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RECEIVED 19 February 2024

ACCEPTED 31 May 2024

PUBLISHED 12 June 2024

## CITATION

Caprotti F, de Groot J, Mathebula N,  
Butler C and Moorlach M (2024) Wellbeing,  
infrastructures, and energy insecurity in  
informal settlements.

*Front. Sustain. Cities* 6:1388389.

doi: 10.3389/frsc.2024.1388389

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# Wellbeing, infrastructures, and energy insecurity in informal settlements

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**Introduction:** Understanding the intricate relationship between energy and wellbeing in informal urban settlements is essential for developing effective interventions that address the diverse needs of residents. This paper explores this nexus through a multi-dimensional lens, examining the complexities and dynamics involved in off-grid renewable energy interventions, focusing on solar microgrids in an informal settlement in Cape Town, South Africa.

**Methods:** The paper is based on empirical research analysed through a theoretical framework articulating the pathways through which energy insecurity influences various dimensions of wellbeing, encompassing economic, physical, social, and environmental aspects. By applying this framework to our empirical research, the paper reveals the intricate interplay between neighbourhood factors, housing conditions, social processes, and economic insecurities, shedding light on both the challenges and opportunities associated with off-grid energy interventions.

**Results:** The understanding of wellbeing presented in the paper is based on what we term the energy-wellbeing-informality nexus. Understanding the nexus necessitates: (a) moving past universalist and technocratic understandings of wellbeing, and towards a relational and networked basis for wellbeing analysis; (b) moving beyond conventional narratives of off-grid electrification as mere technical fixes, emphasizing the importance of recognizing informal settlements as sites of innovation and experimentation; (c) understanding the multi-sectoral nature of energy-related wellbeing impacts, extending beyond energy provision to encompass broader dimensions such as education, health, and social cohesion.

**Discussion:** The paper not only advances theoretical understanding but also offers practical insights for policymakers and practitioners. It emphasizes the need for context-sensitive policymaking that acknowledges the complexities of informal settlements and fosters innovative approaches to energy service provision. By integrating energy interventions into broader development strategies and adopting a multi-sectoral perspective, stakeholders can work towards more equitable and resilient solutions that enhance the overall wellbeing of residents in informal urban contexts.

## KEYWORDS

wellbeing, infrastructure, energy insecurity, informal settlements, global south, off-grid city

## 1 Introduction

Rapid global urbanisation, and the concurrent growth of informal urban areas, bring with them significant and interlinked challenges related to infrastructural access, livelihoods, and health and wellbeing in cities. These issues have emerged as a key focus for global policy enshrined in the UN's Sustainable Development Goals (SDGs). SDG 1 aims for no poverty, SDG 3 promotes good health and well-being, SDG 7 aims for affordable and clean energy, SDG 10's objective is reduced inequalities, and SDG 11 promotes sustainable cities and communities. Though there is recognition of significant links between the goal for affordable and clean energy and all other goals, deeper understanding of how projects designed to address issues of clean energy access and its implications for health, inequality, and sustainability within cities is still required. This is the context within which this paper is situated: we argue for a consideration of the link between informality and energy, and for an understanding of the overall impact of this on wellbeing.

The paper offers a conceptual framework aimed at understanding what we call the energy-wellbeing nexus through a conceptual framework focused on energy insecurities. Understanding the nexus necessitates: (a) moving past universalist and technocratic understandings of wellbeing, and towards a relational and networked basis for wellbeing analysis; (b) moving beyond conventional narratives of off-grid electrification as mere technical fixes, emphasising the importance of recognising informal settlements as sites of innovation and experimentation; and (c) understanding the multi-sectoral nature of energy-related wellbeing impacts, extending beyond energy provision to encompass broader dimensions such as education, health, and social cohesion. By applying this framework to our empirical research, we reveal the dynamic interplay between neighbourhood factors, housing conditions, social processes, and economic insecurities, shedding light on both the challenges and opportunities associated with off-grid energy interventions. The paper not only advances theoretical understanding but also offers practical insights for policymakers and practitioners. It emphasises the need for context-sensitive policymaking that acknowledges the complexities of informal settlements and fosters innovative approaches to energy service provision. By integrating energy interventions into broader development strategies and adopting a multi-sectoral perspective, stakeholders can work towards more equitable and resilient solutions that enhance the overall wellbeing of residents in informal urban contexts.

Building on this, we aim to forge a link between understandings of off-grid energy practises around solar energy, and the complex phenomenon of urban wellbeing. Geographers have sought to understand how political-economic configurations contribute to the formation of inequalities, injustices and precarity around energy (Petrova, 2018; Robinson et al., 2019; Phillips and Petrova, 2021). We argue that one of the ways in which inequalities around energy are (re)produced in informality is through the interaction between energy insecurity and urban wellbeing. We argue for the establishment of deeper research informed dialogue on the link between energy insecurity and wellbeing in contexts of urban informality where 'solutions' such as off-grid renewable energy are proposed, installed, and operated. Such 'solutions' increasingly form part of the constellations of tensions, conflicting incentives, and infrastructural perceptions that involve the generally poor 'recipients' of off-grid

energy interventions (Haque et al., 2021b). It is in this context that a complex tension exists between energy insecurity in informality, and the promise of a level of security via the provision of off-grid systems such as solar microgrids.

This paper aims to deliver conceptual development and understanding of the relationship between wellbeing and energy provision in a context of urban informality in South Africa, where 13.9% (4.4 m people) of the population live in informal settlements (Runsten et al., 2018; Monyai et al., 2023). Even though most South African households are connected to the national electricity grid, 47% of the country's population is classified as energy poor (Caprotti et al., 2020). The issue of a lack of reliable, affordable, and safe energy access in informal settlements is also increasing in importance not least because the rate of growth of informal settlements in South Africa, at 3.5%, is greater than the 2.5% growth rate of formal urban areas. The paper's empirical data are from an informal settlement in Cape Town: the city is in the Western Cape, where 16% of households are in informal settlements, and of these, 89% have access to grid electricity (although these are often not usable connections due to affordability, loadshedding, and other factors). However, in the city of Cape Town itself, it is estimated that only 60% of households are connected to grid electricity, even though 'only' 16.5% of the city's residents live in informality (Runsten et al., 2018). In a national context, the stated policy aims of the 2008 National Energy Act (NEA) are uninterrupted energy supply as well as the facilitation of energy access to all South Africans (Monyai et al., 2023). Thus, in Cape Town specifically and South Africa more broadly, energy access is positioned as a key part of socio-economically sustainable equitable and just urban development.

Urban informality is a key milieu in which to study and understand the link between wellbeing and energy provision. Globally, the urban population reached 4.52bn in 2022 (World Bank, 2023), of which c.1.1bn lived in informal settlements in 2023. This is an expanding reality: the number of people living in informality has grown by c.165 m in 2003–2023 (Reckford and Aki-Sawyer, 2023). Whilst urbanisation has often been associated with increased economic opportunities, and whilst 'urban populations have on average been healthier and more affluent than their rural counterparts' (Vardoulakis and Kinney, 2019, p. np), at the same time those living in informal settlements bear a disproportionate 'double burden of communicable and non-communicable diseases' (Vardoulakis and Kinney, 2019) including those related to mental health and wellbeing.

Informality is associated with poverty, but it is a highly significant economic reality: in some countries in Sub-Saharan Africa, the informal economy is responsible for more than 90% of total employment, and up to 62% of official GDP (Elgin et al., 2022). At the same time, several key challenges exist in informality, many of which are linked to lack of, unsafe or unstable infrastructural access and its societal knock-on effects:

'[W]idespread informality tends to limit government revenue and hence public expenditure on infrastructure; conversely, poor access to infrastructure can discourage firms or workers from joining the formal sector and engaging with the government (Ohnsorge et al., 2022, 163).'

A key global challenge is represented by the interlinked issues of energy access, affordability, reliability, and safety in informal

settlements. Indeed, in contexts with high employment in the informal economy there is access to electricity in only 69.4% of the population; where in low-informality areas this figure rises to 96.3% (Ohnsorge et al., 2022). Current research is critical of tendencies to characterise informal infrastructures according to deviance from idealised notions of so-called modern infrastructure (Baptista, 2019), and points to the need for contextual understandings of informal infrastructures as hybrid (Verdeil and Jaglin, 2023), and for a propositional understanding of infrastructural futures that are focused on ‘what could be (as opposed to what ought to be)’ (Baptista and Cirolia, 2022, p. 928).

In the following, we first introduce our empirical materials and methods before moving to discuss the link between energy insecurity and wellbeing and considering the context of informality. The paper then analyses the wellbeing-related impacts of off-grid solar electrification in an informal settlement in Cape Town, using a conceptual framework based on impacts specifically related to energy insecurity. Our analysis is focused on the multi-sectoral impacts of energy insecurity on urban wellbeing, whilst at the same time also acknowledging the role of innovation and experimentation in spaces of energy insecurity.

## 2 Materials and methods

The paper is informed by engaged research with the Qandu Qandu informal settlement community, in the partially informal area of Khayelitsha, Cape Town, South Africa (Figure 1). The Qandu Qandu community is relatively new: the settlement dates from 2018.

At the time of writing, about 3,500 households lived in Qandu Qandu, and there were no formal electricity connections in the settlement. In 2019–2022, the authors were involved in two projects that introduced 11 solar microgrids into the community (Figure 2): these were installed, and are operated, by Cape Town-based solar utility Zonke Energy, who opened a ‘shack office’ in Qandu Qandu during this period. Each solar microgrid was based around a solar tower, taller than the surrounding shacks and which contained a solar panel with underlying, 5 kWh battery storage. Each tower provides 1.3 kWp of solar electricity and was, in turn, linked by cables to up to 16 households in a 40-m radius. The solar electricity provided through the microgrids was digitally metered, with service levels ranging from lights and charging packages, to the most expensive option, which was based around powering a Direct Current (DC) fridge or chest freezer. Whilst the capacity of each microgrid was very limited when compared to the formal grid, what each microgrid connection offered was a largely stable and reliable energy supply. Solar electricity is also safer than ‘illegal’ connections to high-voltage power lines and enables the use of technologies like electric lights which are safer and healthier to use than candles (the most commonly used source of lighting in Qandu Qandu). In addition, each solar tower (due to its location in and around the settlement’s thoroughfares) features a streetlight, providing public lighting during the hours of darkness. The paper’s arguments around wellbeing, energy, and informality are informed by working with the Qandu Qandu community.

The paper is based on a primarily qualitative dataset composed of microgrid project documentation, a baseline survey, and in-depth interviews with Qandu Qandu community members. A qualitative approach was selected given the argument, presented here, of the need



FIGURE 1  
Qandu Qandu, Cape Town (source: Authors).





FIGURE 2  
Installation of the microgrids (source: Authors).

to focus more closely on granular and relational understandings of wellbeing and socio-electric landscapes (Munro and Schiffer, 2019). The research team were involved in the design and study of the microgrid-based project detailed above. This informed their understanding of the energy-wellbeing-informality nexus as discussed in the paper. The microgrid intervention was extensively documented through project and partner meetings, site visits and community discussion sessions in Qandu Qandu. A baseline survey was carried out with 52 Qandu Qandu residents through DataHuddle, a data-free app developed by the Thrie Energy Collective and that can be used on the sort of entry-level mobile phones commonly used in Qandu Qandu. The survey was focused on forming a basic understanding of energy use and access to different forms of energy by Qandu Qandu residents.

Interviews were focused on understanding the wellbeing impacts of off-grid solar electrification and were carried out with a total of 22 participants. Interviews were undertaken on three occasions using an intensive longitudinal design (Kvale, 2008) with participants interviewed before the microgrids were installed; during the installation process; and after installation (Figure 3). This enabled us to examine and reflect on changes in wellbeing before and after connection to a solar microgrid in the settlement. Interviews took place between February 2020 (prior to installation) and June 2021 (when all microgrids had been installed). Interviews were carried out mostly in isiXhosa and then translated and transcribed in English. For this paper, interview data were analysed using a thematic approach (e.g., see Bryman, 2004; Kvale, 2008) involving iterative engagement with the data to identify material relevant to the theoretical framework presented below and coding to corresponding meta-themes (e.g., different dimensions of wellbeing, neighbourhood factors, social processes, and built environment; Bryman, 2004) and more refined themes

within them (e.g., socioeconomic inequality and social cohesion). The analysis was then developed and refined further through the process of writing with the involvement of all authors to interrogate assertions and data and arrive at the insights presented here.

### 3 Energy insecurity and wellbeing

Defining wellbeing in general, as well as in relation to energy and in urban and/or rural contexts, is a complex task. Whilst the intricacies of understanding urban wellbeing are beyond the scope of this paper, we acknowledge the fact that whilst wellbeing can be defined in multiple ways, it is important to link wellbeing to socio-spatial scale. This is because wellbeing is experienced differently at individual, household, community and practise scales (Coburn and Gormally, 2020). Statistically-driven approaches to understanding wellbeing often flatten these multiple scales into globalised descriptions of wellbeing that have little link to specific urban and socio-spatial contexts on the one hand, and can lead to the reproduction of notions of human and urban development rooted in Northern and/or neoliberal perspectives on the other (Ratuva, 2016). Indeed, health research on urban wellbeing has highlighted how wellbeing can be thought of not just through top-down, metrics-driven assessments (Maggino, 2016), but as something that is both relational, and rooted in subjective experiences of the environmental landscape (Barua et al., 2021). At the same time, there is a need for decentering universalist and Northern-focused understandings of wellbeing, and to consider Southern and other contextual determinants (Mahali et al., 2018; Fowers et al., 2022). These insights are key for engaging with the unequal landscapes of wellbeing in informal settlements.



FIGURE 3  
Solar towers installed in Qandu Qandu, Cape Town (source: Authors).

Crucially, then, there is a key productive tension between understanding wellbeing and its link to energy through generalised, normative conceptualisations of how wellbeing should be defined, measured and operationalised; and more granular, dynamic and relational understandings of wellbeing as subjective as well as partly knowable in generalisable ways. This tension is replicated at the global policymaking scale, as well as at scales concerned with municipal and regional governance, although policymakers have made efforts to engage with subjective wellbeing. In 2011, for example, the OECD's publication *How's Life? Measuring Well-Being* devoted its twelfth and last chapter to the question of measuring subjective wellbeing, which it defined as life satisfaction, and positive and negative affect (OECD, 2011). Whilst this recognises the emotional aspects of the experience of wellbeing, there is a need to engage with the notion of wellbeing as not only a passive state *experienced* by individuals, but also a dynamic

part of everyday life *produced* by individuals, households and communities. By 2020, the focus on subjective wellbeing had been advanced to the eighth chapter out of 16 (OECD, 2020), and multiple chapters were devoted to aspects of subjective wellbeing including social connections and various forms of capital.

#### 4 Informality, energy, and wellbeing

In the following, the focus is on solar microgrids that were installed and operated in an informal settlement in Cape Town. The emphasis on off-grid solar is significant in several ways, first and foremost because of its foregrounding in a context of informality. This is crucial not because informality is exceptional or separate from the formal grid, but because it participates in, and intersects with, the



formal city and its infrastructure grids in socio-economically and spatially specific and complex ways (Haque et al., 2021a; Munro and Samarakoon, 2022). Second, it is key to critically engage with off-grid solar, which has increasingly emerged as a technology that is marketed and described as a potential 'solution' to issues of energy access in low-income, informal and rural settings (Munro and Samarakoon, 2022), whilst posing key issues around reliability and repair (Ramakrishnan et al., 2021; Samarakoon et al., 2022; Munro et al., 2023), longevity, and equity vis-à-vis formal areas connected to the grid (Caprotti et al., 2022). Thirdly, the introduction of solar technologies in the complex energy landscapes of informal settlements often results in the generation of micropolitics around solar access (Bobbins et al., 2023), and in sometimes unexpected changes in existing energy practises and economies in informality, all of which can have consequences with regards to both energy justice (Barnes, 2022; Jaglin, 2023) and broader notions around the link between infrastructural networks and everyday energy practises (Lemanski and Massey, 2023).

In focusing on informality in Qandu Qandu, South Africa, and on the household scale, we highlight the need to:

- a Engage with wellbeing in ways that move past understandings of energy poverty and wellbeing rooted in Northern and globalised definitions and measurement attempts. In so doing, we build on work that has highlighted the continuing production and performance (from above) of subaltern identities in the Global South (Ratuvu, 2016), as well as research that has sought to understand indigenous and other perspectives on wellbeing (Yates et al., 2023).
- b Understand wellbeing relationally and in its subjective facets, rooted within individual, household and community experiences.
- c Propose a relational and context-specific understanding of wellbeing linked to energy in informality that is both informed from household and community level experiences, and that can yield some insights for epistemological enquiry into wellbeing that can be sensitively related to other informal contexts, where sensitivity means the continuing need to not parachute understandings from one informal context into another without community engagement and careful understanding of the specificities of each informal community context. This, in turn, can lead to methodological refinement and to informing a more context-sensitive policymaking process in relation to informal settlement communities.

There are multiple complexities and tensions related to the energy-wellbeing link in informal settlements. In order to analyse these, we draw on research in energy geography that has sought to critically engage with the complex ways in which energy-society relationships are articulated and materialised (Calvert, 2016), and with the production and reproduction of inequalities and injustices around energy. Our focus on the link between energy insecurity and wellbeing contributes to attempts to forge links between studies of energy and the production of inequalities that are related to, often dependent on, but not necessarily wholly encapsulated by a focus on energy. Furthermore, in focusing on energy practises around solar microgrids in an informal settlement in Cape Town, South Africa, this paper also responds to calls to ensure that research in the broad area of energy geographies is more responsive to Global South contexts, broadening

the research focus to include aspects of energy beyond extraction and production (Baka and Vaishnav, 2020; Kumar, 2022).

## 5 Energy (in)security, informality, and off-grid clean electricity

Having explored the multifaceted nature of the energy-wellbeing-informality nexus, we turn to Hernández's (2016) conceptual framework, which we use here to examine how this nexus can be understood in relation to the approach of delivering off-grid renewable energy 'solutions' in informal urban contexts. Hernández's (2016) framework is based on close engagement with insecurity as a concept that has multiple repercussions for those living with it, and that is multi-dimensional in its constitution. It is based on the interaction between economic, physical, and behavioural aspects of insecurity, and can be used to model pathways that lead to an understanding of how disadvantage flows from energy insecurity expressed in those three areas. We argue that energy insecurity can be seen as part and parcel of broader processes that affect wellbeing (Courard-Hauri, 2020), and that Hernández's (2016) framework can be mobilised to understand how specific energy interventions, such as those around off-grid solar power, can be used to affect wellbeing outcomes.

In her conceptual model, Hernández (2016) outlines how multiple factors affect the link between energy insecurity and wellbeing. Neighbourhood factors (such as residential segregation, socioeconomic inequalities, and various environmental elements such as poor air quality or land prone to flooding); social processes (including low social cohesion, social capital, and violence); and the built environment, including the (lack of) quality of physical stock and (lack of) use of building codes. Whilst Hernández (2016) referred to housing conditions rather than the built environment, in this paper, we use the latter to broaden the scope of consideration of the ways in which the buildings, layout and materials of the overall informal settlement environment affect energy insecurity and wellbeing, over and above the conditions of individual housing stock.

In turn, these processes and conditions influence the development of insecurity at two levels: economic, such as around high energy expenditure related to income, and physical insecurities around poor building quality, unreliable heating, cooling, and cooking appliances and methods, and the like. These economic and physical insecurities generate coping insecurities, defined by Hernández (2016) as a broad category encompassing a range of impacts from the need to rely on alternative heating methods, to hypervigilance and impacts on hope. The tripartite action of physical, economic, and coping energy insecurities leads to multiple knock-on consequences. These are, firstly, adverse environmental consequences, from environmental quality within housing, to thermal discomfort and other factors; secondly adverse social consequences, which encompass multiple factors such as disruption of family life, residential instability, stigma, and educational impacts; and thirdly, adverse health consequences, such as increased stress, mental health triggers, and the exacerbation of medical problems such as around respiratory issues.

In our engaged work with the Qandu Qandu informal settlement community, we have been able to apply and extend the above framework to develop understanding of the interconnections between off-grid electricity provision, energy insecurity, and wellbeing (Figure 4). We expand it by specifically linking energy insecurities to wellbeing, and

by grounding the framework in a consideration of the impacts of off-grid innovations in informal settlements. Furthermore, since Hernández’s framework was based on data collected in the United States, this paper expands and examines its relevance for analysing experiences of insecurities in a more global, and especially Southern context. In the following, we move to present our data analysis, first discussing the ways that energy has implications for wellbeing spanning the multiple dimensions laid out by Hernández and expanded here. We then move to examine how this is reshaped and shifted with the implementation of solar mini-grids giving attention to the interweaving of the technological innovation with existing systems of provisioning and the implications of this for wellbeing.

### 5.1 Multi-dimensional energy-related wellbeing impacts

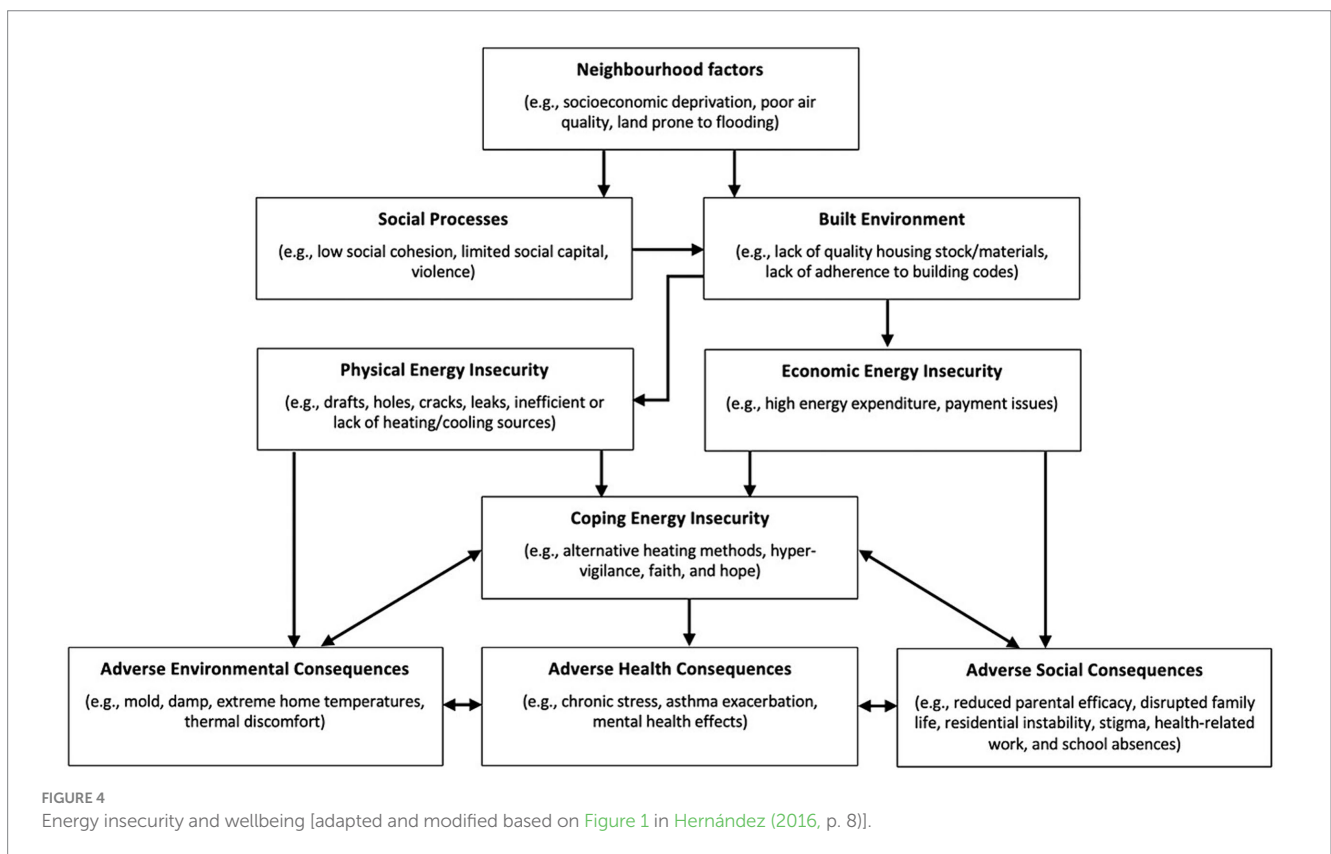
To begin, neighbourhood factors are key in terms of lack of access to formal electricity connections and their consequences for wellbeing. This is deeply related to other factors, such as long-standing socioeconomic inequalities, that affect the South African informal sector. These include the fact that settlements are not only segregated by legal fiat but also by the socio-economic *status quo*, and the historical path-dependencies around the history of South African urbanisation and urban development processes (Essex and de Groot, 2019). Likewise, housing conditions are a stark and highly visible factor linked to wellbeing in Qandu Qandu: the settlement is built on low-lying land that floods regularly; it is off-grid even though high-voltage power lines run through the settlement; shacks are built with materials that lack insulation and are easily flammable;

there is poor ventilation in most if not all shacks. These overlapping neighbourhood and housing conditions have deep impacts across multiple dimensions of wellbeing including physical and mental health and safety. They are also deeply relational in being connected to the reproduction of socio-economic inequality.

Social processes are also clearly affected: for example, the residents we interviewed frequently mentioned fears around violence, personal safety, and a lack of trust of others in the community, especially after dark with a lack of public lighting as well as private access to energy services. Most residents are also deeply affected by a lack of access to, and affordability of, data infrastructures and associated energy needs which means that social connections to family and other networks outside the settlement comes with high transaction costs. An example of this is the need to pay a fee (usually around R5, or USD \$0.34) to a shop or acquaintance to charge one’s phone, and the difficulty of using the internet to look for, and apply for jobs:

‘You cannot do anything without a phone. I use phone to apply. So you cannot apply because you have to save your battery. Maybe if I am going to work Monday and Tuesday, I have to charge my phone at work. Sometimes I keep my phone for 2 days without charging because there was no electricity’ (Participant 22, June 2021).

There are cultural and social capital impacts too, as explained by a participant who informed us that having no reliable electricity meant that her children suffered because ‘Their friend talk about watching cartoons and they cannot watch everything like that’ (Participant 4, June 2021) due to a lack of electricity.



These processes can be seen to affect economic insecurity, which is a feature of daily life in Qandu Qandu, and which, in turn, affects wellbeing via energy because of the combination of low incomes and high energy prices (for example for paraffin). Physical insecurity was also often mentioned by participants, especially around fire and other safety hazards, risks to children of illegal and at times unsheathed electricity cabling on the ground, poor insulation, and flooding risk. As a resident of Qandu Qandu interviewed in February 2021 stated with regard to the risk of fire and electric shock from illegal grid connections, and the safety potential of off-grid solar:

‘There will be less people that will get killed by [illegally connected] electricity and kids as well, because people are dying because of being shocked by this electricity. Houses are being burnt some of us have to rebuild our houses because of the electricity that has burnt the house because we just do it yourself. You see it is dangerous. The wires that are cut open. So, the [solar] energy will bring us hope and the clean environment. In terms of safety we will be safe because there will be less shocking of people that die from the lines or the open cables that we just pull the electricity from, you understand?’ (Participant 1, February 2021).

The adverse environmental consequences of these forms of insecurity are multiple, from poor indoor air quality, to shacks which are too hot in the summer and too cold in the winter. Adverse social consequences are also striking, from the intergenerational consequences on education of a lack of lighting, to residential instability related to real and perceived housing precarity due to fire and flooding risks. With regard to education, for example, it is not only children who are affected by lack of reliable and stable energy access. As one participant told us, she was keen to study to improve her living conditions and provide for her three-year old child, but the combination of no lighting and no heating meant reduced chances to engage with her evening study:

‘I will perform bad because sometimes I will just say oh maybe when it is cold I cannot stay outside, I must get into the blanket and I cannot read well when I am in the blankets in bed, I will just sleep’ (Participant 14, March 2021).

Additionally, the insecurities associated with coping are multiple, and involve the stress related to dealing with multiple energy sources and their cost, the constant need to source energy and be aware of risks and dangers, and the like. In turn, this leads residents of Qandu Qandu to experience adverse health consequences such as continuous traumatic stress, much of which is gender-differentiated, the exacerbation of mental health conditions, and worsening of respiratory and other conditions. Our observations in Qandu Qandu echo recent calls (Andres et al., 2021; Yaguma et al., 2024) for reducing the need for residents to necessarily rely on coping strategies as a way of enhancing urban wellbeing in contexts of infrastructural disruption.

The framework outlined above is a useful way of conceptualising the pathways that lead to negative impacts in terms of wellbeing. When applied to a specific example such as the Qandu Qandu informal settlement community, it can be seen how a multiplicity of processes lead to impacts in terms of wellbeing as they relate to energy. This can be seen as part of an analytical process of engaging with specific contexts, as the multifaceted configurations of the energy-wellbeing nexus emerge through the provision of ‘rich and nuanced

narratives of the lived experiences of those affected’ (Hernández, 2016, p. 9) by the wellbeing impacts of insecure and precarious energy access. Building on Hernández’s (2016) work, we propose that a consideration of off-grid energy interventions in informal settlement contexts can contribute towards an amelioration of the negative cascade that links contextual factors, insecurities, and wellbeing.

## 5.2 Innovation, experimentation, and wellbeing

When considering off-grid renewable energy interventions such as solar microgrids, it is key to understand how neighbourhood factors affect renewables interventions as well as current modes of energy provision (formal or informal), and how existing inertias (around energy practises, and informal businesses tied to providing energy to residents in the form of paraffin, LPG and the like) also impact on interventions and the change they can introduce. An example of this, from our work in Qandu Qandu, relates to the potential economic barriers felt by residents when signing up to use a solar microgrid: this is because installation of a microgrid connection generally involves an upfront payment, followed by regular bill payments or pay-as-you-go arrangements to secure access.

In terms of housing conditions, microgrids and similar interventions cannot ameliorate the structural integrity or material composition of individual shacks: however, stable and affordable energy access may have an indirect impact on housing conditions if income is freed up that can be invested in shack upgrading. Social processes can be positively affected to some degree as well: participants reported an increased sense of safety, both indoors and outdoors, due to the availability of stable and affordable electric lighting, something that is reflected in research on lighting and fear of crime in South African informal settlements (Meth, 2017); furthermore, several participants stated that children and other family members were more likely to spend a longer amount of time indoors, especially in the evenings, due to the availability of lighting, television, and radio powered by microgrid access.

With regard to economic insecurity, solar microgrid access had the clear benefit of reducing the complexity associated with energy practises, and of rendering the economic costs of solar electricity clear and relatively predictable, especially when compared to informal sources of energy. For example, one participant (Participant 19, June 2021) who ran a business selling magwinya (fat cakes) argued that connecting to the microgrid would benefit her because of the ability to sell during low light conditions: she stated that lack of electricity ‘affects me very much because I cannot wake at 6 o’clock in the morning because it is very dark. I must wait until the darkness is gone maybe by 8 o’clock. Say maybe by 8 o’clock then I can open. Then the people who are going to work have already passed so they do not buy much’.

Nonetheless, solar microgrid access does not provide enough power capacity for energy uses such as cooking or hot water provision, which has necessitated the inclusion of solar electricity amongst energy stacking practises, rather than the complete replacement of informal and fossil-based energy sources with solar electricity. As we were told by a resident who only accessed the most basic (lights and charging) service offered by the microgrid operator:

‘I was happy about [the microgrid]. But the only think that I do not like about [the microgrid] is that you cannot use it like the



normal electricity. You cannot cook, you cannot watch TV, it is only the lights and the charger. Unless you buy their own TVs. They have got their own TV' (Participant 21, June 2021).

This has knock-on effects on physical insecurities, since combustible fuels continue to be used in the home. On the other hand, access to lighting has meant that the use of candles is no longer necessary to light indoor space. Access to solar microgrids has also meant an improvement in environmental consequences in some ways (such as reduction of candle use for lighting) but the need to use fossil fuels for uses such as cooking and heating water remains, and thus so do their negative environmental effects within the home, as well as their potential safety consequences indoors and outdoors.

The social consequences experienced by Qandu Qandu residents connected to microgrids have also improved in an incremental fashion, as a result of increased presence of members of the household, and increased educational provision potential as a result of electric lighting. A significant positive impact of solar microgrid interventions such as those in Qandu Qandu has been the amelioration of coping insecurity, owing to the ability of residents to reduce hyper-vigilance linked to the need to source and use multiple forms of energy, most of them combustible and hazardous in the home. There was also a notable reduction in stress related to safety and other fears and risks; and a reduction in negative health consequences through less use of combustible fuels in the home, and less continuous traumatic stress due to a lack of stable energy access.

## 6 Conclusion

In this paper, we have presented a theoretically and empirically engaged approach to understand the nexus between wellbeing and energy in the context of informality. We have attempted to reconcile the sorts of standard macro-level approaches that characterise policymaking and understanding of both wellbeing and public service delivery, with the need to consider the more granular contexts of informal settlement communities. In so doing, we have underlined how focusing on the informal context is a productive way of moving past technocentric and top-down perspectives that often inform policymaking. This is because informality exists alongside formal contexts, and considering the former is key for infrastructural approaches that are more holistic and inclusive. Approaches that address informality directly and include it within planning and policymaking practise are therefore more likely to address the needs of a broader range of citizens than more technocentric approaches that are largely focused on exclusively serving the formal city. In addition, our engagement with the Qandu Qandu community, through the lens of a conceptual framework that links energy to wellbeing through an understanding of energy insecurity, helps draw together broader understandings of wellbeing with an awareness of the specific factors that link energy insecurity to wellbeing in settlements like Qandu Qandu. Here, we offer three points to inform future research on energy and wellbeing in the informal city, followed by three policy and practise-related recommendations.

First, *the energy-wellbeing nexus is dynamically grounded in informality*. We have shown that whilst the current literature evidences a clear link between energy and wellbeing in formal urban contexts, informal settlements are characterised by a range of multidimensional, multi-scalar realities that involve both energy and wellbeing. An

example of this is the complex set of links between energy stacking practises, wellbeing impacts of solar microgrids, and continued wellbeing externalities that continue to exist even after the addition of solar to the mix of energy sources used in informal settlements. Furthermore, it can be argued that the wellbeing impacts of energy insecurity are amplified and become part of everyday lives in informal settlement contexts, for example around the continued experience of insecurity found in dealing with the fluctuating availability and unstable pricing around fuels such as paraffin or LPG. Conversely, the social and educational benefits of off-grid solar, including mobile phone charging and indoor lighting, can be seen to positively affect a range of wellbeing aspects ranging from the social, to the educational, to those aspects related to health and sense of safety. Future research on wellbeing needs to take into consideration the interlinkages between energy and wellbeing in the significant (and expanding) realities of the informal city.

Second, *the informal city is a dynamic site of innovation and experimentation*. As seen above, it is important to move past narratives of off-grid electrification via technical fixes such as solar-powered microgrids as 'solutions' and to remain aware of the key issues encountered in the provision of decentralised energy systems. It is also imperative to recognise incremental (Silver, 2014) and other attempts to deliver energy and other infrastructural services to informal settlements as innovative and experimental ways to tackle policy and development bottlenecks that affect informal settlements. Indeed, Nagendra et al. (2018) have argued that cities in the global South are crucial sites of innovation and opportunity for transformations towards sustainability, because of their capacity to innovate and experiment, and Amankwaa and Gough (2022) have underlined how this is linked to generation of opportunity and transition. We argue that innovation and experimentation are occurring in informal contexts, as exemplified by the approaches to off-grid and decentralised energy for informal settlement communities explored in this paper. This has policy implications in that experimental infrastructural urbanism in off-grid urban spaces opens up opportunities for productively unsettling well-worn policy and development discourses that simply restate the difficulties of service provision in informal contexts. There are, however, key issues that need to be tackled in relation to treating the informal city as a site of innovation and experimentation. These include challenges for agile and context-sensitive policymaking, a need to move past policy silos that consider only one or few aspects (such as energy) of these complex, urban informal socio-technical assemblages; the question of how to enable innovative experimentation to thrive (Jaglin, 2019; Sengers et al., 2019) and to be socially and financially sustainable, whilst at the same time delivering equitable outcomes to communities; and the key issue of longitudinal support to communities and their innovative infrastructures, including commitments to repair, maintenance, and appropriate mechanisms for co-design and, where feasible and appropriate (for example, through community energy structures), co-ownership.

Third, *energy-related wellbeing impacts are multi-sectoral and extend beyond energy*. Factors that affect wellbeing and that are directly linked to energy and energy-related infrastructures are in turn connected to, and have impacts on, aspects of wellbeing that exist well beyond the energy sector and its associated socio-technical and infrastructural systems. An example of this is the link between solar electricity, lighting, and increased sense of safety and household social cohesion that was discussed above. Likewise, our participants clearly highlighted the link between reliable and stable electricity access through solar microgrids, and the sense of increased educational and employment opportunities

that this enabled. There is a need, therefore, to consider energy service provision in informal contexts as part and parcel of a broader, complex system of impacts that affect wellbeing in a range of different ways. This necessarily involves working across technical, sectoral, and disciplinary boundaries to map and assess the shifting and dynamic landscape of interactions between energy and wellbeing more accurately.

Our research on the energy-wellbeing nexus emerges three distinct recommendations for policy and practise relating to municipal and other projects in the informal city.

## 6.1 Placing informal communities at the centre of urban policymaking

Our research underlines the need to consider the specific contexts and risk and inequality profiles of informal settlement communities vis-à-vis the practical realities of infrastructural service provision. When considering energy and other infrastructures, or projects aimed at enhancing urban wellbeing, livelihoods and other facets of urban life, there needs to be a concerted focus on policy interventions aimed specifically at informality. This recognises the fact that whilst part and parcel of the city, informal settlement communities are often targeted with broad-brush, city-wide policies that do not speak to, or are sensitive to, the complexities and needs of informal settlement communities. Examples of this could include informality-focused departments, and attempts by municipal governments to move past siloed models of, and approaches towards urban service delivery, and towards integrated infrastructural policymaking that focuses primarily on informal communities rather than on single infrastructural interventions.

## 6.2 Dynamic policymaking for innovation

Following on from the above recommendation, there is a need to ensure that policymaking is agile and able to respond to the dynamic and fast-changing infrastructural environment in informal urban contexts. This is because whilst innovations (such as solar microgrids) may at times seem short-lasting, complex and fast-moving, it is desirable for policymaking to engage with the experimental and innovative nature of many of the novel approaches to informal service delivery that are currently available. This requires a rethink of the project management and policy engagement structures and processes aimed at service delivery in the informal city.

## 6.3 Leveraging communities for policy-focused data gathering

Our research shows that in-depth engagement with informal settlement communities can help in emerging data that is useful for understanding infrastructural needs, the wellbeing impacts of specific innovative solutions, and the utility of co-producing knowledge with the community. Based on our research, our recommendation is for municipal policymakers to seriously engage with informal settlement communities in order to gather a rich understanding of the infrastructural complexities, barriers and opportunities within each community; and to valorise data-gathering approaches that draw on qualitative insights as well as more traditional quantitative forms of data

collection. Apart from the service design and delivery benefits of such an approach, engaging communities in this way enables them to exercise agency, and can be a pathway towards engagement with the policy process.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving humans were approved by University of Exeter Department of Geography Research Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

## Author contributions

FC: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. JG: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. NM: Data curation, Investigation, Methodology, Validation, Writing – review & editing. CB: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Validation, Writing – original draft, Writing – review & editing. MM: Conceptualization, Data curation, Methodology, Project administration, Validation, Writing – review & editing.

## Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. The research presented in this article was data collection funded by the British Academy (UWB190088), and the Newton Fund (NP2020PB).

## Acknowledgments

We acknowledge project partners at Zonke Energy, and we are also grateful to the residents of Qandu-Qandu informal settlement.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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