are vital.

In practice, including a range of urban actors in the implementation and use of smart infrastructures can challenge existing notions of the state in infrastructure provision and present new opportunities for engaging in new forms of public citizenship. This is because the state is often associated with playing a critical role in the financing, delivery, and management of urban infrastructures. While scholars have already identified the disruptive influence of smart

technologies concerning the ownership of infrastructure (Baker et al., 2021) where it can 'impress' new 'diagrams of government' (Vanolo, 2014: 884) through its influence on citizenship, this work is yet to be fleshed out more broadly through notions of infrastructural citizenship, where 'identities, perceptions, and actions of citizens who are deeply embedded in the system created by the state (e.g. networked infrastructure)' (Lemanski, 2020b: 590). Although scholars have touched on notions of shifting state–society links by way of off-grid electrification modes for achieving universal access to infrastructure services, such as in informal settings in Cape Town and Mumbai (Haque et al., 2021), we broaden these studies by heeding the call to consider the off-grid spaces of cities (Caprotti et al., 2022; Lemanski, 2023) to explore further the disruptive implications of smart infrastructures for state–society relationships. We explore this through our example in Qandu-Qandu.

Re-building knowledge on the informal city: 'Worlding–provincialising–worlding' solar energy

In our work in Qandu-Qandu, an informal settlement in Cape Town, South Africa, we delivered solar energy to 112 residents via solar-powered mini-grids.[2] The project delivered seven solar mini-grids and provided productive use appliances to 21 female entrepreneurs to enable sustainable livelihood development by providing solar-powered energy. The mini-grids were based on a configuration comprising a solar tower with a panel and an underlying battery and the ability to provide direct current (DC) electricity to households within a 40 m radius of each tower. Zonke Energy, a small renewable energy utility company, implemented the solar mini-grids and supporting digital technologies to streamline the billing and metering of energy using online websites and smartphone applications to provide a holistic service. The 112 clients were among those living within each tower's radius; each tower was sited based on an assessment of tower suitability and installation access and potential client demand. The entrepreneurs were selected based on a two-month programme, delivered as part of the project-by-project partner organisation Story Room, which delivered entrepreneurship training to 100 local women. Based on participation in the programme, 21 women developed business cases for the productive use of refrigeration-based appliances. The entrepreneurs were mentored, following the programme, to help them develop their businesses using refrigerators or chest freezers. We show how the findings of our work re-build knowledge on the informal city where we understand Qandu-Qandu as being off-the-grid and as an example to help build narratives on the informal as a site of diversity and learning (see Roy, 2011; Sharp, 2022). We also mobilise scholarship on smart infrastructures which can increase the number of service-based options while acting as a critical opportunity for re-defining ownership and control (Baker et al., 2021; Easterling, 2014; Vanolo, 2014).

'Formal' and 'informal' infrastructure(s)

Worlding–provincialising strategies reveal the implementation of solar did not replace one or more forms of energy access in their entirety in Qandu-Qandu, as might be expected in other Euro-American contexts. Instead, it broadened the gambit of energy sources used by residents. Even after solar energy was available, residents continued to draw on a range of energy sources part of the formal (grid) energy network, informal sources (illegal connections, paraffin, candles, etc.), and new 'innovative' energy

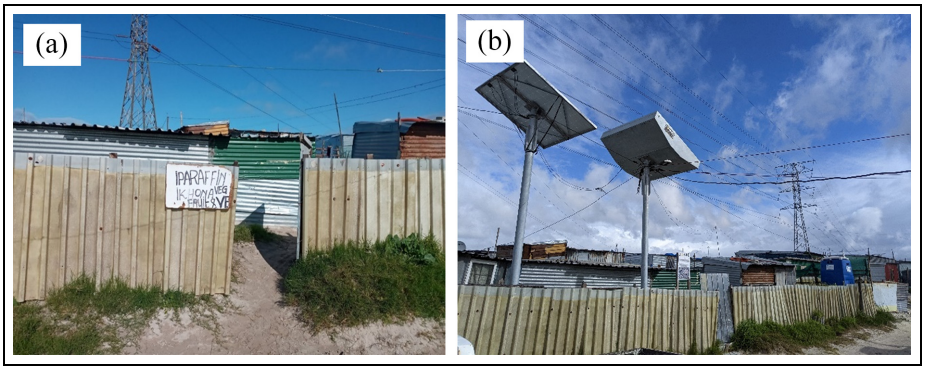

Figure 1. The use of one or more infrastructures in informal settings forms an integral feature of the everyday life of the informal city: (a) solar mini-grids exist alongside the formal grid (overhead) (source: author) and including (b) illegal and/or clandestine electricity connections (source: author). Existing modes of energy access are sustained by hidden and deeply embedded socio-economic networks with critical livelihood opportunities such as through the buying and selling of paraffin, candles, and diesel for generators (a).

solutions (such as solar mini-grids), and they could engage in one or more of these solutions at any one time. Figure 1a and b show the overhanging grid network (top) and illegal or clandestine connections (foreground above dwelling height) interspersed between solar mini-grids and informal dwellings. Therefore, while solar energy has momentarily replaced and/or constituted an additional energy source, the broader range of heterogeneous infrastructures remain, confirming widely documenting 'energy stacking behaviours' (see van der Kroon et al., 2013). Considering these options side-by-side provides a more nuanced understanding of heterogeneous infrastructures, including their implications for existing infrastructure configurations.

To explain this further, 20 solar mini-grid clients in Qandu-Qandu shared their preferences for the use of solar energy as part of a study on energy and wellbeing.[3] Respondents outlined their preference for solar, which provided cleaner and safer energy access and was not susceptible to the rolling blackouts affecting the South African national energy grid. During times of increased rainfall (seasonal and once-off weather events), residents also indicated access to solar energy was preferable as it was more reliable than other energy options available to them, which supports growing evidence that choices around energy sources are not only associated with household income (van der Kroon et al., 2013). Despite their preferences, residents continued to use illegal connections, including paraffin and candles, where the affordability of solar was a concern or where they had already used their daily allowance of solar energy. Therefore, while solar energy constitutes part of the 'overlapping system' of energy infrastructures (see Truelove and Cornea, 2021: 231), its influence and interaction with other forms of energy and socio-economic activities (Figure 2) vary in relation to preferences, affordability, seasonality, and localised high rainfall events.

Self-organising activities to buy and sell energy have established socio-economic activities in Qandu-Qandu. Figure 1a demonstrates instances of socio-economic activities in relation to paraffin. Images such as these highlight the established socio-

Figure 2. Diversification of goods sold in Qandu-Qandu to include those supported by solar energy, such as the use of solar-powered lighting or fridges (Source: Authors).

economic relationships underpinning the diverse heterogeneous network, where buyers and sellers of fuel sources exist alongside solar mini-grids and sellers of clandestine connections. As more residents draw on solar energy, the need for other forms of energy sources, and associated socio-economic activities, may dwindle, while others may diversify (Figure 1a and b). Diversification through solar energy created additional opportunities for enhancing and expanding the local business beyond selling paraffin in Qandu-Qandu (Figure 1a), which offers opportunities for improving livelihood development (Figure 2).

Worlding–provincialising–worlding strategies demonstrate changing individual and community needs where residents draw on 'formal', 'informal', and 'smart' infrastructures in relation to shifting temporal and material-based needs. Reflections on mainstream notions for conceptualising smart infrastructures as a silver bullet solution tend to ignore the rich, self-organising, and dynamic ways energy, including its use in underlying socio-economic activities, is used (see Vanolo, 2014). Personal preferences, such as cost, seasonality, and safety, are therefore a primary feature of the use of smart energy infrastructure in informal settings, where it influences the tightly knit networks of buying and selling, sharing, and accessing different forms of energy be they through 'formal' or 'informal' supply chains. Focussing on the complexity and constantly shifting boundaries and uses of energy challenges the assumptions of the informal being 'underdeveloped' (see Roy, 2011). In addition to existing categories, or appearances of 'formal' and 'informal' infrastructures (after Sharp, 2022), it is, therefore, necessary to redefine the scope of infrastructures in policy and practice in informal settings.

Smart urbanism and citizenship

Worlding–provincialising–worlding strategies highlight new avenues for citizen

autonomy in the diverse and constantly evolving energy landscape in Qandu-Qandu. The use of smart infrastructures flags ongoing resident activities to 'negotiate' informal networks, including government practices and self-help options (Amankwaa and Gough, 2022). Exploring the provincialisation of solar energy in Qandu-Qandu in addition to, or over and above, other kinds of electricity infrastructures illuminates how and why residents engage in self-help options, including long-term relationships between infrastructure and citizenship in the informal city. Citizen-led action to ensure local infrastructural needs are met in 'good' ways can highlight the complexity of state-society interactions (after Lemanski, 2020a, 2020b). Along this vein, the use of solar mini-grids via worlding–provincialising–worlding supports understanding a new mode of citizenship, where residents take action to negotiate their options concerning government practice.

Focussing on how actors gain autonomy over energy infrastructures through solar mini-grids enables a closer engagement with the relationship between the state and society. While it is acknowledged that cost, politics, governance, and sustainability are critical considerations, we focus primarily on the use of one or more interventions, including the impacts of solar energy on the existing infrastructure landscape by way of the worlding–provincialising–worlding interplay outlined. As mentioned previously, the local government is responsible for essential services such as health care and waste removal, and this includes the maintenance of urban infrastructure. Considering which choices and actions residents take to engage with solar mini-grids supports autonomy from state-led processes. In doing so, it can illuminate the state's receptiveness at all levels to innovation around budgeting, policy-making, and investment at a national, regional, and local scale. This idea, explored in the section below, builds on existing accounts of understanding change and transitions to the use of technologies for supporting sustainability at large (Frantzeskaki and Rok, 2018; Frantzeskaki et al., 2021).

A second way smart infrastructures encourage citizen autonomy over infrastructure services is through increased ownership over the metring and billing of energy services used. Granular household data can support greater autonomy over energy services, including how residents spend their household funds on infrastructure services. On the one hand, standalone infrastructure systems such as solar mini-grids support greater autonomy and control supported by digital technologies. On the other hand, control over the provision of services may be ultimately managed by a private service provider who can monitor their billing and metring via their mobile telephone, thus underlining the disciplinary impact of smart technologies (Vanolo, 2014) in the tension between formal and informal. Given our understanding of Qandu-Qandu, we caution against the notion that solar energy is 'a' or 'the' solution to infrastructural deficiencies. This is because the monitoring and management of daily capacities and the use of other kinds of fuels (alongside solar) for lighting and cooking require refinement. Therefore, despite offering the potential to address a range of 'deficits' associated with the informal city, there is a need to consider how solar mini-grids are tested alongside other forms of energy, where residents have strong dependencies on energy options. After all, many residents are limited by what their available finances afford them or not, for example, relying on illegal connections due to limited finances, or bulk buying paraffin or candles. We believe testing and experimentation as part of the provincialising process is key for understanding how energy options as part of a heterogenous infrastructure configuration come to exist and

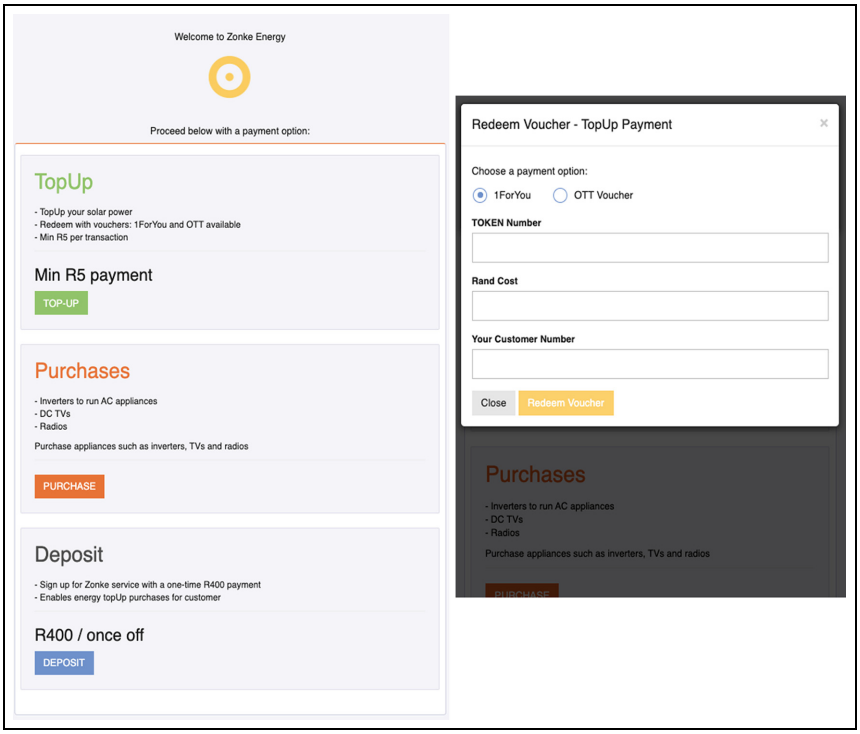

Figure 3. Web-based platform used by clients to monitor and purchase electricity for household and business use in Qandu-Qandu. While online platforms are intended to support the widespread and equitable use of solar energy in informal settings, we caution risks associated with access due to obsolete technology and excessive costs of internet access which can serve to divide local populations (source: Zonke Energy).

interface with one another, including how they translate into practice in 'good' or other ways.

In Qandu-Qandu, clients can pay via a web-based platform which is set up by the solar energy utility called Zonke Energy and is accessible to all their customers[4] (Figure 3). It is set up in an easy-to-navigate platform, with the option to pay or top-up solar energy packages at any time. Zonke Energy has also used Unstructured Supplementary Service Data[5] (USSD) for residents without smartphone access, which connects with the monitoring system used to track energy usage. The software uses commonly available cloud providers, where wireless or other forms of internet enable access to services via personal computer or mobile phone. Clients, therefore, benefit from lower operations costs for using energy for their businesses and/or households. It also provides autonomy over energy access for household and small business clients.

While we outline the use of other smart technologies as enabling autonomy in energy access, we also note caution. Given the significant role of smart personal technologies, if they are not carefully managed, their adoption can generate a greater digital divide. The use of obsolete-type smartphones and difficulties accessing certain types of smart services (and digital data) linked to infrastructure can

divide solar mini-grid clients from other residents, including aspiring clients. As residents of informal settlements often have limited data or digital resources, often use out-of-date technologies, and need free wireless connections, there exist critical equity concerns (including intergenerational aspects) around inclusivity and access to the billing and monitoring functions therein. It is, therefore, necessary to consider these aspects while being sensitive to how residents of informal areas understand and consume information.

(In)forming sustainability: Informal city as a site of learning

The use of solar mini-grids in Qandu-Qandu offers learning opportunities for refining the technicalities of using solar mini-grids as worlding–provincialising strategies in practice. This is because it enables the testing and refinement of ideas that can offer new insights as part of the worlding–provincialising–worlding interplay. The use of online and USSD platforms for payment and management of energy usage is one example of this. Others include the gathering and using of granular data on energy usage, which can be upscaled and used more widely across other technologies or even the formal energy grid.

Due to the scale (hourly household data) and type of data (voltage, cost), the use of solar mini-grids and other smart infrastructures can offer insights on managing electricity in resource-constrained environments, where efficiency and financing options are integral to its support and maintenance. Testing the methods of gathering this data and the data itself can provide valuable insights on how households (and businesses) with limited financial resources use energy and which energy services they derive the most utility from, including improvements to decentralised off-grid solutions. How provincialisation takes place, therefore, offers opportunities for learning and refining technical aspects of smart infrastructure, but also the mechanisms through which they support community needs and are used in local contexts.

Conceptualising Qandu-Qandu as the site for such experimentation and learning recasts it as a space to strengthen the sustainability, efficiency, and longevity in other global contexts, thus placing it at the centre of worlding–provincialising–worlding strategies, where its use in informal settings can contribute something far more significant to the development of solar mini-grids. This builds on the findings of Caprotti et al. (2022), which highlight the off-grid city as a site for innovation by identifying opportunities to develop and share knowledge globally. The use and development of solar mini-grids in Qandu-Qandu has also illuminated critical avenues for investing in additional infrastructure and services. Such examples include the development of repeaters for enabling community Wi-Fi, community infrastructures such as cold rooms, and the embedded generation of energy through grid-linked transformer units.

Re-framing the informal city as a site for learning, therefore challenges the appearance of informality (see Sharp, 2022). Learning not only helps to shift engrained notions of informality but also changes the role of the informal city in refining the use of smart infrastructures at the global level. Learning, therefore, enables re-framing briefs around part of the city where informal settlements are often located (such as on the margins) and how they are written and spoken about in policy and practice. The idea that informal spaces can offer such opportunities directly challenges notions of the informal city being underdeveloped (see Roy, 2011) or lacking formality (see Kovacic et al., 2021). Generating knowledge on these aspects and how they come to manifest can encourage more equitable policymaking and maintenance practices by engaging with a broader set of locations and

uses of solar energy, including how they are used to build efficiencies over time.

Conclusion

Exploring the dynamism of urban development and energy transitions using the worlding–provincialising–worlding interplay as a conceptual device, we have highlighted three ways the use of smart infrastructures can disrupt existing notions of the informal city. In re-positioning notions of 'formal' and 'informal' infrastructures, highlighting new avenues for citizen autonomy, and recasting the informal city as a site for continuous innovation and learning, we have demonstrated how the use of smart infrastructures in the informal city can challenge Euro-American conceptualisations of urban development. Focussing on informality and on the construction and negotiation of forms of 'smart' infrastructure in the specific context of a solar mini-grid intervention in Qandu-Qandu enables us, in turn, to link our discussion in this commentary to the broader need to learn from the informal city as a way of challenging near-hegemonic narratives around smart urbanism, urban infrastructure, the formal–informal continuum, and more. Informing urban agendas from this perspective can be productive in letting knowledges (usually ignored or airbrushed out of both corporate and globalising city governments' narratives) about the city emerge. It also helps to surface key questions – raised again and again in the literature critical of smart cities in Northern and Western contexts – around how citizens engage with, resist, opt out of, and change smart infrastructures and networks through their lived everyday lives. We conclude by acknowledging the role of the informal city as a key player in the development and use of infrastructural solutions in the city, enabling a more balanced understanding of the use and value of so-called smart infrastructures. Re-building knowledge on the informal city in this way has implications for urban planning and management, offering new avenues for testing and refining smart solutions to strengthen not only their technical, but socially just outcomes in the future.

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Notes

1. 'Turn Down Harassment' in English.
2. The project was a joint University of Exeter and University of Cape Town project initiated in 2021 and funded through the Newton Fund and the British Academy.
3. The study formed part of a British Academy funded project (UWB190088).
4. The website used to access and purchase energy is topup.zonkeenergy.com.
5. Unstructured Supplementary Service Data is a form of communication protocol used to

communicate with mobile phones (personal or other) to communicate.

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