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A deep-narrative analysis of energy cultures in slum rehabilitation housing of Abuja, Mumbai and Rio de Janeiro for just policy design

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Keywords energy justce; poverty; computational social science; policy design; machine learning ; textual analysis

JEL Classification D63, I30, Q48, R20

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1. Introduction

Distributive energy justice as a policy instrument is crucial to meet UN-SDG 7 (clean and affordable energy for all) targets at the poorest section of the society, especially for rapidly urbanising Global South. The forces of urbanisation are mobilising millions of citizens from rural and low-income areas to cities for a better quality of life. However, the cost of this mobilisation is reflected in the ever-increasing slums settlements. Recent estimates show that a quarter of the world's population lives in slums (1). Energy is regarded as the 'golden thread' that can aid in poverty alleviation by connecting economic growth, social equity and environmental sustainability (2). However, energy, which is measured in physical quantities, cannot be weaved to address poverty. Instead, it is the benefits that people derive from energy carriers that contribute to well-being (2).

People use energy to derive specific energy services that contribute to their well-being, termed as human-scale energy services (3). For people living in poverty, they are likely to be concerned with the provisioning a range of essential energy services that can improve their well-being (4). Physically these essential energy services must provide the minimum of lighting, cooling, heating, charging and powering appliances. At the same time, socio-culturally, it must also satisfy the need for comfort, convenience and cleanliness (5). The current energy governance regimes in the Global South are based on top-down institutional narratives focussed on assessing modern energy and arbitrary rates of minimum consumption that do not necessarily always translate into improved well-being effects (4,6). Distributive energy justice provides a conceptual platform to integrate the spatial, temporal and social dimension of energy to maximise welfare benefits from energy services in poverty (7–9). Distributive justice deals with the 'distribution of material outcomes, or public goods such as resources or wealth and public bads such as pollution or poverty' (10). We believe it can be a useful tool in wielding poverty alleviation policies by appropriating the needed human-scale energy services in the poorest section of society.

In this purview, we explore policy pathways in poverty through a distributive energy justice lens in three rapidly urbanising cities of Global South using narratives as the primary data object. Here, the context of poverty in rapid urbanisation is established through the investigation of slum rehabilitation housing (SRH) in Brazil, India and Nigeria. Slums become the first habitus of the low-income population which migrates to 'big' cities. The government often use policy instruments like social housing and SRH to rehabilitate these people from the slums to formal houses with a vision of improving the quality of life (11,12). However, market and political-economic forces often impede the trickle-down welfare effects of these social housing (12,13). Recent studies have shown that poor built environment design of SRH deteriorates the quality of life of occupants, putting them to added poverty burden, including energy poverty (14–17). We investigated this built environment – poverty link by exploring energy cultures (after (18)) in SRH in the three metro cities, Rio de Janeiro in Brazil, Mumbai in India and Abuja in Nigeria. The SRH models are now being replicated across the Global South as a successful poverty alleviation strategy (19). The associated injustices must be removed before it further deepens the divide and increase the poverty penalties (20).

The novelty of this study lies in the applied policy design strategies for distributive energy justice in poverty in a bottom-up manner. In doing so, we derived critical policy focus points in the SRH by connecting the grounded realities of energy service demand, built environment design and utility governance. Such voices on energy injustices in urban informality remain scarce in the current literature, and this study uniquely contributes to this gap. This study is an empirical extension of a data-driven policy design methodology presented in (21), that uses machine learning and constructivist grounded theory for narrative analysis. In doing so, this study uniquely analyses the narratives of energy injustices in three contextual typologies of SRH of the Global South for enabling distributive energy justice at the grassroots population. This study intends to generate a methodology of collective intelligence from words against energy injustices in poverty in a bottom-up manner. It can extend contextual energy interventions that are just and sustainable to the vulnerable groups.

The primary research question of this study is, 'What are the energy injustices in slum rehabilitation housing?' To answer this question, we employed three boundary conditions. First, we adopted the welfare-based definition of distributive energy justice in poverty that builds on the accessibility and subsistence of the energy system which provides people with an equal shot of getting the energy they need for improving their quality of life (see Chapter 7, (8)). It set the scope of this study towards investigating the current state of human-scale scale energy services in the SRH and its associated energy cultures.

Second, we expanded on the poorly built environment design characteristics of the slum rehabilitation housing across Brazil, India and Nigeria as a common point of analysis. It enabled us to interpret distributive energy justice as an externality of the built environment design. This assumption was critical to envelop the distinct socio-cultural difference in the three SRHs, however, allowing a comparative ground for inclusive policy design.

Third, we extracted the pinch points of just policy design in the study areas through a macro- and micro-level deep-narrative analysis. The macro – level analysis consisted of an aggregated (*zoomed-out*) assessment of energy cultures narratives to extract latent themes of energy injustices in the SRH built environment. The micro – level analysis involved a granular (*zoomed-in*) investigation of the case-specific energy narratives in poverty and the demand for human-scale energy services (HUSES). The zoomed-out and zoomed-out approach was to discover the commonalities and contrast the injustices in the study areas.

The specific research objectives of this study are, a) to evaluate the latent links between human scale-energy services and built environment characteristics in slum rehabilitation housing; b) to use narratives as a data object for energy policymaking using computational textual analysis; c) to derive policy focus points that can promote distributive justice in low-income communities, like the SRH. Policy implications for SRH were drawn concerning UN – SDG 7 (clean and affordable energy) and SDG – 11 (sustainable cities and communities) goals.

2. Background

2.1 Energy justice, poverty and energy services

The contemporary research on energy justice and poverty alleviation focus on two broad themes of essential energy services and well-being (4) that redefines energy as a "… golden thread that connects economic growth, social equity, and environmental sustainability" (22). In this vein, global efforts to address energy poverty are primarily framed in technical terms that modelled the physical dimensions of 'modern' energy services. Furthermore, achieving minimum rates of energy consumption to improve the health and well-being of people living in poverty (23,24). The search for 'good' heating and cooling policies in the Global North and Global South, respectively, remains an 'energy justice' challenge in the uncertainties of climate change (25). Addressing this challenge is more critical in poverty as the well-being outcomes are deeply coupled with the availability of a broad range of socio-economic energy services that happen to require energy for lighting, cooking, cooling, heating, charging and powering appliances. The 'golden thread' embodiment of energy in poverty alleviation, is not an end in and of itself, but rather, a means through which a wide array of 'human-scale' energy services can be provisioned for better well-being (2,4).

Human-scale energy services are referred to the socio-technical dimension of energy needs that extend beyond the physical quantification of energy and power (e.g. in kilowatt-hours, kWh, or kilowatts, kW). The human dimension of energy services relates to socio-cultural drivers of energy service demand, which sociologist Elizabeth Shove categorises as the energy needed for comfort, cleanliness and convenience (26). This concept was further expanded in the theoretical proposition of urban service energy ladder (5), and energy cultures (18). Brand-Correa, Martin-Ortega, & Steinberger (2) expanded the applicability of such an abstract concept of human-scale energy services through the introduction of a community-led participatory approach, called HUSES

(Human-Scale Energy Service provision framework). HUSES intended to identify connections between energy services and human satisfaction, such that the community paves its pathways to satisfy its socio-technical needs for energy services. Application of HUSES in local communities of Medellin Columbia has shown that communities derived effective provisioning of energy services of Information and Communication Technologies (ICT) and mobility. It indicates the need for similar human-centric energy service considerations in the current policy regimes as drivers of sustainability and well-being.

Samarakoon (4) expanded the understanding between HUSES and well-being in the energy-poor of the Global South by forwarding a conceptual framework to link eudemonic well-being with energy justice. The framework is based on two foundational concepts, a need-centred understanding of eudemonic well-being, and viewing energy use through the lens of energy services. The author implied that a strong understanding of the issues of energy justice is needed to provide energy services for poverty alleviation efficiently. However, this study did not empirically define energy service into the specificities of social and technical dynamics of energy services. Such an empirical representation of the social dimensions of energy services in the Global South remains a critical literature gap (see Fig 1). It is primarily because top-down narratives have long shaped energy narratives in the Global South from institutions in the Global North.

The non-western philosophical background of energy justice was framed in (27) using Amartya Sen's capability-based interpretations of the Hindu *Bhagavad Gita*. The authors expanded on *Gita's* time-based designs of 'duty-focused' and 'consequence-sensitive' decision outcomes to short-term and long-term policymaking concerning energy poverty alleviation and just energy-transition, respectively (27). A post-colonial conceptualisation of just energy transition in Mozambique (28) destabilised the common assumptions in energy research, and the authors called for more empirical evidence and contextual understanding from the Global South to enable just energy transition. In Sub-Saharan Africa, energy injustices were associated with gender and education inequalities (29). In a recent review paper by (30) on energy justice in the developing world, the authors suggested four ways of expanding the current theoretical developments of the field. It includes contextual attention to neglected regions, the inclusion of non-western philosophies, emphasising on systems approaches to low-carbon transition and developing empirical frameworks to aid decision-making.

2.2 Policy design and modelling approaches for distributive energy justice

Public policy is often considered as the solution to correct injustices associated with the challenges of energy transition (10). However, policies intended to transform the energy system are observed to have justice issues themselves as the energy and climate models have some degree of directional biases in the current regime of energy policymaking by scientists and technologists (25,31,32). It is attributed to the justification of technocratic propositions of preferred 'science and technology' complimenting the objectives of the leading political forces (25). It restricts the scope of climate and energy system models, making them ineffective across the horizontal societal domains. Technology is indeed inevitable to address climate change and sustainable development goals, but policies should also be wielded with the welfare goals that a specific technology can deliver. Thus, resolving the 'last mile' problem in systems planning (33,34). While a growing number of studies have empirically investigated injustices associated with energy and climate policies in the Global North, but they were exploratory. They did not converge into the specificities of policy modelling for energy justice. For instance, Grover & Daniels (35) spatially explored the distributional injustices associated with the feed-in tariff as a policy instrument for deploying clean energy in England and Wales. They had used cross-sectional regressions to link settlement density, homeownership status, physical dwelling type, local information spill overs, and household social class as crucial non-income variables of distributional energy justice (35).

Similarly, Day, Walker, & Simcock (36) have used the capability approach to conceptually scope the policy route to distributive energy justice in energy poverty. It was then expanded in (37)in establishing a minimum of energy use in the United Kingdom for addressing energy poverty. The authors have reasoned that establishing a minimum of energy-use is multidimensional that traverses public policy concerning questions of

health, social participation, opportunity and practicality (37). They argued that public deliberations on bare essentials of energy services should be taken as legitimate grounding for defining minimum standards (37). This argument serves as a critical foundation for this study, as we derive policy focus points through public deliberations of living in slum rehabilitation housing and the demand for human-scale energy services. In a recent exploratory study by Zhou & Noonan (38) on distributive justice implications of clean energy policies in the United States have observed racial and socioeconomic disparities in three government-driven clean energy programs. The authors reported that the likelihood of smart meter rollout is governed by the racial bias of utility companies, and inequalities in funding clean energy programs (38). They also found that improving the government's procurement policy can improve distributive equity for energy-efficient buildings (38). Thus, revealing race and socioeconomic composition as a crucial element of distributive energy justice policy planning.

A recent book edited by Bombaerts, Jenkins, Sanusi, & Guoyu (39) titled 'Energy Justice Across Borders' sheds light on energy justice in practice in the Global South. Kruger & McCauley (40) conducts a qualitative-based spatial exploration of justice in the Democratic Republic of Congo and the grid systems derived from hydropower. The authors explore injustices in macro and micro typologies to deconstruct the pre-determined Wester logics of justice associated with energy provisioning. Similar conclusions were made by (41) at a global scale. We apply similar deconstructivist approach through topic modelling in this study. In the same book, (42) argued the need for gender parity and social inclusion in the context of just electricity policies in India, Kenya and Nepal. They assert that the assumption that electricity access itself is enough for associated welfare benefits for both men and women is wrong, and this 'gender-blind' approach in energy policymaking needs to change (42). They found that the lack of documented evidence on the merit of gender parity in electrification policies and programmes further aggravates gender-blindness in the current regimes of energy policy. Our study contributes to this gap by exploring women voices in energy cultures in poverty.

Tucho (43) argues that a significant barrier to distributive energy justice policy modelling is the weak understanding of local contexts and societal needs, and lack of bottom-up innovations. The author calls for gender parity in energy policies for low-income countries such that just energy provisioning materialises in income generation and poverty alleviation (43). A conceptual policy modelling approach for addressing energy injustices was presented by (44), which was then applied to the case of South Korea's nuclear power system and Seoul's One Less Nuclear Power Initiative. The authors argue that in just low-carbon energy policymaking shedding light on underlying drivers of energy injustice embedded in the dominant modern energy paradigm is crucial for energy justice (44). Debnath et al. (45) presented an empirical approach to just policy modelling in a low-income built environment through the lens of socio-cultural energy services of comfort, cleanliness and convenience. Similarly, (21) presented a computational approach to extract critical energy narratives in a bottom-up manner through a nested application of natural language processing and grounded theory. This study is an empirical extension of (21) to enable inclusive energy policy design in slum rehabilitation housing of rapidly urbanising Global South.

3. Methodology

The overall methodological framework adopted in this paper is illustrated in Fig 1 that consisted of focus group discussion in slum rehabilitation housing (SRH) across the study areas, and its deep-narrative analysis using the computational framework presented in (21). The empirical expansion of the deep-narrative analysis framework was performed in two scales, macro and micro-level (see Fig 1). The macro-level consisted of aggregated narrative analysis of the energy cultures across the SRH's in Brazil (Rio de Janeiro), India (Mumbai) and Nigeria (Abuja). This macro-level analysis provided an overarching ground for discovering energy injustices from the narratives in the low-income built environment. It is the case of *zooming-out* of the narratives to view the broad energy cultural identities associated with the SRH. Whereas, the micro-level analysis provided a comparative ground for crystallising the narratives of energy injustices of the socio-culturally distinct SRHs by *zooming-in* into the narrative texts. This feature of zoom-in, zoom-out and zoom-through the narratives made

the empirical application of the deep-narrative analysis framework unique to this study. Thus, enabling us to simultaneously visualise the horizontal and vertical elements of distributive injustices at the grassroots level.

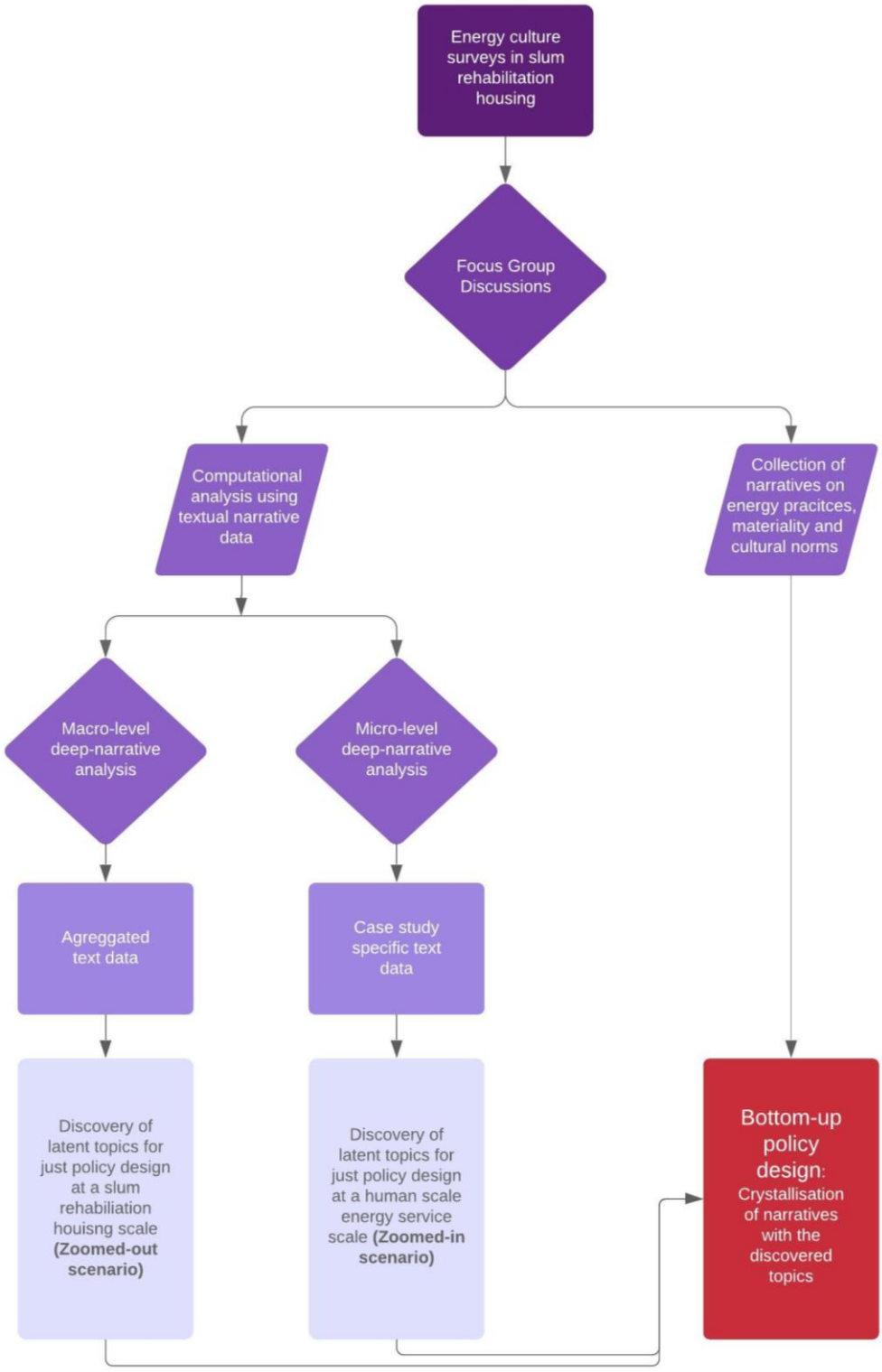


Fig 1. The methodological framework of this study

3.1 Data collection and study area

Focus group discussion (FGD) was the primary tool of data collection in three distinct slum rehabilitation housing in Brazil, India and Nigeria, in the cities of Rio de Janeiro, Mumbai and Abuja, respectively. FGDs were conducted as per the best practice guidelines of (46,47). The interviews were conducted to extract grassroots-level information on human-scale energy service demand in poverty, using the lens of energy cultures (after (48)). Recently, (49) have used a similar approach to energy cultures investigation in Kenya, and it provides valuable clues for this study to conduct the FGDs, offering coherent explanation as to why electricity consumption in rural households remains low even after connection to an electricity grid, and analyses the value ascribed to different end-uses.

Energy cultures theory explores the interaction between energy practices, socio-cultural cultural norms and material reality that shapes the need for certain energy services (48). It provides a theoretical tool to map the cultural barriers associated with human-scale energy services (HUSES). A recent application of energy cultures theory explored cultural barriers to just low-carbon transition, emphasising contextual factors associated with energy end-use, demand, and consumption (50). Similarly, (51) argued that insights from culture are critical in guiding energy planners and policymakers to stimulate just transition at the time of rapid technological change.

Using this applied epistemology of energy cultures, we encouraged informal dialogues with women of the SRH communities concerning practices (like appliance use, energy-built environment connections), norms (like the use of a specific appliance) and material reality (like appliance ownership drivers) of energy consumption in the study areas. The open-ended questions of the interviews are illustrated in Table 1. We specifically interview women as the women in such low-income communities spend most of their time in the community, interacting with the built environment, while the male member goes out to work.

Table 1. Questions to explore energy cultures in the study areas through FGDs

Energy cultures components	**Open ended questions on**
Material reality	• Household appliance ownership • Energy sources and services • Cooling devices • Built environment and architectural characteristics
Norms	• Aspirations associated with housing and appliance uptake • Expected comfort levels • Expected changes to built environment and housing characteristics • Gender roles on appliance purchasing decision • Energy bill expectations and realities
Energy Practices	• Utility governance in the neighbourhood and tariff mechanisms • Appliance usage and cooking practices • Cooling device usage • ICT device usage and interactions (smartphones and Wi-Fi use) • Energy use and socio-architectural influences • Utility of welfare appliance (refrigerator and washing machine) • Maintenance of devices • Power quality and reliability (load shedding)

The labour force participation of women in slums across the world shows that women suffer from time poverty and has a very low labour force participation rate. Women are often responsible for a large share of the household's unpaid care and domestic work, leaving them little time for paid employment, rest and leisure (52). Hence, they were overrepresented in the slum rehabilitation households during our survey hours. For example, as per the Census of India 2011, the workforce participation in slums was 36.4% for all persons, 54.3% for males and 17.1% for females in the working-age group 15-65 (53). In Brazil, women remain the principal caregiver of the family and have a bigger share of domestic responsibilities; this is specifically severe for informal settlements

(54). The 2014 total female labour force participation in Brazil was 43.8% (54). In Nigeria, unemployment is higher for women, with most women employed in casual low-skilled and low-paid informal jobs. Besides, the life of women Nigerian women is heavily affected by myriads of discriminatory, traditional, socio-cultural practices that force their underemployment even in the informal labour force (54).

The gendered approach in this study was further influenced by the findings of (17) that specifically inferred more in-depth investigation of gender-design nexus for energy justice in the low-income built environment. A comparison of SRH typologies showed that building design has a significant influence both on gendered use of space and electricity use through specific appliance ownership (17). It further advocated that gender equality can and should be influenced by energy and housing policies.

The FGD participants were recruited by us asking a local female-contact in each community to bring along some of her community members to a focus group. This method was employed so that a familiar trust was built during the interview process, at the same reduce differential to intra-group differences. The total number of participants in the FGDs in Rio de Janeiro, India and Nigeria were 7, 11 and 7, respectively. The primary occupation of the participants was noted as 'housewife'; however, it was acknowledged that some members were engaged in informal economic activities from home. For example, in Mumbai, many participants engage in tailoring and garland-making to support their livelihood.

Systematic biases in the participant selection process were avoided by discouraging fellow group members from recruiting 'the best' or 'most suitable' members for the task, as per (47). The participants were rewarded with a lunch package on the day of FGDs as a gesture of gratitude for the time committed to the group and as a means of minimising participant attrition. The education level of the participants varied in the three cases. In Rio de Janeiro, most of the participants were primary school dropouts. In Mumbai, the education level of the participants was at a middle school. In Abuja, participants did not attend formal schooling but had some form of informal schooling.

All members of each focus group spoke the same mother tongue that aided in a good conversation. The moderators in the three FGDs were bilingual (mother tongue – English) who transcribed the interviews from the local language to English. In Mumbai the translation was done from *Hindi – English*; in Rio de Janeiro, *Portuguese – English* and in Abuja, *Hausa – English*. The moderators were part of the community, and they obtained verbal consent from each participant before the start of the FGD. They facilitated open, uninhibited dialogues during the FGD through a non-prescriptive and semi-structured interview schedule. It aided in supplementing prepared questions with sub-questions that enabled the authors to clarify a topic and prevent group-effects (47). Reducing the influence of group effects was critical to meet the point of saturation within the 90 minutes duration of each FGDs. A picture of the FGD process is illustrated in Fig 2.

Fig 2. A focus group discussion in progress in Mumbai, India

In qualitative coding, the doubt arises with such heterogeneous transcription as to how far we can transfer concepts and terms across languages and feel confident that they mean the same thing. The multilingual nature of the process will involve uncertainties about the meaning that may induce directional biases in its interpretation (55,56). The use of the deep-narrative analysis methodology is said to reduce such biases as it disintegrates the narrative text corpus into its fundamental elements, 'words'. These words were then reconstructed using the grounded-theoretic lens to reveal latent processes in the society, thus, crystallising the narratives (see Section 4 in (21)). This method provided a higher degree of freedom to zoom-in, zoom-out and zoom-through the problem statement (21,57) (see Fig 1).

The socioeconomic, energy use and built environment characteristics of the study areas are shown in Table 2. The three cases represented variability in the slum rehabilitation context that is critical to understanding energy cultures in poverty. For example, the SRH in Rio de Janeiro was due to informal displacement due to loss of employment in waste-recycling industries. It was privately done by the community members and did not have any state participation. The SRH in Mumbai was a slum upgradation policy of the federal and state government, with state government being the nodal agency. The SRH in Abuja was a federal policy of rural rehabilitation migrants into the city (see Table 2).

Such variability in the SRH further translated into energy provisioning. For example, the Indian case is a vertical slum rehabilitation that restricted access to public/open spaces, in contrast to the Brazilian and Nigerian cases. The Indian households had access to metered electricity grid connections. The Nigerian household had grid connections, but meters were non-uniform across households. Contrastingly, the Brazilian households did not have any formal grid connections or meters. Occupants directly used electricity from overhead electric transmission lines through metal hooks. Such heterogeneities in the slum rehabilitation built environment illustrated the spatial characteristics of distributive energy injustices at the grassroots level. This study further investigates into such injustices within the built environment and cultural scope of SRHs.

Table 2. Socio-economic, built environment and energy-use characteristics of the study area

Characteristics	**Brazil**	**India**	**Nigeria**
Built environment			
City	Rio de Janeiro	Mumbai	Abuja
Percentage of population living in slums in the cities	~ 22% (58)	~ 41% (59)	~ 79% (60)
Slum rehabilitation housing typology	Horizontal, single storey	Vertical, multi-storey	Horizontal, courtyard-type
Slum rehabilitation case	Displaced due to loss of employment in waste-recycling industries	Displaced from horizontal slums due to political-economic forces of urbanisation	Rural to urban migration, forced resettlement
Responsible government agencies	None. Rehabilitation is done privately due to internal displacement and job loss.	Rehabilitation is done through a state-government agency called Slum Rehabilitation Authority. They plan, sanction and allocate the rehabilitation housing. The design and implementation of the plans are performed through market-based approaches (see (11) for more detail on the policy mechanism).	Rehabilitation is performed through federal agencies who have complete autonomy in the rehabilitation planning, allocation and design process.
Number of rooms	2	1	1-3 (variable)
Floor area (m^2)	~20	~25	~24
Socio-economic			
Average household income (monthly)	80 – 160 USD (when employed in the waste-recycling industry)	70 – 140 USD	70 – 100 USD
Primary earner	Head of household (was the husband)	Head of household (The husband)	Head of household (The husband)

Present primary occupation of the HoH	Unemployed at the time of survey and dependent on charity	Daily wage labourer in construction industry, security guard, watchman, taxi-driver	Daily wage labourer, taxi-driver, security guard
Average number of people per household	~5	~5	~7
Informal economic activities	The female members (adults) work as domestic help. The job is irregular.	Few households offered tailoring and garland-making services, run by the wives.	Households with refrigerators, offered water and cold drink cooling services for a fee.
Energy-use			
Grid connected	No, but distribution transformer is present	Yes, some buildings have community owned rooftop solar PV for water pump operations	Yes
Highest household electricity bill (2018-19)	NA	112 USD	83 USD
Average household electricity bill (monthly)	No billing (No grid connection). Electricity stolen from overhead transmission lines (220V lines)	7 – 10 USD (Grid connected). Every household is metered.	8 – 15 USD (Grid connected). Meters are non-uniform across the houses.
Special electricity tariff program	NA	NA	NA
Cooking fuel	LPG, electricity	LPG, electricity, kerosene	Firewood, cow dung, biomass-based
Typical appliances in the surveyed households	Fans, light bulbs, television (TV), oven, smart phones, refrigerators	Fans, light bulbs, television (TV), smart phones, Wi-Fi routers, refrigerators, washing machine	Fan, light bulb, mobile phones, power adapters
Photos of the built environment	 	 	 

3.2 Performing the deep-narrative analysis

The methodology for deep-narrative analysis was adopted from (21). It involved four key steps that employ topic modelling to develop a statistical foundation for grounded theory-based narrative analysis (see Fig 4, (21)). In this study, these four steps were emulated as, step 1 involved deconstruction of energy cultures narratives into word-word, word-topic and topic-topic probabilities (denoted by β) using unsupervised machine learning-based topic modelling. It further removed any panel effect as the interview text corpus was disintegrated into its fundamental constituents. Step 2 involved contextualisation of the derived topic based on high β for crystallisation of the critical narratives on energy cultures in the study areas. The β value-based probabilistic ranking of words in the topic clusters emulated the qualitative steps of open and selective coding process in grounded-theory (21,61). The advantage of using topic modelling was the reduction of biases during this process through unsupervised machine learning (see Table 2 and Section 6 (21) for a detailed reference to the biases involved in computational textual analysis). The best practices on textual analysis for energy research and social sciences was adopted from (62).

Step 3 involved crystallisation of the core arguments from the narratives that began the reconstruction of latent processes associated with energy injustices in the slum rehabilitation housing (SRH) under study. This step enabled theoretical sampling of key term and topic clusters based on high β values, which were then fed into the policy focus point generation (see Fig 1). The step-4 involved derivation of policy implications based on

the topic clusters and theoretical sampling in step 3. This step reconstructed new theories based on latent linkages between energy service and built environment in SRH. This reconstructed represented our policy modelling process that could generalise critical energy injustices in the study area based on the word-topic probabilities. Thereby successfully applying deep-narrative analysis for understanding distributive justice pathways in poverty.

3.2.1 Topic modelling using Latent Dirichlet Allocation (LDA)

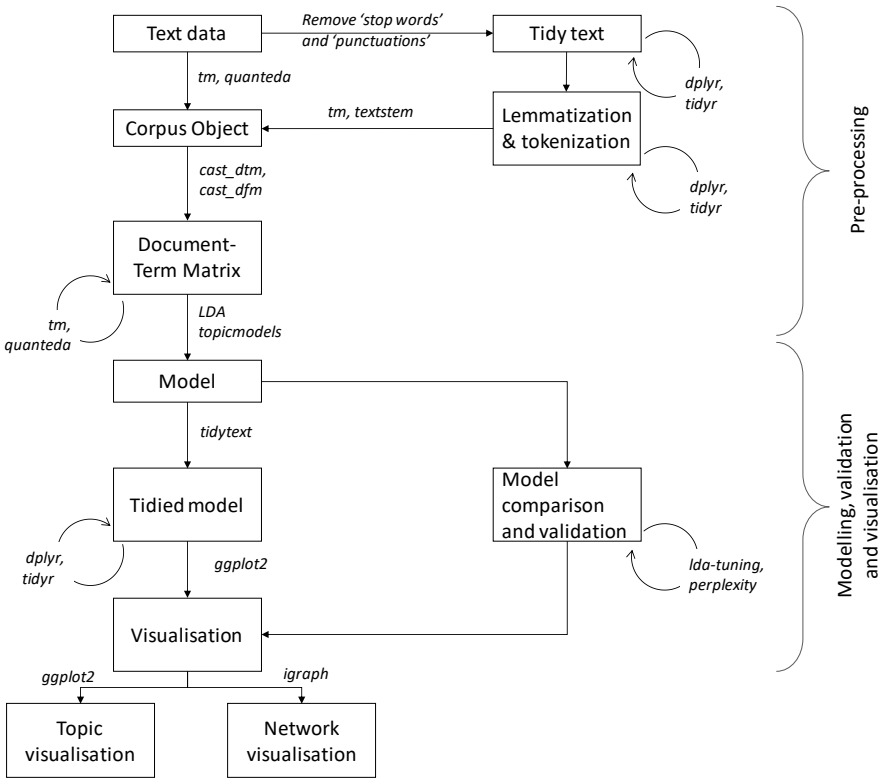


Fig 3. Analytical steps adopted in the LDA-based topic modelling of the narrative text data.
[Note: the text in italics represent the R-library in use. It includes packages like dplyr, tidyr, lda-tuning, perplexity, quanteda, tm, LDAtopicmodels, ggplot2 and igraph]

The LDA computation was done by a publicly accessible toolkit called tidytext; computational tools are written in the R programming language (63). The steps followed in our topic modelling and text analysis is as follows: (1) pre-processing, (2) determining the number of topics, (3) setting the control parameters, (4) cross-validation. The process flow of the topic modelling approach is illustrated in Fig 3. The pre-processing stage consisted of the construction of a Document-Term Matrix (DTM) that structured the text data into a corpus as per the specifications of the tidytext R-package (see Chapter 1, (64)). The entire text corpus had around 27,000 words that included the combined energy cultures narratives from Rio de Janeiro, Mumbai and Abuja (see section 3.1). Each sentence was treated as a unique document in the DTM, that resulted in 504 sets of unique documents (***M***) that had ***w*** (words) and ***z*** (topics) as per LDA model specification (see Fig 4), after the best practice guidelines of (65).

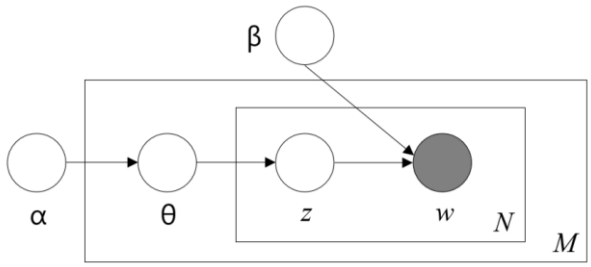


Fig 4 . Graphical model representation of LDA. The boxes are "plates" representing replicates. The outer plate represents documents (M), while the inner plate represents the repeated choice of topics (z) and words (w) within a document (N). 'Θ' is the topic distribution for document i. 'α', 'β' are the hyperparameters of Dirichlet distribution (Source: (65)).

$$p(D|\alpha,\beta) = \prod_{d=1}^{M} \int p(\theta_d|\alpha) \left(\prod_{n=1}^{N_d} \sum_{z_{dn}} p(z_{dn}|\theta_d)\ p(w_{dn}|z_{dn},\beta) \right) d\theta_d \quad (1)$$

The mathematical foundation for LDA is illustrated in eq (1), after (65). As mentioned above, the hyperparameter α and β modulate the word and topic distribution over the corpus documents. Since LDA-driven topic modelling is an unsupervised machine learning (ML) technique, a third hyperparameter gamma (γ) is needed to set the number of topics. This unsupervised nature of LDA-based topic modelling reduces directionality and interpretivist biases in narrative analysis (21,66,67) which are prone to qualitative text classification techniques using commonly used qualitative data analysis tools (like NVivo, ATLAS.ti, MAXQDA, etcetera).

Pre-processing also involved the reduction of stop words from the narrative corpus. Stop words (e.g., 'the', 'of', 'from', words that carry limited information) and punctuations were removed from the corpus using a process called *lemmatisation*. Lemmatisation process involved removal of inflectional ending of words, and converting the grammatical form of a word into the base or dictionary form (known as *Lemma*) (68). The corpus object now contains only the base or dictionary form of words arranged in the required form of DTM. Parameter estimation was performed using variational expectation-maximization (VEM) algorithm in the tidytext package (69). Using this DTM, visualisation of extracted topic and semantic network maps were created using ggplot (70) and igraph (71) packages (see Fig 3).

Cross-validation of the derived topic models was done through perplexity scores (72) and using the ldatuning algorithm in R (73). Perplexity is a measure of how well a probability model fits a new set of data. It was calculated for cross-validation using the 'perplexity' function in the topicmodels package in R (74). The analytical procedure included dividing the data into five different subsets, and each subset gets one turn as the validation set and four turns as part of the training set. Perplexity scores for the given DTM were estimated at both macro and micro-level analysis (see Fig 1). The other cross-validation method using ldatuning algorithm was used in an iterative process to best-fit the model using the benchmarking criteria of Arun2010, CaoJuan2009, Griffiths2004 and Deveaud2014. A similar cross-validation approach was adopted by (75,76).

3.2.2 Grounded theoretic reconstruction for policy focal points

Another core process of the deep-narrative analysis framework of (21) is the reconstruction of the latent process from the narrative texts and topic models for policy applications. This step involved the generation of new theories for policy modelling of distributive energy justice in the SRH using the probability (β) values of word and topic clusters. The policy design steps involved in this analytical process is illustrated in Fig 5. Here, we refer to policy design as the process of reconstruction of the contextualised narrative using grounded theory to inform specific policy focus points in the study areas.

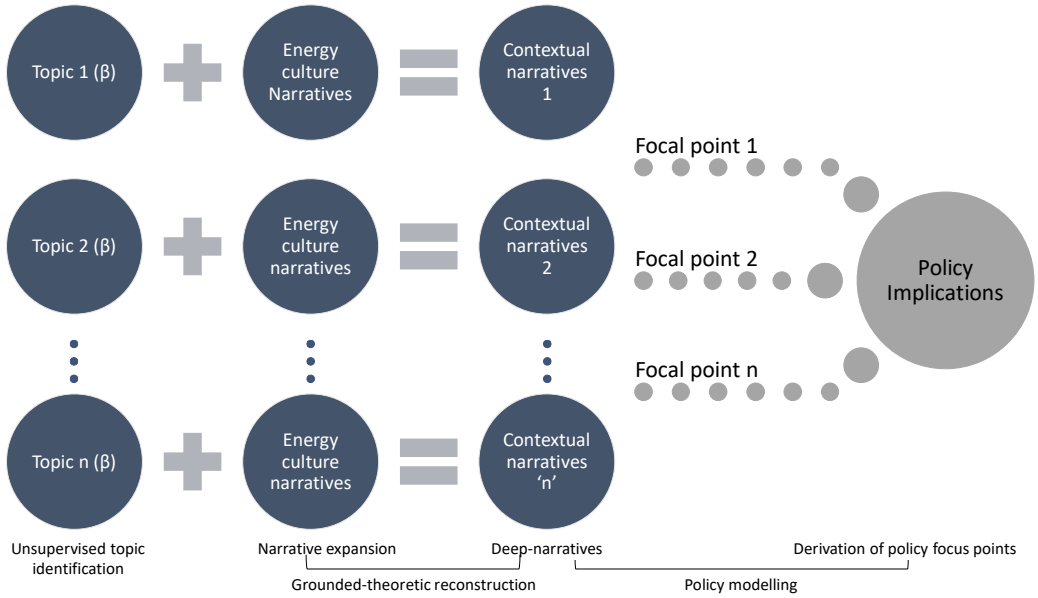


Fig 5. Derivation of policy focus points from topic clusters using grounded-theoretic reconstruction

The grounded-theoretic reconstruction used in Fig 5 is influenced by the constructivist theoretical lens of Charmaz (77). We adopted Charmazian grounded theory (GT) as it offers a broader scope of interpretivism (56), a comparison of Charmazian GT with other approaches can be found in (77). It has allowed researchers to apply structured and systematic inductive methods to investigate real-world contexts of social processes, which remains a critical application of Charmaz's GT to policy research (78). In this study, we employed the deep-narrative analysis framework (21) that demands an inductive and multi-layered approach to narrative interpretation for contextual policy design. Besides, this approach acknowledges the post-modernist turn in the humanities and social sciences to computational social sciences (79,80). It is especially relevant to our analytical context of distributive energy justice as this study uses culture-based identification of injustices associated in slum rehabilitation housing under study (see Table 2).

4. Results

4.1 Description of energy cultures in the slum rehabilitation housing in the study areas

The energy cultures in the slum rehabilitation housing (SRH) in the three cities under study has heterogeneity concerning energy practices, norms and material culture that relates strongly with the typology of the built environment. The SRH typology modulates energy practices from outdoor to indoors. For example, it was found that in Mumbai, the SRHs are vertical buildings that had influenced the energy practices to become more energy-intensive through an indoor shift due to lack of open and community spaces. In Rio de Janeiro, the SRH had a higher degree of informality due to no state control on the planning and execution of the housing. Here, the energy practices were defined by the appliances that were received as donations from higher-income groups. However, in Abuja, the energy practices were highly interwoven with the community ownership of appliances, as these SRHs were horizontal and had well-defined community spaces. Such descriptive characteristics of energy cultures in Abuja, Mumbai and Rio de Janeiro are further discussed in detail in Table 3.

Aspirations play a critical role in defining the norms of the SRH communities under study. It can be seen from Table 3 that owning certain appliances are characteristics aspiration of the study areas. For example, in Rio de Janeiro, energy aspirations are towards owning air conditioners for thermal comfort. In Mumbai, aspirations were for better comfort and convenience through modern appliance ownership like washing machine, microwave ovens and information and communication devices (ICTs). The occupants in the SRH in Abuja revealed aspiration towards refrigerator and TV ownership to shift away from the shared-living situation.

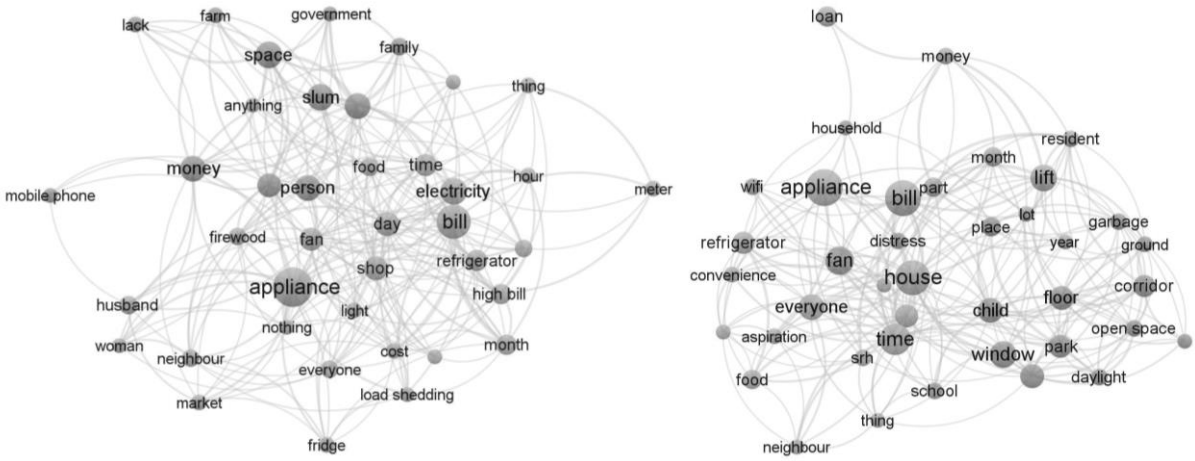
These energy aspirations are also shaped by the built environmental characteristics such that in Mumbai lack of open spaces and cramped vertical structure of the SRH forces occupants to spend more time indoors. It created a shift in energy practices (evident from (16)) that is influencing the socio-cultural energy service demands (also shown in (45)). Similarly, in Abuja, the strong rural-community settings of the SRH had established a shared energy cultural identity which is distinct from urban-living. It is, therefore motivating structural shifts in energy service demand through specific appliance ownership. In Rio de Janeiro, the lack of regulations in the built environment design led to increase in distress and energy demand (see Table 3).

Table 3. Characteristics of energy cultures in slum rehabilitation housing of three cities

Energy cultures	**Rio de Janeiro, Brazil**	**Mumbai, India**	**Abuja, Nigeria**
Practices	- Mixed-use of indoor and outdoor spaces for cooking and washing clothes. - TV watching during the day is a common practice. - Energy service demand for baking, cooling using multiple fans, charging phones, lighting, entertainment (TV) and refrigerator use. - Outdoor open spaces are utilised for thermal comfort when indoor temperature becomes very hot.	- Cooking and washing are all performed indoors due to lack of open spaces. - Common mode of watching TV series is on smartphones. - Energy service demand for cooling through fans, lighting, smartphone charging, entertainment (TV and Wi-Fi), washing machines and using refrigerators. - Lack of outdoor open spaces results in higher thermal discomfort during hot summer days. - Unhygienic neighbourhood conditions (like garbage disposed in the open spaces) pushes activities indoors, increasing the energyuse	- Mixed-use of spaces for cooking and washing clothes. - Limited TV-sets, families watch TV communally. - Energy service demand for lighting, cooling through a single fan and charging mobile phones. Only few houses had a TV and refrigerator. - Outdoor open spaces are often used for community activities (like watching TV series) and maintaining thermal comfort.
Norms and aspirations	- Aspiration of air conditioner (AC) ownership is high due to hot climate. There is also a high aspiration of smartphone ownership. - Lack of employment forces the occupants to depend on charity. - Most appliances are pre-owned, and refrigerators are received as donations. - Lack of toilets and proper sanitation is a health vulnerability.	- High aspiration of modern appliance ownership for better comfort, convenience and cleanliness, representing middle-income consumption pattern. - Multiple utility of appliance ownership for increasing informal income generation. For example, refrigerators are also used to store fresh flowers that is later sold to garland-making market. - High utility from ICT devices like smartphones and Wi-Fi service for the women of the house. It is used for online shopping and watching TV series. Here, ICT devices have a strong gendered advocacy.	- Aspiration of owning just the bare minimum for subsistence. - Occupants have a strong rural-living characteristic that organises community-sharing of appliances. - TV is watched as a social activity in the community. Refrigerators are owned by only few families that levies a fixed charge for drinking water cooling services in summer months. - People tend to derive higher utility from refrigerators, they store cold drink, and sell it the community during hot days. People must pay to store food and drinks in the refrigerators that are owned by only few households.
Material reality	- No electricity meters in the houses, occupants steal it from nearby electric poles. - Appliances are either handed down from higher income households or are received as a part of donation drive. - Lack of toilets, sanitation and hygiene are the most pressing concerns. It has a heavy health burden on the children. - Drug abuse is also a major problem, and the poor quality of built environment enables the proliferation of the drug abuse.	- Utility companies have irrational tariff system that pushes occupants to energy poverty. There is no grievance redressal system with the utility administration and is a major cause of distress in the neighbourhood. - Lack of social spaces in the built environment is a major well-being concern. Occupants say that it is makes them lonely and they must counter it through higher TV-watching. - Lack of safety and hygiene is a serious concern in the built environment. Like illegal parking in the open spaces invites unwanted allied activities and	- Poor power quality and reliability is a significant issue. Heavy use of power stabilizers that damages appliances. - Lack of responsiveness from utility companies concerning high and irrational billing and frequent load-shedding. - Strong community living that enables sharing of specific appliances like TV and refrigerator. - Lack of enough indoor living space is a major built environmental concern.

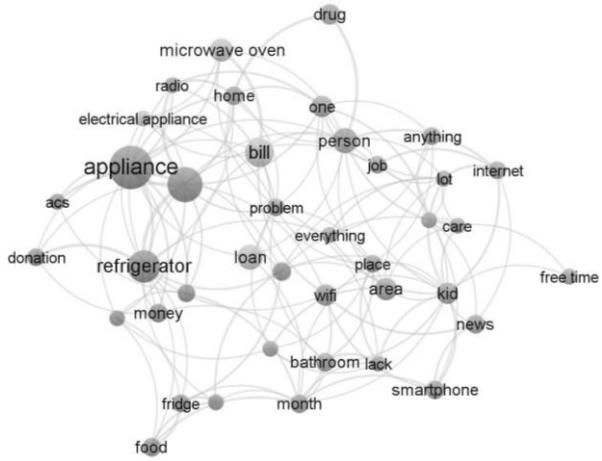
		people which makes the neighbourhood unsafe. the spaces between the buildings have become garbage dumping grounds for people living in the higher floors where sanitation services like garbage collection are often skipped. - High diffusion of ICT devices and occupants avail services from it.	

The heavy influence of the SRH built environment factors in the energy cultures narratives of the occupants in the three cities can also be observed from the semantic network of high co-occurring terms in Fig 6. The built environment effect on the energy cultures is distinct for Abuja, Mumbai and Rio de Janeiro, where the size of the circle denotes the frequency of co-occurrence of that term. Fig 6a indicates terms like 'load shedding', 'firewood' and 'high bills' illustrate energy injustices in the SRH concerning cooking fuel and power quality. Firewood was the most common cooking fuel in Abuja, indicating energy stacking practices in an urban setting. Frequent load shedding and high energy bills were the most raised problem, and it had ramifications in the short operational life of appliances. It added to occupants' energy burden as the repair shops were far from the SRH, and the time – cost associated with it was significant, an example of the spatial characteristics of distributive injustices at the grassroots level.



a) Abuja, Nigeria

b) Mumbai, India



c) Rio de Janeiro, Brazil

Fig 6. Semantic network maps of high frequency co-occurring terms derived from the energy cultures narratives in the slum rehabilitation housing of Abuja, Mumbai and Rio De Janeiro.

High co-occurring terms associated with low built environment quality are across the three semantic network maps in Fig 6. For example, in Abuja, 'lack' and 'space' denoting lack of space in the SRH dwelling units (see Fig 6a). 'Garbage', 'corridor' and 'open spaces' illustrate the lack of open spaces and open garbage dump between SRH buildings in Mumbai (see Fig 6b). Lack of 'bathroom' implicating poor sanitation and hygiene conditions in the SRH of Rio de Janeiro (see Fig 6c). These built environment design factors have an indirect implication on the energy cultures and high energy 'bills' in the study areas, which were discovered through the deep-narrative analysis.

4.2 Zooming – out: topic discovery in aggregated narratives

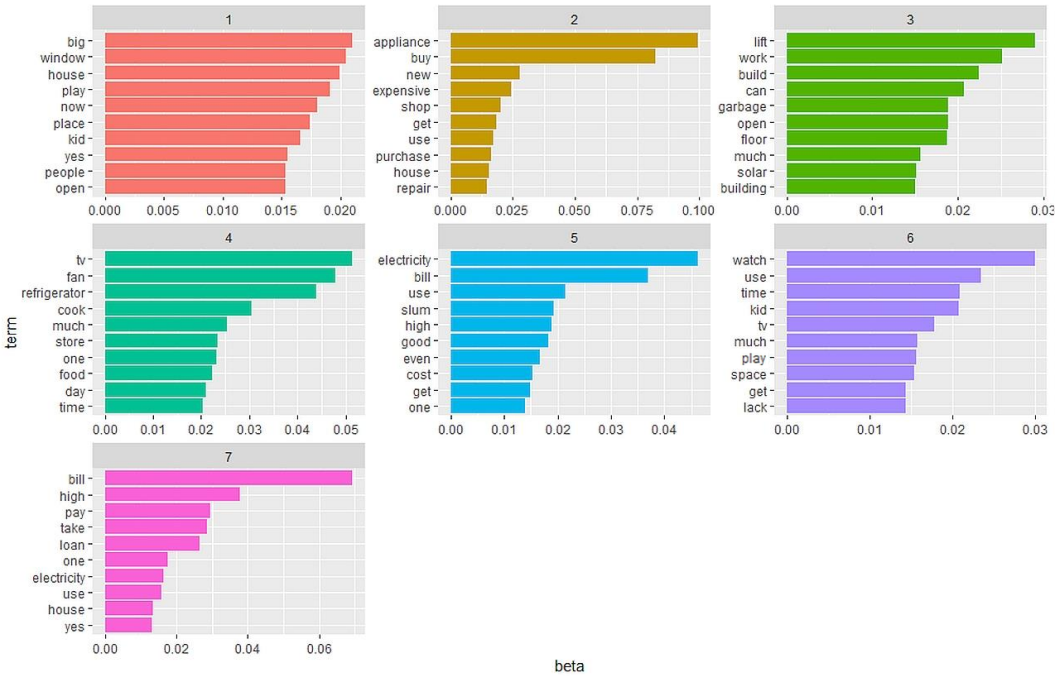


Fig 7 Topic discovered by LDA from the energy cultures narratives in the slum rehabilitation housing of Abuja, Mumbai and Rio de Janeiro. [Note: 'beta' represents per-topic-per-word probability]

Seven topics were discovered through topic modelling using LDA (see Appendix for cross-validation metrics). These topics represent the high probability (β) term/word clusters in the aggregated narrative texts from the slum rehabilitation housing (SRH) of Abuja, Mumbai and Rio de Janeiro. These topic clusters show the zoomed-our view of the aggregated narratives that exemplifies the commonalities of energy cultures in the low-income built environment. The discovered topics generate critical inference for identifying distributive injustices at the grassroots level.

The topic 1 and topic 6 appear to be related to the socio-spatial dynamics of the SRH built environment (see Fig 7). It shows the built environmental requirements with an adequate number of windows for ventilation, open and social spaces for a better quality of life. The word-word distribution in topic 6 also shows a probable relationship between high TV viewing (a critical energy practice in the SRH) by children in the absence of public spaces in such low-income built environments. Such characteristics of energy cultures in the SRH can be observed in the semantic maps as well in Fig 6. For example, an occupant from Mumbai said that her kid ran away from home as he had not playground as compared to living in horizontal slums.

> *"… the kids are the biggest sufferers here; they do not have any place to play. They cannot play on the staircases because they can fall hurt themselves… due to lack of playground here, my son ran out of the house…. He is just 5 years old, and he said he misses his friends and open areas of slums... A taxi driver caught him crying all alone near our previous home, and then bought him to us…"* (R10, Mumbai, India)

Similar built environment concern resonated in the Rio de Janeiro's case where the occupant mentioned lack of toilets and sanitation is a significant concern. She could not invite guests in her home because of such built environment conditions. In Abuja, the small size of the room and lack of space for storing firewood for cooking was abundant in the narratives (also shown in Fig 6).

Energy cultures associated with TV watching in the SRH was also revealed in topic 6 for the three cases. It has a broader significance on the role of technology diffusion of TV, Wi-Fi and mobile phones that have increased the screen-time which is also influenced by the lack of social spaces, see Table 3 (also observed in (15,16,45)). Energy cultures associated with thermal comfort and appropriate ventilation can be referred from Topic 1 through the high probability (β) of the word 'window'. In all the three SRHs lack of ventilation and insufficient comfort levels were the commonalities of poor built environment design. The associated health burden with such insufficient ventilation in the SRHs can be referred from (81).

Availing internet services through Wi-Fi informs on the changing energy cultures and the kind of energy services that are currently derived in the SRH. A participant in the Mumbai FGD even added the convenience of online shopping and the money she saves from added discounts and transportation costs (see Table 3). Moreover, she gets the freedom of watching her favourite TV series online while the children and husband occupy the only television is home. Similarly, in Rio de Janeiro, a participant revealed that she gets updates on the local news through mobile phone as her son and husband is always on the TV. It was observed that the fast diffusion of ICT devices is influencing energy service demand towards convenience that can have a welfare effect in poverty (also discussed in (5)).

Topic 2, topic 4 and topic 5 revealed information on the energy cultures and appliance uptake in the SRH (see Fig 7). Change of household practices due to slum rehabilitation was found to be associated with higher energy intensity through higher appliance uptake in Mumbai (16). The energy cultures associated with appliance uptake in the SRH was found to be highly intertwined with the socio-cultural energy services that were derived in poverty (see Table 3). For example, in Mumbai SRH, appliances like refrigerators were bought to derive greater economic utility for improving household welfare. It ranged from storing flowers to sell in the daily *bazaar* (local market) to levying charges for availing cooling services for household vegetable storage. It indicated that 'welfare appliance' like refrigerators has a more significant role as subsistence devices than cooling-only device in this SRH. In Rio de Janeiro, refrigerators were used as a storage cabinet as well. The ownership of the refrigerator was highly communal in the Nigerian case. The participants stated that they have an active community that share everyday appliances. However, refrigerator ownership remained scarce as the power quality was low and suffered from frequent load shedding (see Fig 6a).

The occupants also revealed that in Abuja instead of refrigerators, people buy deep freezers so that they can store and sell cold drinks and ice-cream during hot days. It highlighted a norm of sharing appliances and social uptake of utility-specific appliances like the deep-freezers to generate informal income in SRH. In the Rio de Janeiro SRH, the appliance sharing had a hierarchical dimension where appliances are often passed from higher-income household to the SRH in the form of donations. Such an informal e-recycling chain is a salient characteristics of a Brazilian energy culture that can also produce repair and second-hand retail shops in Rio de Janeiro (82). However, it raises the question of the energy efficiency of such pre-owned and passed-on appliances for people living in poverty as high energy bills remain a constant struggle in low-income communities. The word 'bill' shows a higher probability value (β) in topic 5 (β = 0.037) and topic 7 (β = 0.068) (see Fig 7).

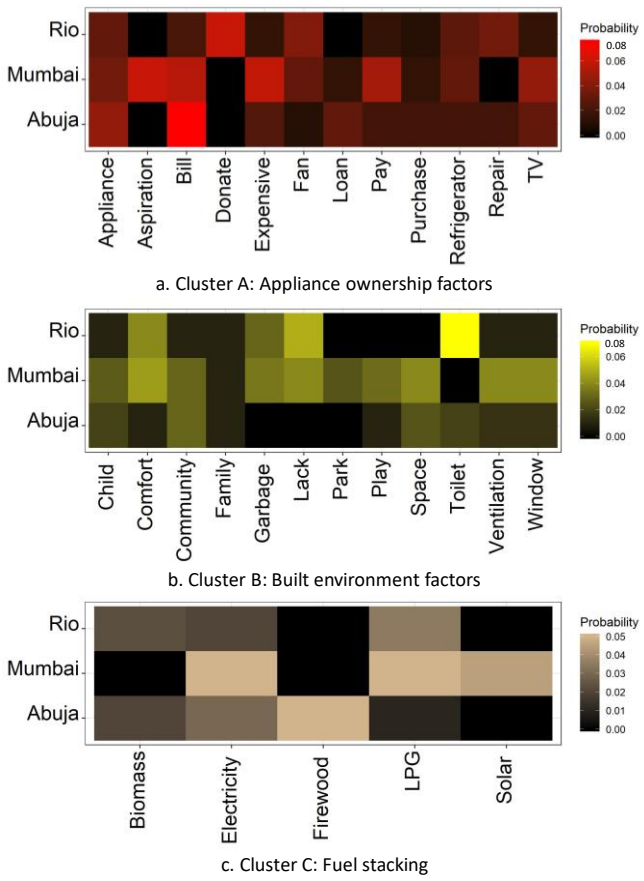
High electricity bills were the most common complaint in the Indian and the Nigerian case (see Table 3 and Fig 6). In Mumbai, the SRH occupants revealed that frequent shuffling of electricity distribution company caused administrative lags that resulted in high and irregular bills. The range of bills usually accounted for 40 – 50 % of their monthly household income, pushing them into energy poverty. Similarly, in Abuja, a significant cause of economic distress was high energy bills, frequent power cuts and low power quality that damages

appliances. Occupants usually spent more money to replace a damaged appliance by buying a brand-new product that created a poverty trap. Participants revealed that despite frequent load-shedding, they get very high bills, almost 90 - 150% of their monthly households' income. Surprisingly, they were yet to have electricity meters. Therefore, administrative lag of the DISCOMs at the low-income end-use side is a critical distributive justice issue in the SRH.

High probability (β) of words like 'loan', 'bills', 'electricity' and 'house' in topic 7 (see Fig 8) further emphasised on the poverty penalty of living in SRH due to injustices caused by poor governance and high tariff rates of the utilities. Additionally, in the three case studies, occupants revealed they had to travel far to repair or purchase appliances that added to the poverty penalty of living in the SRH built environment. Moreover, there was no trusted pre-owned appliance shop in the Indian and Nigerian case and no culture of handling-down used appliances (like in Brazilian case). It further illustrated that occupants had to pay the full price along with travel and daily wage costs to purchase a brand-new (expensive) appliance. It showed the nexus of poverty penalty and human-scale energy services in such built environment. Just energy policy should address this nexus to reduce poverty penalty.

We also enquired about the community-grown solutions in the study areas to see if the energy cultures accommodated such strategies even in low-income. The Abuja and Rio de Janeiro's SRH did not have such a program. However, the Mumbai case had a solar rooftop PV led initiatives to improve the community energy services. Topic 3 illustrate it where community-led microdonations schemes are being used to fund communal energy services like streetlights and lift-operations in the buildings (see Fig 7). Section 4.3 zoom-in through these topics to extract crystallised narratives of energy injustices in the study areas.

4.3 Zooming – in: deep-narratives of distributive injustices from the study areas



a. Cluster A: Appliance ownership factors

b. Cluster B: Built environment factors

c. Cluster C: Fuel stacking

Fig 8. Zooming -in the high probability words in the energy cultural narratives from the slum rehabilitation housing in Abuja, Mumbai and Rio de Janiero (Rio)

Zoomed-in view of the narratives further illustrates the factors determining the energy cultures in poverty across three discovered clusters through topic modelling (see Fig 8). These clusters represent the energy injustices in the respective slum rehabilitation housing (SRH). Fig 8a illustrates the injustices associated with energy service demand through appliance ownerships. Highest probability words in this cluster are associated with the word 'bill' and 'expensive' that represent the injustices associated with high electricity bills in Mumbai and Abuja. In the case of Mumbai SRH, the considerable variation in monthly electricity bills were related to poor management by the distribution companies,

> *"… there is always huge variation in the bills, sometimes we get Rs. 1300 (~19 USD) and sometimes Rs. 2000 (~28 USD). But it is usually on the higher side and extremely irregular…I got my latest bill after three months…"* (R3, Mumbai, India)

> *"… many people complained to the distribution company about high bills, my neighbour got a bill of RS. 10000 (~140 USD) in a month… no action was taken by them to reduce the bills. The company told us to pay the exact bill, and it will be later resolved in the successive months…but no one here can afford to pay it…"* (R4, Mumbai, India)

In the case of Abuja SRH, injustices are in the form of high and irregular electricity bills. The low quality of power and frequent load-shedding also adds to this distress, as it shortens the operational life of the appliances. The poverty-penalty associated with repairing and replacing the damaged appliances are very high. Occupants must travel to the city centre to avail repair and maintenance services at the cost of daily wages. Besides, like the Mumbai case, administrative lags of the distributive companies further add to the injustices,

> "*… the bill is too high…sometimes we can go for up to a week without light but at the end they would still bring a bill of around NGN 20,000 (~55 USD) or NGN 30,000 (~83 USD)…it is more surprising that with just one fan and two bulb the bills can be so high…"* (R1, Abuja, Nigeria)

> *"…there was a month one of us was given a bill of NGN 50,000 (~139 USD) by the distribution company…we went to their office to complain and they said we should write a letter and they would address the problem. They are yet to resolve the issue…*
> *… we don't have meters. They are just bringing bills anyhow without measuring our electricity consumption. For example, one of my houses has collapsed long time ago but they keep sending us bills even yesterday although no one lives in the house. That bill is now up to over NGN 200,000 (~554 USD) …"* (R5, Abuja, Nigeria)

> "*…I get very high bill of around NGN 90,000 (~250 USD) due to TV usage. This is very high, and we have complained many times to the distribution office, but nothing is solved…"* (R3, Abuja, Nigeria)

> *"…though the company has cut off the electricity, they would still provide a bill even though we have no electricity… last month the coil of my fan was destroyed due to load shedding, which remains unrepaired... It is too much effort and cost to repair an old fan …"* (R2, Abuja, Nigeria)

> *"… there was a market in nearby Kubwa village where we used to buy items. For big purchase like appliances we used to go to town…"* (R1, Abuja, Nigeria)

The purchase decisions of the household appliances are further intertwined with the broader socio-cultural norms of 'aspirations' for Mumbai and Abuja (see Fig 8a) and 'donations' for Rio de Janeiro. The aspiration associated with moving in from horizontal slums to permanent houses (i.e. the SRH) in Mumbai and Abuja sets a cultural norm of owing appliances for comfort, convenience and cleanliness (also empirically shown in (45)). It defines the 'norm' specific element of energy cultures of this places, whereas, the poverty-penalty associated with such aspirational buying adds to the energy-distress of the household (as discussed in (15)). In the Rio de Janeiro case, the aspirations were of buying was in parallel with that of receiving appliances as 'donations' (see Fig 8a). However, this donation-based model passes on energy inefficient or older appliances that have higher operational and maintenance cost (also mentioned in section 4.2). It adds to the poverty-penalty as well in the Rio de Janeiro's SRH; translating into distributive energy injustice.

> *"…I bought all appliances in brand new condition, except the refrigerator, it was donated…. most of the houses here have received used refrigerators in the form of donation…"* (R1, Rio de Janeiro, Brazil)

"… I have a fridge, and usually share it with the neighbours. Load shedding is a major problem which do not allow the fridge to run properly, if it breaks, I cannot afford another one… We share appliances as required, we have a strong community…" (R4, Abuja, Nigeria)

"… people often buy deep freezers to sell cold items and drinks…they make a good business…" (R1, Abuja, Nigeria)

"…not everyone allows sharing fridges as electricity cut is very common, they need to store food for longer time in hot days…. the electricity bills are too high, and no one wants to let other store it for free…" (R5, Abuja, Nigeria)

"… I asked my husband to buy new appliances on moving to this neighbourhood…. Now we have a permanent structure so new appliances are needed… we took loans to buy them…' (R1, Mumbai, India)

"… It is not only our aspiration; it has become our need. Earlier in slums, even if we aspire to buy the temporary conditions of the house did not permit to purchase such expensive items….
… we need to travel more than 5 kilometres to purchase appliances…." (R2, Mumbai, India)

A critical element of distributive justice in the SRH is welfare appliances like refrigerators and washing machines. The refrigerator was the most common welfare appliance in the three SRH. The utility derived through it show contrasting patterns that further demonstrate the energy cultures of these areas. As mentioned in section 4.2, households in Mumbai and Abuja try to derive economic utility from a refrigerator by storing flowers to renting racks in the refrigerators for cold storage. However, in Rio de Janeiro refrigerator had a greater utility as a storage cabinet.

"…food is prepared three times a day and no one stores it in the fridge… common items that are stored are vegetables, milk and water…item like flowers and garlands are also kept as they stay fresh longer, and are then sold in the market..." (R3, Mumbai, India)

"…in the slum, out of 450 houses, only one corner shop had a refrigerator… the shop owner used to charge for using that fridge… Owing a fridge has made my life easier by saving a lot of time…" (R5, Mumbai, India)

"…my son likes to keep everything inside the fridge: sugar, rice, coffee. I tell him there is no need for this, but he insists…" (R8, Rio de Janeiro, Brazil)

"… I have a fridge, and usually share it with the neighbours. Load shedding is a major problem which do not allow the fridge to run properly, if it breaks, I cannot afford another one… We share appliances as required, we have a strong community…" (R4, Abuja, Nigeria)

"… people often buy deep freezers to sell cold items and drinks…they make a good business…" (R1, Abuja, Nigeria)

Fig 8b shows the high probability word clusters associated with built environment design and energy cultures in the study areas. Section 4.1 and 4.2, respectively, define how poor design elements in the SRH are affecting energy decision-making in the households and influencing the energy cultures (see Fig 6). The deep narratives from the occupants further illustrate these factors,

"… we cannot share our daily life stories with anyone that's the biggest cause of stress… No spaces for us to sit and chat, neither children have any space to play…they just stick to the TV or mobile phones, either watching cartoon or playing games. It is making them lazy and dumb…" (R2, Mumbai, India)

"… well-being is affected for sure, in addition, the community support system has gone weaker. Previously in the slums, if anything bad happens to any member of the community the information used to travel very fast… everyone used to contribute in supporting the victim. Now, no-one knows their neighbour…" (R11, Mumbai, India)

"… I cannot have guests…we do not have toilets…condition is same as previous" (R3, Rio de Janeiro, Brazil)

"… we have to spend all day outside because the heat inside the house is not good…fans are useless" (R4, Rio de Janeiro, Brazil)

".. rooms are small… it is very difficult to get the room you want as the process of allocation is done by the government. The rooms are very small for a family of 3 and usually most of us are a family of 5…" (R2, Abuja, Nigeria)

Fuel stacking in SRH also revealed the duality of energy practices in the slum rehabilitation housing (SRH) under study (see Fig 8c). It has critical implications for distributive energy justice at the grassroots level as it translates to climbing the urban energy ladder to improved household welfare in poverty (also implied in (5)). For example, in Abuja, cooking fuel primarily remains firewood based that has a significant health burden associated with it. In contrast, the primary source of energy for the households is grid-based electricity that remains unreliable and expensive. The occupants want alternate sources of energy that are affordable and accessible. Discussions around solar-based solutions are growing in this study area.

> *"… even in the small room we must keep space for firewood for cooking during the monsoon and winter, or else we do not get cooking fuel. The rooms are not the problem, but their small size is…"* (R1, Abuja, Nigeria)

> *"… I saw my neighbour use solar lights…I wanted one, but it is expensive…" (*R6, Abuja, Nigeria)

> *"… I read in news solar energy can reduce energy bills…"* (R4, Abuja, Nigeria)

In the Mumbai SRH, the energy mix consisted of electricity for household appliances while liquefied petroleum gas (LPG) and kerosene for cooking. Lack of energy services at a community level like operation of lifts and streetlights are major injustices here. Occupants revealed that the community is now collecting micro-donations to power these services using rooftop solar PV.

> *"… we have recently installed solar panels on the roof to power the stairway passage, lifts and water pumps in one of the buildings…the bill of the building maintenance has gone down…"* (R3, Mumbai, India)

5. Discussion

This study provided a zoomed-in and zoomed-out view of energy injustices in poverty through the investigation of energy cultures narratives in slum rehabilitation housing (SRH) across Abuja (Nigeria), Mumbai (India) and Rio de Janeiro (Brazil). Topics extracted through deep-narrative analysis framework were analysed at a macro and micro-scale to identify critical factors that can aid in just policy design in a bottom-up manner. The narrative space connecting the built environment design with energy cultures in the SRHs were established through semantic analysis, as illustrated in Fig 6 and Table 3. Utilising this connection is critical in policy design for the UN SDG – 7 (clean and affordable energy) and UN SDG – 11 (sustainable cities and society) goals in poverty.

The discovery of latent topics through topic modelling revealed crucial interdependencies between the built environment design and energy cultures in low-income settings. Section 4.2 established the commonalities linking lack of built environment design elements with distributive energy justice in the SRH. The common themes were clustered around seven topics based on probability values (see Fig 7). These themes revealed that injustices around human-scale energy services (HUSES) in the SRH are dependent on the built environmental design flaws. For example, in Abuja, lack of repair infrastructure and mechanisms for household appliances result in lost wages. The occupants must travel far to get appliances frequently repaired that are damaged due to low power quality and recurrent load shedding in the SRH (see section 4.2).

Similarly, in Mumbai, lack of open spaces in the vertical slum-like structures of the SRH is affecting the well-being of the occupants that, in turn, force them to stay indoors and increase the energy intensity. It results in higher electricity bills and associated poverty penalties. In Rio de Janeiro, significant energy is spent on cooling the houses due to the poor design of the dwelling units (see section 4.2).

The seven discovered topics (see Fig 7) inform broadly towards the following horizontal variables for just policy design in such low-income built environment. For example, topic 1 and topic 2 indicate the quality of the built environment as a crucial distributive justice factor along with affordability and accessibility of appliance ownership. Topic 3 indicated the role of community-driven initiatives in distributive energy justice planning like refrigerator sharing in Abuja to generate economic-utility in the community (see Fig 7). Solar rooftop PVs, installed through micro-donations from the communities in Mumbai SRH for delivering communal energy services was another example of such community-led initiative. The donation chain of appliances from higher-income households to SRH in Rio de Janeiro is another example of a community-driven energy justice

mechanism. The topic 4 (see Fig 7) further showed the need for provisioning of affordable repair and maintenance shops and trustworthy outlets of pre-owned appliances. It will reduce the poverty penalties associated with repairing of appliances and promote affordable appliance uptake. Appliance uptake is critical to improving household welfare in low-income (5,45).

The topic 5 informed on the critical role of distribution companies in such low-income settings. Administrative lags, irregularity of billing cycles, and low power quality had detrimental effect on the households. These factors were pushing the households to energy poverty and increasing the poverty penalties of living in the SRH (see section 4.1 and section 4.2). Just policy design must create a robust feedback mechanism to report the grievances of the occupants in low-income settlements. The billing should be transparent, and the tariff mechanisms should be sensitive to the HUSES in such communities.

Similarly, topic 6 indicated that information and communication technology (ICT) devices are the fastest-growing household devices in the SRH, and they should be leveraged for better energy governance (see Fig 7), thus supplementing the implications of topic 5. Moreover, topic 7 showed that the role of banking institutions and finance mechanism is critical in enabling occupants to climb up the urban energy ladder that is significant to distributive energy justice in poverty (see section 4.2).

The zooming-in view aided in to explore the depth of energy injustices from the narratives (see section 4.3). Three topical clusters of high probability words were extracted that illustrated the granular differences in energy cultures in the study areas (see Fig 8). These clusters are crucial in fine tuning the just policy design variables as it contextualised the spatiality of distributive energy justice. For example, in Mumbai, energy culture is highly influenced by the transitioning built environment of the SRH. As occupants move from horizontal slums to vertical permanent structures, appliances ownership is envisaged through the lens of aspirational buying (also empirically shown in (16)). This aspirational sentiment gets embedded into the energy cultures of the SRH that often motivates the occupants to take loans or borrow money from informal money lenders. It had created poverty traps for many households living in the SRH (see section 4.3). A similar observation was made in Abuja where the occupants are pushed into poverty trap through frequent damage of appliances due to low power quality, (see Fig 7, also discussed in section 4.2). In Rio de Janeiro, the norm of donation of older appliances to low-income households created a poverty trap associated with the energy inefficiency of the appliances. The occupants often need to pay out-of-pocket to avail repair services that are situated on the other side of town. Thus, additional costs associated with travel and lost wages must be factored in a distributive energy justice policy in such low-income settings.

The influence of poor built environment design was equally represented in the three case studies in the zoomed-in view (see Fig 8). It implies that just energy policy must factor in the inclusive design and planning of the built environment. It is coherent with the recent findings of (17). This built environment design and energy justice link is generalisable for the upcoming wave of low-income housing in the Global South due to the forces of rapid urbanisation.

Cluster C in Fig 8 showed the energy cultures of fuel stacking in the SRH that indicates that energy justice policies must focus on improving the fuel mix in low-income households. Dirty cooking fuel like firewood and biomass must be replaced with cleaner fuels like LPG. It was observed that in Abuja SRH, the cooking fuel was entirely firewood based that further raised question on the health burdens of the occupants. Just energy policy needs to decouple this health burden from the energy burden. Contrastingly in Mumbai SRH, occupants stacked kerosene with LPG cylinders. Recent studies had shown that such fuel stacking behaviour in the crammed indoor spaces of SRH poses a severe health burden to the occupants (81,83). Replacing the current fuel mix with solar-based solutions can promote distributive justice in such low-income housing units. Diffusion of community-led solar energy solutions was observed in Mumbai (see section 4.3) which must be financially supported and replicated by government agencies to enabling cleaner fuel switching.

6. Conclusion

This study intended to derive policy design focus points on distributive energy justice in poverty. In doing so, injustices associated with acCessing human scale energy services (HUSES) were investigated through the theoretical lens of energy cultures in slum rehabilitation housing (SRH). The SRHs are transitioning built environment that is characteristic of low-income urbanisation across the Global South. In this study, three SRH across Abuja (Nigeria), Mumbai (India) and Rio de Janeiro (Brazil) were investigated to gather narratives on HUSES through appliance ownership.

The narrative analysis was performed along the lines of the deep-narrative framework (21) that involved machine learning-based topic discovery and application of constructivist grounded theory. The results revealed critical interdependencies of appropriate built environment design in poverty with the energy cultures. The commonalities in the three SRH involved lack of open spaces, high electricity bills and poor governance of utility companies in low-income housing communities. These commonalities are implied as poverty penalties for the occupants that obstruct UNSDG-3 (Good health and well-being) , UN SDG – 7 (clean and affordable energy) and UN SDG – 11 (sustainable cities and communities) goals.

The key conclusions that can be drawn from this study can be divided into three parts. First, the conceptualisation of distributive energy justice in poverty must emerge from the contextual appropriateness of built environment design. This approach to policy design will ensure that the cultural identities of these communities associated with availing specific energy services are transferred across the transitioning built environment. This will mean exploring newer definition and theories of contextual distributive energy justice, which can enable more explicit identification of injustices.

The second part of the conclusion is on enhancing the existing administrative mechanisms around the utility governance of electricity in low-income communities. The findings of this study showed administrative lags, irregularity of billing cycle and low power quality in the SRHs are directly linked to more significant poverty penalties of living there. The administrative lags are translated into injustices in low-income communities, and they must be addressed systematically in inclusive policy design. It is even more significant as millions of low-income building stocks will be built in the Global South, creating a space for bottom-up just policy planning following UN SDG – 11 (sustainable cities and society).

The third part is cleaner fuel switching at household level in low-income settlements like the SRH must be accelerated to avoid fuel stacking behaviour. Results showed that in Abuja SRH, the energy mix of the household consisted of firewood for cooking and electricity for appliances. Similarly, in Mumbai SRH, the energy mix consisted of kerosene and LPG for cooking and electricity for appliances. Therefore, the fuel mix is not clean, and it is a representative of such low-income urban housing. Diffusing cleaner and affordable energy sources in this fuel mix are critical to the fulfilment of UN – SDG 7 (clean and affordable energy for all) goals in such housing communities. It was also observed in the Mumbai SRH that the occupants are collecting micro-donations to install rooftop solar PV systems to power public goods like lifts and streetlights. It shows that with solar energy solutions becoming cheap and accessible, it is influencing the cultural identity of such low-income communities. Just energy policy in this context must support such micro-scale transition in the household fuel mix.

The findings of this study are representative of specific low-income urban communities living in slum rehabilitation housing; it was not entirely possible to objectively capture energy cultural differences among the occupant groups. The low-income urban community is diverse and often informal; the bounded scope of this study is a limitation. A theoretical limitation was posed by the static definitions of distributive energy justice that are represented in the state-of-the-literature. These definitions are derived from the context of the Global North and supply-side energy system. However, this study contributed to filling this contextual gap in just policy design at a grassroots level. Future work lies in the empirical extension of this study and investigating panel effects so that the changing cultural identities with human-scale energy services in poverty can be identified. It can inform

researchers to design solutions to improve household welfare through infrastructural, administrative and technical means.

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Authors contribution

RD: Conceptualisation, Methodology, Software, Validation, Formal analysis, Investigation, Data Curation, Writing – Original Draft, Writing – Review & Editing, Visualisation, Project Management, Funding Acquisition. **RB:** Investigation, Writing – Review & Editing. **SD:** Writing – Review & Editing. **KM:** Writing – Review & Editing. **MSB**: Supervision, Writing – Review & Editing. **ACVC:** Investigation. **AI:** Investigation

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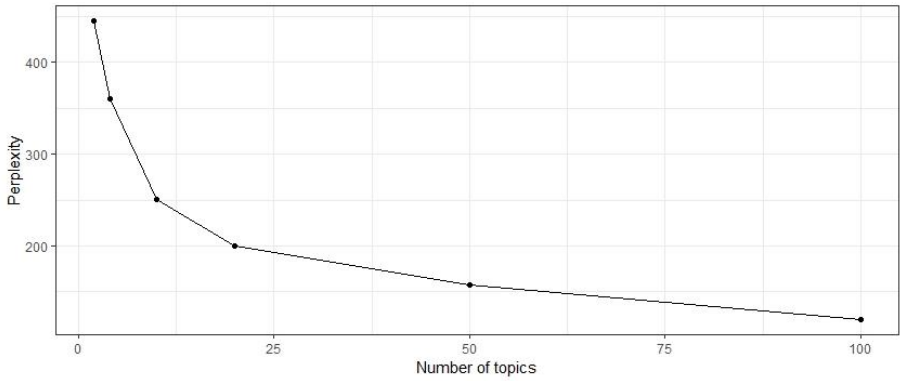
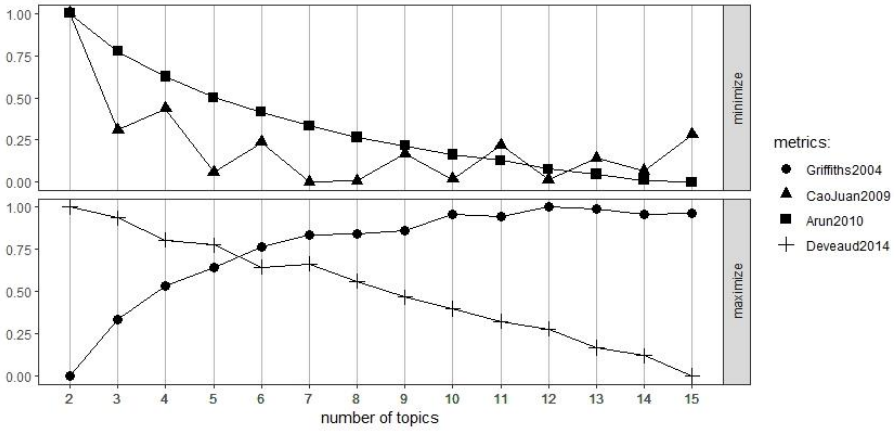
Appendix:

Topic identification and model validation for Section 4.2



a. Perplexity scores (lower is better)



b. Optimal number of topic determination using LDAtuning algorithm

Fig A1. Cross validation for topic determination in the topic modelling

The model validation results are illustrated in Fig A1 that shows an approximate convergence of topic number around 6 to 8 topics for ldatuning estimations. A global minimum was achieved around 7 – 8 topics as per CaoJuan2009 (see Fig A1b). The perplexity measure showed a sharply localised bent around 7 topics in Fig A1a. Using the elbow rule in interpreting perplexity score, 7 topic clusters were decided as an appropriate number for this study. Cross-validating with Fig A1b, it showed agreement with CaoJuan2009 metric.