Towards inclusive urban building energy models: incorporating slum-dwellers and informal settlements (IN-UBEMs)

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Abstract

Urban building energy models (UBEMs) are emerging as a data-driven method for predicting energy consumption and assessing the impacts of policies aimed at reducing carbon emissions in cities. To date, the majority of these models have been developed for cities in the global north where urbanisation rates are relatively slow, the building stock turnover is low and data are relatively easy to obtain. As their use expands, they are being applied in faster-growing urban areas in the global south, where considerable investment is planned in capital infrastructure. This paper focuses on slums, which include populations that are hard to reach, underserved by current energy systems, and largely absent from UBEMs. It asks: what are the social, economic, and environmental implications of excluding slum dwellers and informal settlements from UBEMs used for policy development?

If existing UBEMs do not adequately capture the needs of low-income urban residents, then planning decisions based on these models risk both carbon lock-in and deepening poverty for already marginalised groups. To redress these problems, this paper considers three key questions:

- How informal settlements and low-income groups have been represented in UBEMs to date and the potential implications of their exclusion
- The politics, norms and behaviours of energy supply and demand within informal settlements
- What issues should be explored to integrate these marginalized housing groups within UBEMs.

In conclusion, it calls for additional social science research to reduce the impacts of exclusion and to co-produce new methodologies with energy modellers. Future steps include fostering ongoing engagement with both expert and non-expert populations to facilitate citizen participation in evidence-based planning decisions.

Introduction

Over the past few decades, the world has experienced rapid urbanisation. Today, 55 % of the world's population lives in urban areas, which is expected to increase to 68 % by 2050 (United Nations, Department of Economic and Social Affairs, Population Division 2018). Growth in urban populations is driven by overall population growth and increases in the percentage living in urban areas. Urbanisation rates in the global south are especially high, and 90 % of world's urban population growth is expected to occur in the developing world, with Africa and South Asia the fastest growing continents. Informal settlements, or slums, are a feature of many cities in the global south as city planning and governance systems have been unable to keep up with rapid rural to urban migration, flux of refugees, high natality rates and globalisation. Slum dwellers are affected by unsafe and unhealthy homes, lack of access to basic services, violence and insecurity, and overcrowding (Mwelu 2015). As the world continues to urbanise, it will become increasingly important to successfully manage this process and to ensure that the benefits of urbanisation are shared and adverse impacts minimised. This will require policies that ensure access to infrastructure and services for all, focusing in particular, on the needs of the urban poor and other vulnerable groups (United Nations, Department of Economic and Social Affairs, Population Division 2018).

The United Nations 2030 Agenda for Sustainable Development (UN News Centre 2015) is a plan of action for people, planet and prosperity that aims to ensure no one is left behind (UN News Centre 2015). It comprises 17 Sustainable Development Goals (SDG) and 169 associated targets. SDG11 focuses on sustainable cities and communities, and aims to ensure cities and human settlements are inclusive, safe, resilient and sustainable. This Goal has multiple linkages with all other Goals, including SDG1 on poverty, SDG7 on energy, SDG8 on decent work, SDG9 on infrastructure, SDG10 on inequality, and SDG13 on climate. For example, cities consume around 75 % of global primary energy, rising to 80 % when the indirect emissions generated by urban inhabitants are included (Mwelu 2015). Buildings also require large amounts of energy and urban form is a key factor affecting energy efficiency (Castán Broto et al. 2017). Energy access in urban settings is also an important issue, with challenges including lack of or unreliable access to energy services, illegality of supply, and lack of affordability of energy, which may be affected by a lack of access to finance, for example, due to illegality of informal settlements (ibid). It is widely accepted that inclusive urban planning processes are required to ensure that the needs and aspirations of all are recognised and met (Porter and Onyach-Olaa 1999). Such processes can help to bridge the gap between rich and poor, including disparities in access to services and infrastructure.

In addition, the scale and complexity of modern cities drives a need for approaches and tools which can assist policy makers and urban planners with the challenges of both understanding the current context, and exploring potential future developments. The implications of applying such approaches and tools – which generally aspire to be data-driven and/or "smart" – to development processes needs to be carefully considered. This paper begins by describing one of these approaches, Urban Building Energy Models (UBEMs) and illustrating how the city and its inhabitants are typically represented in these models. Next, we advance some socio-technical principles and critique the context in which research-based models have been developed and used to date. We outline the implications of excluding informal settlements from UBEMs and the challenges and opportunities that arise from attempting to include them. The paper concludes by calling for more social science research and a greater level of local expert and public participation in the co-production of energy planning methods and tools.

Background: modelling urban building energy demand

This section introduces urban building energy models, reviews their development thus far, and pinpoints some topics missing in existing UBEMs.

WHAT ARE UBEMS?

Urban building energy models (UBEMs) are large-scale models, which incorporate representations of large numbers of individual buildings in order to create a model of a neighbourhood or even an entire city. UBEMs are a relatively recent development (Reinhart and Cerezo Davila 2016). They are physics-based building energy models used to calculate the energy consumption of individual buildings or premises based on calculating heat and energy flows, both within the building and to and from its surroundings. Models vary considerably in their complexity and the timesteps in which they are evaluated; however, all require:

- a representation of the thermo-physical properties of the building, for example, the area of walls and their ability to transmit heat
- details of the energy conversion systems within the building such as heating, cooling or lighting systems
- and a representation of the patterns of occupancy and equipment use.

Since the building stock of a large city can be of the order of 1 million individual buildings, UBEMs require very large quantities of data to characterise a whole building stock. Therefore, models often develop proxies, averages, and simplifying assumptions to manage the data.

An essential element of reducing the scale of the data required to manageable proportions is the use of archetypes. Archetypes are a set of reference buildings, typically created based on factors known to influence energy consumption in the building stock, for example, year of construction and building function. Each building in the stock is then assigned to a specific archetype. A model for the whole building stock can then be generated either by modelling the archetype buildings and scaling the results according to the proportion of the stock represented by each archetype or by modelling each building individually, using the archetype to determine input parameters for each model.

As availability of processing power has increased, UBEMs have emerged as powerful opportunities in urban policy and planning, offering detailed insights into:

- Diagnosing energy consumption across a building stock, allowing energy efficiency interventions to be targeted at areas of greatest need.
- Assessing the impact of potential intervention strategies across the stock, allowing competing strategies to be ranked
- Predicting energy consumption and carbon emissions under climate change
- Exploring the impact of renewable energy strategies, such as large-scale deployment of solar PV installations, or peak demand shaving; and
- Evaluating alternative development options for new construction and redevelopment of existing stock

Although primarily used to investigate energy consumption, UBEMs based on detailed dynamic simulation engines, such as EnergyPlus (US Department of Energy 2018), can also be used to evaluate thermal comfort and some air quality measures.

REVIEW OF EXISTING UBEMS

A recent review of existing UBEMs shows an overwhelming bias towards cities in the global north. Fennell (2018) explored the geographic location of existing UBEMs using a snowball-

Figure 1. Location of existing UBEMs (based on Fennell 2018, World with Countries – outline by FreeVectorMaps.com).

ing technique. This review took two starting points: Sousa et al.'s (2017) review of UK housing stock energy models and Reinhardt and Cerezo Davila's (2016) review of both domestic and non-domestic models. In total, 28 individual models were identified. These models are located on the ASHRAE climate zone map (ASHRAE 2013) in Figure 1. In two cases, a model was applied in more than one location. Each location is shown separately in Figure 1.

The vast majority (91 %) of the models are oriented towards cities in the global north: 73 % of models investigated a European location and 18 % focused on cities in North America. Only three models (9 %) were located in Asia. Of these, only two focus on cities in developing contexts: the Massachusetts Institute of Technology (MIT) model of Kuwait City (Cerezo Davila et al. 2017) and the Centre for Environmental Planning and Technology (CEPT)'s model of Ahmedabad.

While the range of potential insights is impressive, as noted in the previous sub-section, building energy modelling at a city scale remains very challenging for three principal reasons (Frayssinet et al. 2018):

- The number of buildings and diversity of parameters,
- The diversity of occupant behaviour, and,
- Heat exchanges and shading interactions between adjacent buildings.

MISSING PIECES IN UBEMS

Beyond the technical challenges described above, there are additional areas that UBEMs have yet to address. Because they have evolved from a building physics background, it stands to reason that they address energy primarily associated with buildings and their footprints. However, urban energy use extends *beyond* the building footprint. Implications of urban form for energy used by personal and public transportation or municipal energy services (e.g., street lighting and water pumping) have been given less importance in these models.

This paper focuses on a more social and political problem. We contend that the existing concentration of UBEM development in the global north will unintentionally enhance the development challenges associated with slums or informal settlements in the global south. Where building archetypes are described in detail, residential archetypes take the form of single-family homes or apartments in purpose-built blocks. Building code details for the year of construction are used to characterise building fabric and systems, which assumes: (1) there *are* building codes; and (2) that they have been followed. Our concern is that these and other assumptions embedded in the northern models will be inadvertently transferred to models in the south.

Critique: models are not neutral

While the underpinning framework of building physics makes it tempting to view a UBEM as an objective tool to be applied to answer a given question, the process of modelling is inherently value-laden. Philosopher Roman Frigg (2010) draws a clear distinction between two parts of the process of model making – the presentation of a hypothetical system as the object of study (the model system) and the representational relationship with the part of the world we are interested in (the target system). The process of representation necessarily involves simplification and judgements must be made about which details should be included. This process raises the question: "What relation does the model have to bear to the target and what is the role of conscious users when a model system is used to represent something?" (Frigg 2010, 252).

The challenges of modelling at city-scale are largely driven by the scale of the target system as noted by Frayssinet et al. (2018), and thus, a considerable level of judgement must be used when developing a model system which fits the limits of computational power available. In particular, the use of archetypes may be especially sensitive to subjective decision-making about "typical" characteristics. For example, it is easier to model buildings or systems that are well understood and have good, reliable datasets than ones that do not. Building energy data availability and robustness differ dramatically between countries and regions of the world (Shnapp and Lausten 2013), which means that the evolving world of UBEMs is an uneven playing field. This section sets forth three reasons for (re)considering how UBEMs are shaped and by whom: the relationship between research and practice, geography, and human behaviour.

TOOLS FOR WHOM? RESEARCH IS NOT PRACTICE

Models are often described as "tools". But a model that is designed for, and is useful in, an academic setting may have little or no direct applicability in the real world. A recent research report looked at 42 projects covered by the UK's adaptation and resilience in the context of change (ARCC) research network (Jenkins 2017). All of these research projects included dissemination plans, and some of them aimed to provide models, visualisation tools, or data for stakeholder use. Researchers interviewed in the study "highlighted issues surrounding the usefulness of the data they provide, including whether decision makers can fully understand, interpret, and use data in the manner it is provided, and how outputs will fit to the specific needs of stakeholders involved in complex decision-making processes" (Jenkins 2017, 4). In particular, specific expertise, coding experience, and datasets may be needed to run the models. The technical skills and time necessary to turn a research model into one that is useful to an external stakeholder may be well beyond the capability of a single PhD student, or even a larger research group. User-oriented software development has a process and lifecycle that is different than building an internal model run by knowledgeable experts.

GEOGRAPHY MATTERS

The process of simplifying a complex target system to produce a manageable model system is inevitably influenced by geographic context. Where such context is represented by model options, translating a model from one context to another is straightforward. Where the context is implicit in the elements omitted from a model, there is significant potential for mismatch between target and model systems. In particular:

- Models based on developed cities may not be able to represent the stock dynamics of developing cities. UBEMs typically assume a static building stock, but in many developing countries this is not a robust assumption. Manu et al. (2011) estimate that 70 % of India's 2030 building stock had not yet been built, and Africa is predicted to have the fastest construction industry growth rate of all the major regions of the world (African Review 2018).
- Some thermo-physical processes are more important in particular contexts. For example, the impact of shading is reduced closer to the equator where the sun is higher in sky. In addition, higher surface temperatures mean increased importance of longwave radiative heat transfer between surfaces. Few UBEMs currently include long-wave radiative transfer between adjacent buildings.
- An assumption of formal codified construction: where structures are self-built or building code enforcement is weak, existing structures may be poorly characterised by standardised building fabric details based on building codes.

Not only will buildings be designed and constructed differently in the global south, for example due to climate and availability and cost of materials, but also occupancy will vary. Occupancy density and patterns of use are likely to vary significantly from those seen in the global north (Debnath, Bardhan, and Jain 2017). This brings us to the question of how people (not just buildings) are represented in models.

PEOPLE IN MODELS

Janda (2011) argues that "Buildings don't use energy, people do", and Peng et al. (2012) note that building energy use is greatly influenced by the way in which people move, open or close windows, use appliances and interact with building systems. A key challenge in building simulation is how to represent occupant interactions with buildings and their energy-consuming systems. Although an emerging body of work using stochastic models for occupant/building interactions exists, the norm remains to use standardised deterministic schedules (Yan and Hong 2018). These deterministic schedules are based on underlying assumptions of occupant demographics and behaviour, even where not explicitly stated.

The translation from target system to model system described by Frigg (2010) is, at least partly, a subjective process with the modeller deciding which characteristics should be explicitly captured in the model system and which can be omitted. When creating occupancy profiles, this subjectivity can lead to a narrow range of cultural stereotypes being applied. For some UBEMs a single schedule is used, implying a single typical pattern of daily life. More sophisticated approaches introduce a range of different profiles. For example, Shimoda et al. (2004) identify 23 household types. However, a key assumption remains that the domestic and commercial are distinct, with a household's economic activities undertaken outside of the home. In both developed and developing countries, this assumption proves difficult to support as "working from home" is increasingly a global practice (Hampton 2017; Surdoval 2017) and the informal economy active in many countries operates outside traditional workplaces. In addition, social patterns of energy use are changing: between countries, within countries, and over time (Wilson et al. 2015; Johansson et al. 2012). Because of these complexities, energy practices and behaviours generally receive short shift in energy models (Lutzenhiser and Moezzi 2010; Moezzi et al. 2009; Moezzi and Janda 2014).

The (in)visible importance of informal settlements

This section argues that slums are a necessary focus of further study. It begins by describing what a "slum" is. Next we describe ways in which they are invisible to policy makers and how models might help them be made more visible.

WHAT ARE SLUMS?

Slums have many names, including: informal settlements, townships, barrios, favelas, colonias, ghettos, shack lands, or shantytowns. Many of the world's slums are so large and long-standing they have their own proper names, as denoted by Wikipedia's "List of Slums" page (Wikipedia 2019).

Slums are officially defined by UN-HABITAT (Mwelu 2015) as housing in an urban area where the inhabitants lack one or more of the following:

1. Durable housing of a permanent nature that protects against extreme climate conditions.
2. Sufficient living space, which means not more than three people sharing the same room.
3. Easy access to safe water in sufficient amounts at an affordable price.
4. Access to adequate sanitation in the form of a private or public toilet shared by a reasonable number of people.
5. Security of tenure that prevents forced evictions.

Globally, one in eight people live in slums, and informal settlements are a significant feature of cities in the global south. 30 % of the populations of these cities live in slums, and while the proportion of slum dwellers is decreasing, their total population is increasing (UN Habitat 2016, 13). One of the greatest challenges for urban development is "how to build resilience for the billion urban dwellers who are estimated to live in what are termed informal settlements. These settlements have been built outside the 'formal' system of laws and regulations that are meant to ensure safe, resilient structures, settlements and systems" (Mwelu 2015). UN HABITAT's New Urban Agenda highlights the need to address informal settlements to achieve a number of SDGs including improved health, poverty eradication, economic development, gender equality, social cohesion and energy access. The New Urban Agenda also recognises the difficulty in addressing the growth of slums and improving living conditions within them. Factors include inability to build enough adequate housing at a speed to accommodate immigration and population growth, limited municipal budgets, legal complexity and environmental consequences (UN Habitat 2017, 2016). Slums are therefore a significant and enduring reality for urban populations in the global south, improving slum dwelling is a core concern, and energy access is intricately related.

Academic research on slum dwelling and energy use indicate further complexity beyond the economic and technical aspects of providing energy services. Parikh et al. (2012) demonstrate how energy access is linked to livelihoods and aspirations. They show that when slum dwellers' basic services needs are met, they are able to then aspire for better healthcare, housing and education; service provision is therefore bedrock for development. Focusing on the inherently political nature of energy service provision, Gupta (2015) discusses electricity connections in Indian informal settlements, explaining that electricity connections

> … can be leveraged to prove residence and thereby to convert unauthorized hutments into legal occupancy. Therefore, power companies refuse to give official connections to residents of slums. However, they recognize that people need electricity to live in an urban environment. Thus, they unofficially allow slum residents to tap into power lines. Politicians, police, and bureaucrats are all complicit in this lawbreaking, going so far as to collect rent from residents for unauthorized access to electricity. For their part, residents do not pay for the electricity they use, even if they pay an equivalent amount in bribes (A. Gupta 2015).

Such analysis indicates the complexity of extending energy access to slums because it is embedded within politicised struggles to formalise and upgrade informal settlements, but it also indicates the need to investigate energy services in informal settlements in order to produce a more complete picture of current energy use for urban energy planning.

HOW ARE SLUMS INVISIBLE?

Excluding informal settlements from UBEMs could be justified on the grounds that the energy consumption is limited, while the academic resources needed to incorporate this consumption in the model would be high. However, as the research cited above demonstrates, access to energy is about more than energy consumption. Energy access is fundamental to sustainable urban development. By excluding informal settlements from their calculations, UBEMs risk adding to the impediments faced by slum dwellers and contributing to reproduction of their exclusion into the future.

Castan Broto et al. (2017) argue for the need for better approaches to urban development that can include slums. They assert:

> Problems in slums are 'invisible' when government officials do not acknowledge their needs or even their existence. On the one hand, local governments may lack capacity to respond to the needs of informal settlements. On the other hand, urban development practices regularly ignore or misrepresent their existence, which may lead to conflicts over land and violence (Castán Broto et al. 2017).

In recognition of this issue, UN HABITAT identifies service provision to informal settlements as a key concern. Its New Urban Agenda states, "the spatial organization, accessibility and design of urban space, as well as *the infrastructure and the basic services provision*, together with development policies, can promote or hinder social cohesion, equality and inclusion" (UN Habitat 2017).

HOW ARE SLUMS MADE VISIBLE IN MODELS?

While informal settlements are not a feature of existing UBEMs, there have been some promising attempts to characterise informal settlements in building energy models. These exist in both developed and developing countries and could serve to provide a quantitative basis for evidence-based policy making as well as technical guidance for residents.

In the USA, for example, Yenerim et al. (2011) created a 3D model based on four dwelling archetypes for which monitored data was collected in Laredo, Texas. The aim of this study was to provide information, which could be used by residents of the colonia being studied, to improve their dwellings themselves. This study highlighted the need for detailed information on the diverse range of building types found in informal settlements.

In India, Debnath et al. (2017) point to slum redevelopment projects, which move residents from low-lying horizontal developments into purpose-built high-rise buildings. The new morphology compromises opportunities for natural ventilation with negative consequences for internal temperatures and occupant health as a result. Similarly, Nutkiewicz et al. (2018), undertook a parametric study using a dynamic building simulation engine, EnergyPlus (US Department of Energy 2018) to compare three different morphologies for a slum redevelopment project. The study was based on a single dwelling archetype for which on-site data was collected in Mumbai, India. The study found that commercial priorities in slum redevelopment in Mumbai have the potential to compromise living conditions for the inhabitants the redevelopment is theoretically designed to help. Using dynamic thermal simulation, these authors compared the low-rise layout of existing slums to the planned high-rise replacement housing. The choice of vertical morphologies was driven by commercial arrangements which allow vacated land to be redeveloped at market rates, and resulted in developments "constructed with the motive to maximize occupancy […] without paying much attention to ventilation, sanitation, hygiene and access to daylight" (Debnath, Bardhan, and Jain 2017, 2747).

In Asia and Sub-Saharan Africa, Gupta (2017) conducted a study of slums in 52 countries using a bottom up analysis to provide a picture of what slum redevelopment might contribute in terms of energy savings and greenhouse gas emissions reductions. The study concluded that 46 % of final energy in this population could be saved between 2014–2040, with a GHG reduction of 58 million tonnes. Moreover, the developmental benefits of energy efficiency actions would be critical to achieving the UN's Sustainable Development Goals.

These examples show that building models can help make energy use in slums visible, both now and in the future.

Conclusions and next steps: academic research and urban practice

We agree with Ottinger and Cohen (2012) that the complexity of global environmental crisis requires new modes of scientific research. Stock modelling is a powerful tool in local and regional energy research. This paper suggests that bringing in methods and insights from the social sciences can help UBEMs to address their own inherently political nature. The question is: how might this best be done?

Beyond academia, we also recognize that impacting practice in the real world is a critical part of a creating a viable future. The best book or paper in the world will not live up to its potential if it is only read by academics rather than creating change on the ground. So we also offer very preliminary thoughts about how a participatory process might evolve that includes slum residents as decision makers.

MODELING CITIES: OPPORTUNITIES AND CHALLENGES

Cities are 'pathways of global change' (Parnell and Robinson 2017) and are pioneering climate change mitigation and adaptation initiatives (c.f. Castán Broto and Bulkeley 2013 on the global south; Heinrichs, Krellenberg, and Fragkias 2013) City planning and management offer potential for radically reworking the ways that people live and work. Including slums in UBEMs could be an opportunity to pioneer new ways of carrying out urban research. Parnell and Robinson (2017) have argued persuasively that urban theory needs to be rethought from the perspective of the global south in order to adequately interrogate and direct global urban transition. As cities in the global south house ever more of the global population, methods that academics develop to help manage and govern these cities need to be fit for purpose. Ignoring a significant part of the urban environments of the global south not only makes the usefulness of such models uncertain, it also constrains the possibilities to adequately theorise and investigate the world's urban transition.

The arguments to include informal settlements are compelling from a social justice perspective, as well as from an academic perspective. In academic terms it is an opportunity to develop a new approach to UBEM modelling that extends academic knowledge and creates new ways of working. From a practitioner perspective, it offers an opportunity to develop new energy planning with tools that create a more accurate picture of urban energy consumption and which can support inclusive urban development. Nevertheless, the challenges are significant, as briefly outlined below:

- *Archetypes*. Nukiewicz et al. (2018) highlight the challenges of collecting data on building fabric, construction and geometry in informal settlements where accommodation is often self-built using salvaged materials, and emphasise the need for intensive data collection to populate models.
- *Patterns of energy use in buildings.* The distinction between domestic and non-domestic buildings is unclear and unhelpful in settlements in the global south, where people use their homes as part of an informal economy and/or because traffic is too congested to get to work. The recognition and physical upgrading of a slum (e.g. through street networks, tenure and access to services), can generate livelihood opportunities while razing a slum will have huge consequences for livelihoods and income generating opportunities. While opportunities exist to upgrade dwellings to improve energy efficiency, options are often limited and may require reconstruction of an area.
- *Data*. A key challenge in developing any model is data availability. In the global south, there is a lack of data on individual buildings and existing stocks for formal settlements, but there are even fewer data available for informal settlements. Even basic data, such as the population of an informal settlement may be lacking as such settlements may be overlooked and ignored by official censuses. Populations may also be highly variable since intra-regional and rural-urban migration is in flux, meaning such data is quickly obsolete. Possible alternative sources of data include: satellite data, which may be difficult to interpret (Fallatah et al. 2018) and community mapping. This latter can empower marginalised communities (Chambers 2006; Panek and Sobotova 2015) but there have been some barriers, too. Illiteracy may complicate community-led mapping (although this may be addressed through the use of user-friendly GIS and GPS software), and the reliability of the data generated (Warner 2015).
- *Institutions and governance*. Utilities and local authorities are generally not interested in upgrading informal settlements. Utilities see limited financial income generated by electrification (but also safety issues) (Lemaire and Kerr 2016; Castán Broto et al. 2017). Municipal policymakers

still often see informal settlements as places to be eradicated rather than upgraded. Furthermore, many countries do not have land registries, making it difficult to strengthen tenure conditions.

In terms of practicalities, including slums in UBEMs requires a significant commitment of academic resources and stakeholder contributions. It requires interdisciplinary working as well as an engaged approach which embraces practitioner and lay communities' knowledge and aspirations. Even if these practical issues can be overcome, there remains the ethical challenge of carrying out such work and ensuring that slums and residents of informal settlements are adequately represented.

An approach that includes social science academics in the modelling process would still open up questions over who is able to speak collectively for slum dwellers and translate individual lived experiences and energy using practices into useable modelling inputs. Furthermore, working across disciplines does not automatically ensure that contributions are equal. Including informal settlements into UBEMS could embed existing structures of power rather than rework them. Superficially simple issues such as whether a neighbourhood is predominantly residential or mixed use can become politically loaded as they incorporate debates over legitimate use of urban space and the rights of different social groups to support their social and economic reproduction. Questions therefore remain about the possibilities that are opened up if slums and informal settlements are included in UBEMS, such as whether their inclusion would lead to material changes for the communities that live in those settlements, on whose terms and with what social, economic and environmental impacts.

BEYOND ACADEMIA: DEVELOPING A PARTICIPATORY PLANNING PROCESS

Because of the complexities in representing slum dwellers by proxy, we conclude this paper by briefly considering the practice and process of urban planning itself, contrasting the expert-led system with more participatory (Arnstein 1969), inclusive (Porter and Onyach-Olaa 1999), or polycentric (Ostrom 2010) ways of working. A complete review is beyond the scope of this paper, but it is important to note that UBEMs are largely envisioned as an expert system rather than a participatory one. In an expert decision-support system, researchers provide information to planners and policy-makers who, in turn, make decisions on behalf of the populace. However, ensuring equitable solutions across a diverse population is extremely difficult. Managing energy access can privilege certain social groups and disenfranchise others. While extending decision-making to community stakeholders does not automatically grant a "fair" result, chances are it will be more fair if there is greater community participation than if there is less. Toward this end, we point toward the idea of 'polisdigitocracy' recently advanced by C40 Cities and ARUP (Cosgrave et al. 2015). This idea connects digital technology, citizen engagement, and climate action. While admittedly optimistic at the urban scale, there is evidence from environmental justice communities that citizen science can be a powerful tool to help disenfranchised groups interact with formalised groups (Allen 2018). Perhaps the need for greater data for UBEMs may help provide seats at the decision-making table for slum residents.

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