Contextualising energy justice in low-income built environment

Towards data-driven policy interventions for addressing distributive injustices in slum rehabilitation housing of the Global South

Ramit Debnath
Churchill College

May 2021

This thesis is submitted for the degree of Doctor of Philosophy

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Dedicated to global efforts on

energy and climate justice

ABSTRACT

Around a billion people live in slums today globally, and rehabilitating them to formal housing is a significant challenge. Slum rehabilitation housing is a policy effort to solve this crisis and alleviate urban poverty. However, the question of whether slum rehabilitation programmes are accomplishing more good than harm or whether they are creating a whole host of new problems remains unexplored in the literature. This thesis investigates the effect of slum rehabilitation on household energy demand in Brazil, India and Nigeria through the lens of distributive energy justice. Furthermore, this thesis makes methodological innovation to aid in just policy design by improving the objectivity of including local and contextual knowledge on how poor households live and use energy. Doing so makes novel theoretical and methodological contributions: a theoretical contribution to temporality and spatial energy justice studies on how to offer cross-sectional depictions of energy demand within the slum rehabilitation housing, which was evaluated through structural equation modelling, and a methodological contribution in developing a deep-narrative analysis framework using natural language processing and machine learning-based Latent Dirichlet Allocation algorithm to capture the grounded narratives of distributive injustices objectively.

This research highlighted the significance of contextualisation in planning for energy justice in slum communities and the role of digital tools like natural language processing in objectively integrating grounded narratives in just policy design. The contextualisation was done through zoom-in and zoom-out of the grounded narratives enabled through the multi-method approach. Zooming-out view of distributed injustices in the study areas of Mumbai (India), Rio de Janeiro (Brazil) and Abuja (Nigeria) revealed inefficiencies in the administration of electricity distribution companies, lumped billing periods and lack of people-centric built environment design considerations. Similarly, zooming-in the case studies revealed that the poor design of the slum rehabilitation-built environment influenced the increase in energy intensity in the Mumbai case, leading to energy poverty. Whereas created distinct poverty traps in the Brazilian and Nigerian cases through frequent power cuts, high cost of appliance repair, and poor housing design. Finally, policy implications were drawn as per the policy actors across municipal, state and national levels that suggested leveraging digital tools like the deep-narrative analysis and the heavy penetration of Information and Communication Technology devices in such low-income communities. Such tools can improve accountability in decision-making and improve the representation of the occupants through their narratives of injustices associated with living in such communities. Thus, this thesis uniquely forwarded a data-driven pathway for integrating local collective intelligence in just policy design.

PREFACE

This thesis is based on the following original research publications commenced as a part of this doctoral research. These publications are presented as empirical chapters with suitable iterations to match this dissertation's overall narratives and conceptual framework. The original research articles are as follows:

Papers (Empirical chapter)	Citation
Paper 1 (Chapter – 4)	**Debnath, R.**, Bardhan, R. and Sunikka-Blank, M. (2019) 'How does slum rehabilitation influence appliance ownership? A structural model of non-income drivers', *Energy Policy,* 132, pp. 418–428. https://doi.org/10.1016/j.enpol.2019.06.005
Paper 2 (Chapter – 5)	**Debnath, R.,** Simoes, GMF., Bardhan, R., Leder, SM., Lamberts, R., Sunikka-Blank, M. (2020) 'Energy Justice in Slum Rehabilitation Housing: An Empirical Exploration of Built Environment Effects on Socio-Cultural Energy Demand', *Sustainability*, 12(7). https://doi.org/10.3390/su12073027
Paper 3 (Chapter – 6)	**Debnath, R.,** Darby, S., Bardhan, R., Mohaddes, K. and Sunikka-Blank, M. (2020) 'Grounded reality meets machine learning: A deep-narrative analysis framework for energy policy research', *Energy Research & Social Science*, 69, p. 101704. https://doi.org/10.1016/j.erss.2020.101704
Paper 4 (Chapter – 7)	**Debnath, R.,** Bardhan, R., Darby, S., Mohaddes, K., Sunikka-Blank, M., Coelho, A. C. V., and Isa, A. (2021). Words against injustices: A deep narrative analysis of energy cultures in poverty of Abuja, Mumbai and Rio de Janeiro. *Energy Research & Social Science*, 72, 101892. https://doi.org/10.1016/j.erss.2020.101892

Author's contribution

Author's contributory statements of these papers are published online with the papers as per the internationally accepted CRediT (Contributor Roles Taxonomy) author statement (see here). These contribution statements are placed above the acknowledgement section in the respective published papers. In all the four journals, the thesis author was the corresponding and the first author, led the conceptualisation, research design, data collection, fieldwork and was responsible for writing the first draft and addressing the revisions during the publication process. **Written permission from the co-authors have been obtained for reproducing the published work in this thesis.**

The CRediT authorship contribution statements for the papers are as follows:

Papers	CRediT authorship contribution statement for **Ramit Debnath (the author)**
Paper 1	**Ramit Debnath:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration, Funding acquisition. **Bardhan, R**: Writing - review & editing. **Sunikka-Blank, M**: Supervision, Writing - review & editing.
Paper 2	**Ramit Debnath:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration, Funding acquisition. **Simoes, GMF**: Investigation. **Bardhan, R:** Writing - review & editing. **Leder, SM**: Project administration. **Lamberts, R**: Writing - review & editing. **Sunikka-Blank, M:** Supervision, Writing - review & editing.
Paper 3	**Ramit Debnath:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration, Funding acquisition. **Darby, S**: Writing - review & editing. **Bardhan, R**: Investigation, Writing - review & editing. **Mohaddes, M**: Writing - review & editing. **Sunikka-Blank, M:** Supervision, Writing - review & editing.
Paper 4	**Ramit Debnath:** Conceptualisation, Methodology, Software, Validation, Formal analysis, Investigation, Data Curation, Writing - original draft, Writing - review & editing, Visualisation, Project management, Funding acquisition. **Bardhan, R**: Investigation, Writing - review & editing. **Darby, S:** Writing - review & editing. **Mohaddes, K**: Writing - review & editing. **Sunikka-Blank, M**: Supervision, Writing - review & editing. **Coelho, ACV**: Investigation. **Isa, A**: Investigation

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CRediT Term	Definition
Conceptualization	Ideas; formulation or evolution of overarching research goals and aims
Methodology	Development or design of methodology; creation of models
Software	Programming, software development; designing computer programs; implementation of the computer code and supporting algorithms; testing of existing code components
Validation	Verification, whether as a part of the activity or separate, of the overall replication/ reproducibility of results/experiments and other research outputs
Formal analysis	Application of statistical, mathematical, computational, or other formal techniques to analyze or synthesize study data
Investigation	Data/evidence collection
Data Curation	Management activities to annotate (produce metadata), scrub data and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later reuse
Writing - Original Draft	Preparation, creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation)
Writing - Review & Editing	Preparation, creation and/or presentation of the published work by those from the original research group, specifically critical review, commentary or revision – including pre-or post publication stages
Visualization	Preparation, creation and/or presentation of the published work, specifically visualization/ data presentation
Supervision	Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team
Project administration	Management and coordination responsibility for the research activity planning and execution
Funding acquisition	Acquisition of the financial support for the project leading to this publication

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LIST OF ACRONYMS and ABBREVIATIONS

SRA	Slum Rehabilitation Authority
SRH	Slum Rehabilitation Housing
SEM	Structural Equation Modelling
BE	Built environment
HP	Household practices
AC	Appliance characteristics
INR	Indian National Rupees
HH	Household(s)
TV	Television
IAQ	Indoor Air Quality
ICT	Information and Communication Technologies
SHG	Self-Help Group
HUSES	Human scale energy services
TM	Topic Modelling
LDA	Latent Dirichlet Allocation
NLP	Natural Language Processing
GT	Grounded Theory
GTSH	Gandalho and Timbo Social Housing
FGD	Focus Group Discussion
ML	Maximum Likelihood/Machine Learning
DNA	Deep-narrative analysis

CHAPTER 1 Introduction

Research outline, scope, key questions and the structure of the thesis

Around a quarter of the world's urban population lives in slums without access to basic infrastructure like housing, sanitation, healthcare and energy services (Hutt, 2016). Slum rehabilitation housing (SRH) are emerging as the low-income transitional living spaces across the Global South that aim to fulfil the infrastructural deficit for decent urban living (R. Bardhan *et al.*, 2015). The SRH is primarily designed to reduce the housing deficit load by redeveloping the informal settlements that have been a perennial problem in developing nations. The urbanisation *push-pull* tensions have triggered an exodus to the cities which are still in a developmental transition. Slums act as the first stop of the migrants that provide affordable housing within accessible distance to the economic hubs or city-centre, thereby ensuring the basic demand for shelter and subsistence (Nijman, 2008). Without appropriate slum rehousing or redevelopment policies, the informality burgeons, creating a vicious cycle of urbanization-driven slum formation (Ooi and Phua, 2007). Over the past few decades, governments in Global South have made several attempts from removal to re-housing of slums in the city's outskirts, thereby reducing decent urban living aspirations and sustainable development limits (Nijman, 2008, 2015).

The SRH is perceived as the silver bullet solutions by government authorities, especially in India, to the unfavourable effects of removal and re-house schemes of slum redevelopment (R. Bardhan *et al.*, 2015). However, recent studies have shown that the planning and design mechanism of SRH are built on a market-hierarchy governance mechanism that bottlenecks the welfare distribution of such policies (Patel, 1996; Nijman, 2015; R. Bardhan *et al.*, 2015). Such effects become even more apparent when viewed from the granularity of everyday household practices, social norms and material reality of the occupants living in such low-income communities. For example, asymmetries in universal access to affordable and clean energy, healthcare facilities and sanitation are known distributive injustice in the SRH. Moreover, poor built environment quality leading to low thermal comfort and indoor air quality, higher energy service demand for cooling, lighting and convenience; and inaccessibility to urban WASH (drinking water, sanitation and hygiene) are reported as the most prevalent problems affecting the quality of life (Vaid and Evans, 2017; Corburn *et al.*, 2020; Kshetrimayum, Bardhan and Kubota, 2020a). Besides, the cumulative effect of poor built environment planning and design of the SRH is observed to expand poverty traps in the households (Chowdhury, 2009; Aklin *et al.*, 2018; Minna Sunikka-Blank, Bardhan and Haque, 2019). The occupants have to bear the poverty penalty of using essential services like electricity, clean cooking energy, healthcare, education, food security, sanitation and hygiene (Mendoza, 2011).

This research investigates the asymmetries associated with the accessibility of affordable energy services in low-income housing (like the SRH) using mixed-method approaches that captures both the length and breadth of grounded realities of living in such a built environment. Consequently, this research intends to inform contextualized energy policymaking at the local governance level in poverty that promote distributive energy justice. The novel methodological tool developed in this thesis (named 'deep-narrative analysis') can be used as a just policy design tool across the governance hierarchies. Its core functioning is to use public deliberations or narratives as the primary input for data-driven decision making. Moreover, this research's empirical findings can be used to inform regulatory policy instruments at the housing-energy nexus in rapidly urbanising cities.

Distributive energy justice relates to fairness in the distribution of energy resources. It argues that if physical security is a fundamental right, so are the conditions that create it, like food, shelter and an unpolluted environment. Therefore, people are entitled to a certain set of minimal energy services that enable them to enjoy a basic minimum of wellbeing (Sovacool and Dworkin, 2015a; Bouzarovski and Simcock, 2017a). It offers an epistemological space for designing a people-centric policy framework that can address asymmetries associated with affordability, accessibility and choice of specific energy services that can have direct welfare benefits. This doctoral thesis utilises this epistemology to investigate the contextual energy injustices in the SRH from a bottom-up manner by placing people, places, and practices at the centre of the analytical framework (discussed in detail in Chapter 3).

The current literature mentions two distinct knowledge gaps in distributive energy justice-driven empirical research (also discussed in detail in Chapter 2). The first gap relates to current methodological limitations in capturing the time and location-specific (also known as temporal and spatial) characteristics of energy demand at the household-level that are deep-embedded in the local socio-cultural contexts (Bouzarovski and Simcock, 2017a; Malakar, Herington and Sharma, 2019a; McCauley *et al.*, 2019; Bombaerts *et al.*, 2020; Lacey-Barnacle, Robison and Foulds, 2020). The second gap is in the conceptual ontologies of distributive energy justice heavily influenced by western philosophies. Only a handful of recent studies had derived the extent of distributive justice using philosophies from the Bhagavad Gita (Hinduism) (Malakar, Herington and Sharma, 2019a), post-colonial theory (Castán Broto *et al.*, 2018) and post-modern gender theory (Buchholz, 2014a). This doctoral research contributes to these gaps by developing a novel data analysis framework that can extract the contexts from research participants' narratives by enabling the ability to 'zooming-in' and 'zooming-out' of the texts. It can have wide-ranging applications in bottom-up policymaking scenarios where citizen-driven and collective decision-making is critical, like designing policies for distributive energy justice in SRH communities.

The following section describes this thesis's overall research framework, divided into a problem statement, novelty, main research questions and objectives. The structure of the thesis is also discussed in detail by the end of this chapter.

1.1 Research Framework

1.1.1 Problem definition

Urban slums are expanding at an unprecedented rate due to pressures of urbanisation in the Global South. Over 1 billion people who live in slums globally have low-quality housing and poor living conditions (UN-Stats, 2020). Slum rehabilitation housing (SRH) are emerging, transitional low-income living spaces created to rehouse the slum dwellers and provide a decent quality of urban living. In contrast, these policies have been effective in fulfilling the housing deficit but failed to deliver the required standard of living to its occupants in Indian case studies. Spill-over effects are observed in the form of expanding energy poverty in the SRH households (Debnath, Bardhan and Sunikka-Blank, 2019a; Kshetrimayum, Bardhan and Kubota, 2020a; Sarkar and Bardhan, 2020b), which is a symptom of energy injustices in such low-income communities.

Broadly, this doctoral research investigates the energy injustices in the SRH communities and derives necessary inferences for bottom-up policymaking to foster energy justice in the study areas. The primary case study is the SRH in Mumbai, India, while cross-sectional investigations are conducted in similar communities in Brazil and Nigeria. These are low-income households with annual income between USD 70 – 180 across the study areas (detailed socio-economic characteristics are presented in the empirical chapters).

As stated above, the efforts to explore bottom-up distributive energy justice policy design are limited by, i) lack of methodological bandwidth to capture the spatiality and temporality of energy demand at a household-level in poverty. 'Spatiality' infers the place-based effect on energy demand that is ingrained in that specific context. For example, household energy demand in a rural area is distinct from an urban area, even though the socio-economic characteristics can be alike. Similarly, 'temporality' here infers to the time-factor associated with energy demand evolving with the changing household practices and socio-economic status. ii) Lack of contextual understanding of asymmetries associated with energy affordability in low-income communities. Asymmetries can also be due to physical limitations like poor-built environment and socio-architectural design, spatial-isolation of low-income communities from essential energy services (like billing office, complaint department, appliance repair centres, shops, etc), poor-provisioning and administration of electricity distribution networks, etcetera. Asymmetries can also be due to social-economic limitations like loss of social and community networks, extreme poverty, high debt, health burden, etcetera. Similarly, it can be a product of the socio-cultural limitations related to social norms, practices, aspirations, belief systems, etc.

This research addresses both points by adopting a cross-sectional theoretical approach to evaluate socio-technical and socio-cultural energy service demand associated with the built environment (here, it is slum rehabilitation housing (SRH) communities) (discussed in detail in Chapter 3). To test this cross-sectional approach in policy design, a novel computational social science methodology was developed to extract contextualised information from research participants' narratives (explained in detail in Chapter 6-7).

This methodology has a high degree of versatility in policy research where novel text-based datasets like narratives, discourses and crowdsourced opinions can be analysed and objectively applied to just policy design. Therefore, aiding researcher, policymakers, and analysts/consultants in evidence-based energy policymaking.

1.1.2 Research questions and objectives

Based on the problem statement, the following broad questions were formulated for this doctoral research:

1. How does the transition from slums (informal settlements) to a low-income built environment (SRH) affects the demand for energy service?
2. What are the distributive energy injustices in low-income built environment (SRH)?
3. What is meant by contextualised just energy policy for people living in SRH?

4. How to extract context-specific information on energy injustices from the occupants living in SRH? How to quantitatively analyse narratives for just policy design?

Further sub-questions were formulated as per the empirical chapters (see Chapter 4 – 7). These research questions are addressed through the following objectives:

- Investigate the effect of transitioning-built environment (SRH) on changing household energy practices and energy intensity in poverty.
- Explore the causal link between built environment design and energy injustices in low-income communities.
- Derive a data-driven methodology for identifying distributive injustice using novel crowdsourced datasets like narratives of living in the SRH.

The above objectives were further fragmented into a more directed objective for this research's analytical framework (see Chapter – 3). The directed objectives are framed into three core research scopes, **i)** to investigate the changing energy practices on slum rehabilitation in Mumbai, India, using a representative socio-economic survey dataset of 1200 households (HH). This objective was designed to explore the temporalities associated with the transition from horizontal slums to vertical structures (SRH). Causal links between built environment variables and physical energy service demand (illustrated through HH appliance purchases) were established using an empirical modelling approach called structural equation modelling (see Chapter – 4); **ii)** to investigate the built environment effects on socio-cultural energy service demand amidst spatial differences of SRH in Mumbai, India and Joao Pessoa, Brazil. Around 200 HH were surveyed to explore appliance ownership patterns and demand for comfort, cleanliness, and convenience as socio-cultural energy services in the study areas. An empirical relationship was established using Firth's binary logistic regression (see Chapter – 5), and **iii)** to dive deeper into occupants' experience of living in the SRH and its associated distributive energy injustices. A novel methodological framework was developed using a nested application of natural language processing (NLP), machine learning-based topic modelling, and constructivist grounded theory to achieve this objective. This methodological framework was called the 'deep-narrative analysis' framework (see Chapter – 6). This objective also illustrates the just policy design scope of this dissertation, where a proof-of-concept of this methodological framework was presented using case studies in SRH across Mumbai (India), Rio de Janeiro (Brazil) and Abuja (Nigeria) (see Chapter – 7).

1.1.3 Novelty of the research

This doctoral research's novelty can be divided into two broad parts, while more detailed descriptions are presented in the empirical chapter. The first part deals with the theoretical contribution that this thesis makes in energy research and computational social sciences concerning the contextualisation of energy justice at the grassroots level, with case studies from India, Brazil and Nigeria. This research's original analytical design lies in the cross-sectional approach of evaluating temporalities and spatiality associated with energy demand in SRH. It was needed to evaluate energy injustices in the study areas appropriately (as mentioned above in section 1 and section 1.1.1, also discussed in detail in Chapter - 2). This approach was achieved by combining practice-based approach (Shove, Pantzar and Watson, 2012) in evaluating the before and after-effects (temporalities) of moving into SRH on energy demand; with energy cultures theory (Stephenson *et al.*, 2010) to evaluate spatial characteristics of energy injustices in SRH built environment using case studies India, Brazil and Nigeria. This theoretic combination was critical to evaluate a contextualised policy scope for distributive energy justice in the study areas. It is further discussed in detail in Chapter – 3.

The second part of novelty deals with the deep-narrative analysis framework's methodological development to objectively investigate and embed occupants' narratives into a just policy design framework. This data-driven methodology is designed on the principles of collective intelligence that emphasises when people work together with technology to create enhanced capacities that generate solutions that are greater than the sum of their parts. It contributes to the growing field of computational social sciences. The detailed methodological description and its epistemological-fit are presented in Chapter – 6.

1.2 Scope of the research and thesis outline

Main case study and contexts

The context of this research is set in the SRH of Mumbai, India, where the drive for slum redevelopment is motivated by the national goal of 'Housing for All 2022' by the federal government. SRH approach is a key policy action for urban informality removal in Mumbai, where more than half of cities population lives in slums, an estimated 6.5 million slum dwellers (see here). The case of Mumbai SRH provides a foundational background for this study as it represents the most updated picture of a low-income built environment under transition in megacities of the Global South. Here, the SRH is characterised by vertical structures with 8 – 10 storeys, shoe-box like design with 24 sq. metres units and poor housing quality (Minna Sunikka-Blank, Bardhan and Haque, 2019).

Mumbai's SRH process involves state government driven private development through the Slum Rehabilitation Authority (SRA). SRA allows private builders to construct these new properties that consist of a living unit with attached kitchen and bathroom up to 24 sq. metres. Its objective is to help those slum residents whose names appeared on electoral rolls as of Jan. 1, 1995, to find affordable homes. State government rules allow any developer who successfully manages to procure the consent of 70% of the slum residents to redevelop the property. The developer then has to re-house the residents, free of cost, in new buildings constructed on the land. In the process, the developer can also use a portion of the land to build luxury towers for commercial sale. For instance, the Imperial Heights, India's tallest twin residential buildings, in south Mumbai came upon land cleared of slums. The Ritz-Carlton Hotel in Worli has a similar story (see here).

This SRH context has several injustices embedded in the process that has resulted in rebound behaviour among the occupants, where the inhabitants abandon their SRH homes and set up slum settlements elsewhere in the city (Debnath, Bardhan and Sunikka-Blank, 2019a). One such injustice relevant to this thesis is the rising energy bills and energy poverty among the occupants. It aids in developing my hypothesis that the low quality of the built environment is expanding distributive energy injustices. With this vantage point, this thesis investigates the distributive injustices in such SRH communities. For temporal evaluation on energy service demand, it focussed only on the Mumbai case, whereas for comparison and spatial evaluation, recently built SRH (or social housing) in Brazil and Nigeria were studied.

This study's applicability is in understanding the complexity of the problem of affordable housing and energy provision for the citizens living in extreme poverty. Cities develop affordable housing and energy policies; the focus should be on not expanding or reinforcing the existing poverty traps. The findings of this study can inform this nexus that extends beyond the case study areas and is highly generalisable in the current context of low-carbon and just societal transitions.

Key assumptions, scope, and limitations

Key assumptions in this thesis were based on defining the socio-technical and socio-cultural boundaries for empirical analysis. In the socio-technical domain, boundaries were drawn in the adopting practice-based approach through questionnaire surveys that highlighted 'time spent in doing household activities' as a critical variable. This variable was then converted into a quantitative model using structural equation modelling approaches. This novel quantitative transformation of practice-based approach restricted household practices' interpretation to survey specific questions like cooking, cleaning, washing clothes, and TV watching. Rich grounded narratives were collected using the lens of energy cultures theory that investigated the built environment's social norms, practices, and material-reality. In this case, the narratives were bounded by interpreting the translator from the local language/dialect to the English language. Besides, the definitions associated with social norms, practices and material-reality were driven by the SRH-distributive energy justice scope of this study with high contextual-granularity. The development of the deep-narrative analysis methodology intended to address such limitations and improve the objective of energy narratives for just policy design applications. These are further discussed in detail in Chapter 3.

The sample size for the temporal analysis in Chapter – 4 is 1200 households in the SRH of Mumbai. This enabled in deriving a generalised structural model of appliance ownership in the study areas. Such generalisation was limited in Chapter – 5 as the sample size was 200 households for the SRH in India and Brazil, the small-sample bias was reduced by using state-of-the-art regression models. Language barrier was a significant challenge in conducting the focus group discussions across the case studies in India, Brazil and Nigeria. The translation error was reduced by recruiting bilingual moderators that had at least two years of prior participatory research experiences (described in detail in Chapter – 7). The scope of the research design is limited by the assumptions made for the 'socio-technical' and 'socio-cultural' system of this study. These assumptions and its supporting literature-based evidence are elucidated in detail in Chapter – 3.

This thesis is structured according to the stated objectives, as presented in section 1.1.2. The first three chapters (Chapter 1 – 3) provide a general introduction to the research, an in-depth literature review, and the conceptual framework of this thesis. The next four chapters (Chapter 4 – 7) present the empirical results and provides new knowledge on contextualised understanding for distributive injustice in low-income communities. Chapter-8 illustrates the concluding remarks, limitations and future work of this study. Appendix information sections follow it. The brief outlines of the chapters are as follows (see Fig 1):

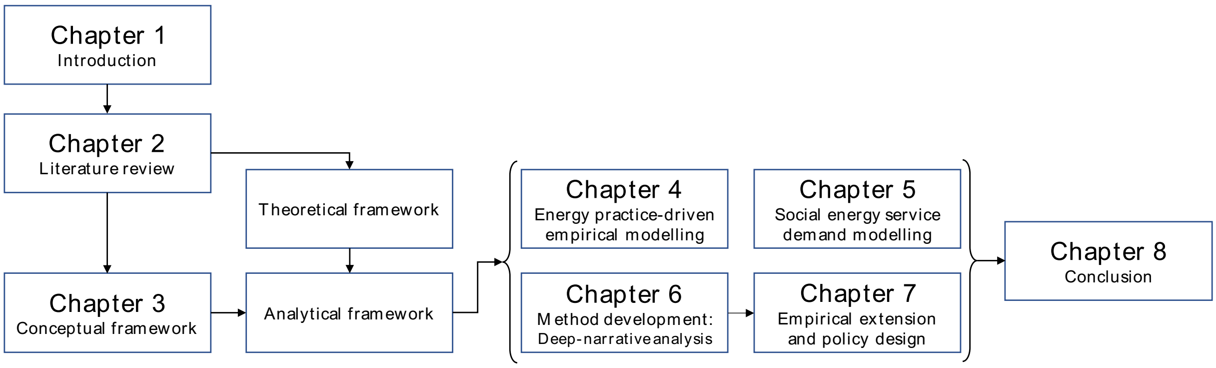

Fig 1. Structure of the thesis

Chapter 1: Introduction

This chapter states the problem statement and motivation of this research. It outlines the broad research questions and objectives, followed by a brief description of this study's novelty. This chapter also establishes the scope of this doctoral thesis.

Chapter 2: Literature review

This chapter provides a systematic literature review of conceptual and empirical studies on distributive energy justice from a bottom-up policy design perspective. The systematic literature review is conducted using a data-driven analysis route. Bibliometric data of the published literature on energy justice and poverty is extracted from the Web of Science and SCOPUS databases, which were then analysed using the methodological guidelines of bibliometric network analysis. It established the interconnected themes and concepts associated with distributive energy justice and poverty, which was then used to perform in-depth methodological and theoretical reviews of state-of-the-art concepts and epistemologies. Concurrently, an overview of the limitation of the existing methodologies and policy design mechanism in distributive energy justice is provided, which informs the conceptual framework development in Chapter – 3.

Chapter 3: Conceptual framework

This chapter presents the theoretical foundation of the cross-sectional and data-driven approaches to design bottom-up just energy policies for low-income communities. The conceptual basis is built on the limitations of the existing methodologies illustrated in chapter – 2. It provides a systematic understanding of the analytical framework and mixed-method methodologies adopted in this thesis. It explains the data-structure of the empirical chapters, followed by a detailed research design.

Chapter 4: Empirical modelling of energy practices in the transitional built environment

This chapter establishes empirical relationships between changing energy practices and energy intensity in the SRH of Mumbai, India. It is a temporal analysis that evaluates the before and after-effects of the transitional built environment (slums to SRH) on household energy practices. The variance in energy intensity is established by exploring the appliance ownership and purchasing behaviour of the occupants. This chapter represents the temporalities of distributive energy justice in low-income communities.

Chapter 5: Built environment effects of SRH on socio-cultural energy service demand

It is a theoretic-transitional chapter that transfers the temporal investigation from the chapter – 3 to a spatial investigation of SRH built environment design-induced energy service demand. Here, the energy service definition transfers from socio-technical (like cooling, heating, lighting, etc) to socio-cultural, representing comfort, cleanliness, and convenience as critical drivers for energy service. This chapter shows the span of distributive injustices concerning different SRH built environments using case studies from India and Brazil.

Chapter 6: Deep-narrative analysis framework for just energy policy design

This chapter presents a detailed description of the development of the deep-narrative analysis methodological framework. It provides a proof-of-concept using a case study in the SRH in Mumbai, India. The proof-of-concept then expands on its methodological polyvalence in just energy policy design applications. Its empirical extension is presented in Chapter – 7.

Chapter 7: Empirical extension of the deep-narrative analysis framework in SRH across India, Brazil and Nigeria for just policy design

This chapter is the empirical extension of the deep-narrative analysis framework using spatially distinct case studies of SRH in Mumbai, Rio de Janeiro, and Abuja. The empirical extension is conducted based on the theoretical framework presented in Chapter 3 using energy cultures' theory. The empirical results are then discussed for contextualisation for just energy policy design in low-income communities.

Chapter 7: Concluding remarks

This chapter includes the conclusions, recommendations for policymakers, and future work in the data-driven just policy design space. On a broader level, it summarises this research's main findings under each objective and explicitly mentions the new knowledge contribution of this thesis. Future improvements for this study based on the limitations encountered and how the study could be appreciated are also recommended.

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CHAPTER 2 Literature review

Energy justice, built environment and poverty alleviation

2.1 Research gap

A lack of local context-specific understanding of energy justice and domestic energy demand in the Global South is a critical research gap (Tucho, 2020). Energy justice refers to achieving equity in social and economic participation in the energy system, while also remediating social, economic and health burdens on those historically harmed by the energy system (Initiative for Justice, 2021). This concept evolved to ensure universal access to safe, affordable, and sustainable energy for all individuals across all areas. Moreover, to protect from the energy system's distributive outcomes, i.e., a disproportionate share of costs or negative impacts relating to building, operating, and maintaining electric power generation, transmission, the distribution system, and to ensure equitable access to benefits (Sourav, 2021).

In the context of just transition in the domestic energy demand, energy justice shapes the distributional outcomes of the energy system such that it advances energy democracy, alleviate energy poverty, reduce energy burden and promote energy security at the grassroots level (Sovacool and Dworkin, 2015b; Mundaca, Busch and Schwer, 2018; Initiative for Justice, 2021). The present policy design discourse for distributive energy justice is heavily influenced by the western philosophy that shapes the low-carbon transition policies in the Global South. Recent studies have shown that such a top-down approach in just policy design renders it ineffective at the local scale and demands context-specific understanding of injustices in the energy system (Malakar, Herington and Sharma, 2019a; Sovacool *et al.*, 2019; Bombaerts *et al.*, 2020; Müller *et al.*, 2020; Sovacool and Griffiths, 2020a). It is the biggest bottleneck translating energy justice concepts into practice (Initiative for Justice, 2021).

Contextualising energy justice and scaling it up for public policy applications in the Global South is challenging due to two primary reasons. First is the lack of local information and data on the energy system's distributional characteristics, especially across the socio-economic categories. Second is the lack of multi-dimensional framework/methodologies that can simultaneously capture and crystallise distributive justice's spatial and temporal extents. This thesis contributes to this gap by developing an original framework of contextualising energy justice in low-income communities.

This chapter provides a systematic literature review to identify research gaps and theoretical discourse on energy justice and poverty alleviation (see section 2.3). Further, explore the state-of-the-art basis for theoretical and empirical approaches in contextualising distributive justice in poverty (see section 2.4 and 2.5). Section 2.6 synthesises the above evidence to support this thesis's conceptual framework.

2.2 Review methodology

An interpretivist approach was adopted here to conduct a systematic review of the current literature on the intersections of energy justice theory and poverty alleviation policy approaches. In doing so, this chapter provides a broad overview of the overarching theories of energy justice and its association with low-income built environment design/planning. The systematic review was conducted on the methodological lines of bibliometric analysis to extract cover the larger bandwidth of energy justice literature. The interpretivist approach aided in crystallising theoretical focal points and their policy implications from the present energy justice/distributive justice and poverty alleviation literature.

The chapter's boundary is limited to the literature concerning energy justice, distributive justice and poverty alleviation to make it coherent with the scope of this thesis (see chapter 1). Moreover, the interpretivist approach in synthesising the review information was adopted to develop a discourse around the policymaking applications of the state-of-the-art energy justice concepts and theories. This discourse is followed throughout this thesis.

This doctoral research aims to contribute to the growing knowledgebase on evidence-based policymaking in low-income communities for provisioning clean and affordable energy (UN SDG – 7). While this chapter illustrates the present theoretical discourse around distributive energy justice and low-income built environment/energy poverty and outlines the challenges and policy implications, a detailed literature review is presented in each empirical chapter (see Fig 1) to support the specific research question and the methodologies.

Bibliometrics is the use of statistical methods to analyse books, articles, journal articles and other publications. Most common bibliometric analysis approaches include social network analysis (SNA); citation mapping; exploring grammatical and syntactical structures of texts; measuring usage by readers; quantifying the value of online media of communication; measuring Jaccard distance cluster analysis and text mining based on binary logistic regression (Kurtz and Bollen, 2010). The bibliometrics analysis was adopted along the methodological lines of Aria and Cuccurullo (2017), as illustrated in Fig 2.

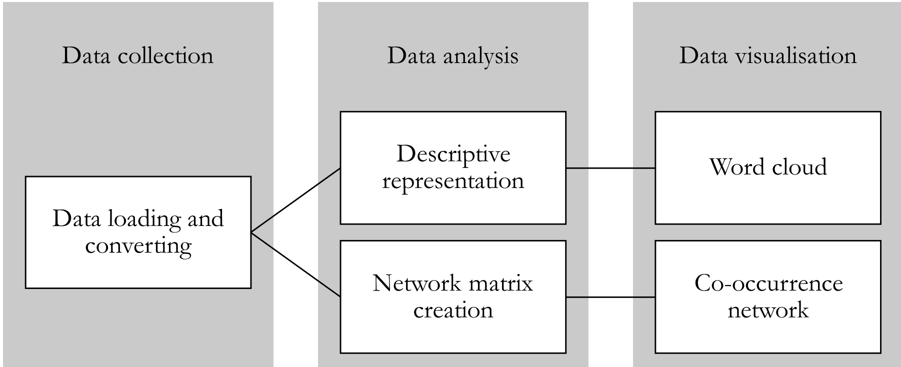


Fig 2. The bibliometric analysis approach adopted in this chapter for conducting systematic literature review

The bibliometric analysis data was accessed from the Web of Science (WoS) and Scopus database. WoS and Scopus are the most used databases in academia. WoS is the most authoritative citation database with high-quality publications, while Scopus is the largest data source on energy and society topics. In this review, we use all the relevant publications from these two databases to make full use of their complementary advantages.

First, a list of keywords related to "energy justice", "poverty", "built environment" and "policy", was determined to align with the scope of this thesis. In the WoS Core Collection database, Topic Subject was used as a retrieval field. "Science Citation Index Expanded (SCI-E)" and "Social Sciences Citation Index (SSCI)" were set to be the citation indexes to ensure publication quality. One thousand five hundred ninety-four publications between 1992 and 2021 with "Article" and "Proceedings paper" as article types and WoS category containing terms "Energy justice" were identified. Furthermore, manual cleaning identified 21 irrelevant publications, making the total article count 1573.

As for the Scopus database, Title/Abstract/keyword was used as a search column. Between 1992 and 2021, 1873 documents were retrieved with the standard keyword of "Energy justice", out of which 245 publications were unique and were not overlapping with the WoS articles.

A raw data matrix was created by combining the WoS and Scopus indexed publications. This combined corpus of 1818 documents were downloaded in both plain text and XML format. Key elements including title, abstract, published year, publication source, author keywords, and Keywords Plus were extracted. Publication number distribution by year is illustrated in Fig 3. The bibliometric analysis was performed in the R programming language.

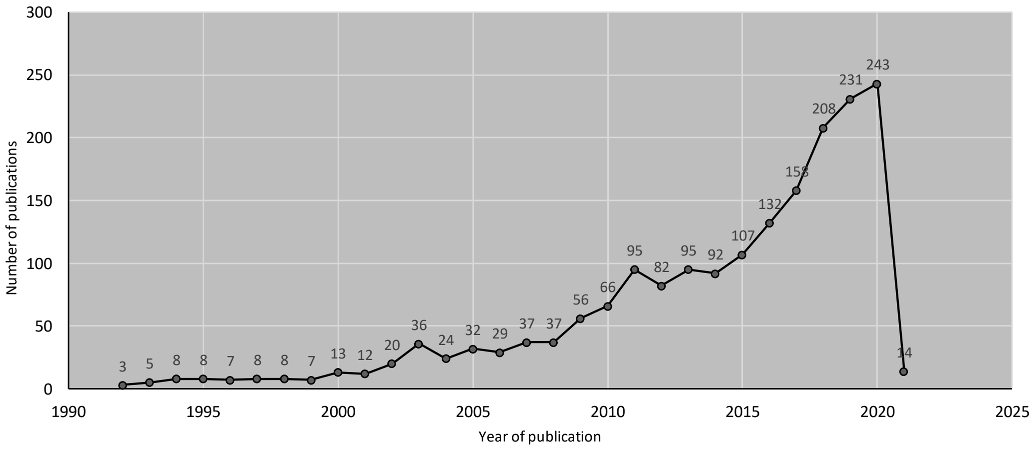


Fig 3. Publication number distribution by year

2.3 Energy justice and poverty alleviation: Theoretical discourse

As a theory, energy justice seeks to apply justice principles to energy policy, energy production systems, energy consumption, energy activism, energy security, the energy trilemma, political economy of energy and climate change (Sovacool and Dworkin, 2014). The reach of energy justice theories as a cross-cutting social science research agenda is illustrated in Fig 4, which shows the most used keywords with energy justice as the central theme in the current literature. The visualization in Fig 4 is known as keyword co-occurrence analysis. Keyword co-occurrence network reflects the knowledge structure and theoretical core that can display the relationship between keywords (Qin, Wang and Ye, 2019). Here, nodes represent keywords, while edges represent co-occurrence relationships among nodes.

Themes associated with social and environmental justice work in tandem with the research domain of energy justice and energy policy (see Fig 4), indicating the movement of energy scholarship to understand how we distribute the benefits and burdens of energy systems. The highest frequency of keywords associated with the term 'energy justice' is 'social justice', 'environmental justice', 'energy justice', 'energy policy' and 'sustainable development' (see Fig 4). These terms were further clustered to derive a network of keywords associated with the current energy justice literature. The red colour bubbles represent a network of keywords associated with 'social justice'; the green colour clusters represent the keywords associated with the term 'energy policy'; and the blue colour cluster represents the network of keywords associated with 'environmental justice' and 'energy justice'.

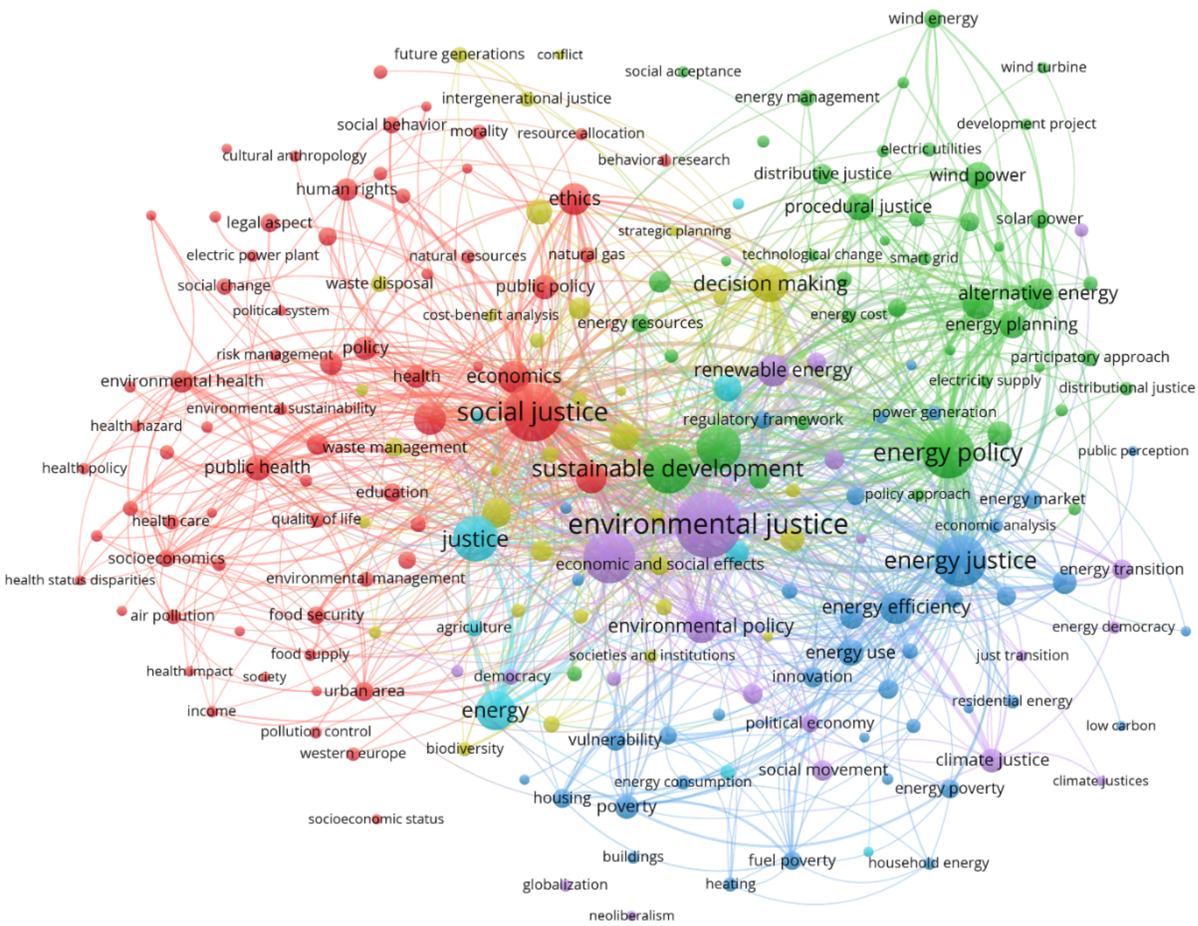


Fig 4. Keyword co-occurrence of themes/words with the term "energy justice" from Scopus and Web of Science databases (n=1818)

[Note: 'Red', 'green' and 'blue' colour represents keyword clusters with respect to high frequency terms like 'social justice', 'environmental justice', 'energy justice', 'energy policy' and 'sustainable development']

Sovacool (2014) raises questions about how the costs and benefits of energy production and consumption should be distributed; and whether we are "fair" to future generations. The uncertainties associated with answering this question are even more severe for the Global South, as millions of its citizens will be pulled up from extreme poverty in the coming decade, significantly increasing energy production and consumption. An energy-just world shares both the benefits and burdens of producing and consuming energy services and it treats its people and communities 'fairly' in energy decision-making (Sovacool and Dworkin, 2014). "Energy services" are often measured in units of heat, or work, or temperature as we derive utility from "end-use energy" like heat for a stove, mobility in an automobile or mechanical energy for air circulation. It is often regarded as the surrogate for measuring satisfaction experienced when we consume or experience them. Energy services are regarded as the benefits that energy carriers produce for human well-being through comfort, cleanliness and convenience (Sovacool and Dworkin, 2014). Thus, energy as a concept has a social and scientific conception that links physical materials with the anthropocentric needs of well-being, making it a sociotechnical system. As late economic E.F. Schumacher said, " Energy is not just another commodity but the precondition of all commodities, a basic factor equal with air, water, and earth. (Schumacher, 1973)". In recent literature, the energy service, welfare and well-being nexus is conceptualised as human-scale energy services or HUSES (Brand-Correa, Martin-Ortega and Steinberger, 2018; Samarakoon, 2019).

Therefore, it is the responsibility of those managing the system that weighs the benefits of energy service against the economic, social and environmental costs it takes to produce and maintain these benefits. In turn, it would make the system 'just and reasonable' for everyone (Sovacool and Dworkin, 2014). Justice primarily involves distributing primary goods of rights and liberties, powers and opportunities, and income and wealth (Rawls, 1971). A just society distributes these goods in the right way by giving each person their due (Sandal, 2009). Sovacool and Dworkin, (2014) provide the most comprehensive definition of energy justice grounded based on the distributional, procedural, and recognition-based justice theories (see Table 1). They define energy justice as *'a global energy system that fairly disseminates both the benefits and costs of energy services and one that has a representative and impartial energy decision-making'* (Sovacool and Dworkin, 2014).

In recent times, energy justice has emerged as a useful analytical tool for altering how energy problems exist or are framed (Sovacool and Dworkin, 2015a). It enables determining how we make the energy transition from fossil-based fuel sources to low-carbon alternatives, and more specifically, *who* gets to make it, and *who* has to pay for it. Sovacool and Dworkin, (2015) connected energy justice concepts with eight philosophical notions (see Table 1), influences, applications, injustices and solutions to prepare an analytical roadmap. The first four of these concepts- *virtue, utility, human rights, and procedural justice* were derived from classical theorists' works, whereas the next four- *welfare, freedom, posterity and responsibility* are synthesised from modern thinkers.

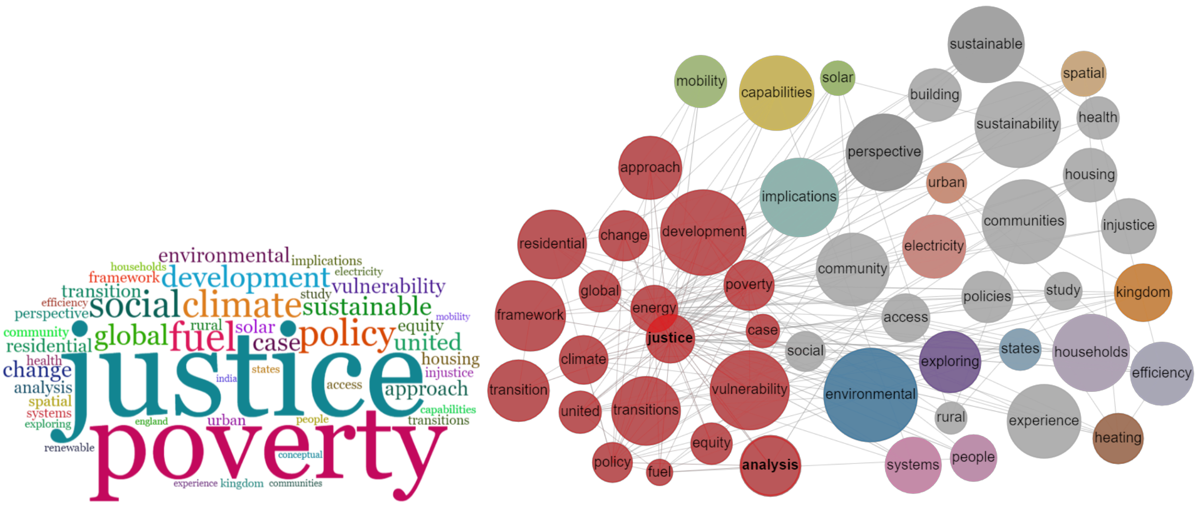
Table 1. Energy justice concepts, philosophical influences and application to energy policy (Source: (Sovacool, 2014; Sovacool and Dworkin, 2014)

Topic	**Concept(s)**	**Major philosophical influence(s)**	**Applications to energy**	**Injustices**	**Solutions**
Energy efficiency	Virtue	Plato and Aristotle	Energy efficiency: high penetration of efficient service	Inefficiencies involved in energy supply, conversion, distribution, and end-us	Fuel economy standards, energy efficiency labelling, industrial retrofits, utility-scale demand side management, ascending block rate pricing, advanced metering and smart grids, training and capacity building, consumer education and awareness
Energy externalities	Utility	Jeremy Bentham, John Stuart Mill, Henry Sidgwick	Well-being: less suffering, pain, externalities, and disasters associated with energy production and use	The imposition of negative social and environmental costs on society such as traffic congestion, the extractive industries affiliated with energy production, the resource curse, nuclear waste, air pollution, GHG missions, and water consumption	Passage of a carbon tax, accurate price signals and tax shifting, and environmental bonds
Human rights and social conflict	Human rights	Immanuel Kant	Universal human rights: an obligation to protect human rights in the production and use of energy	The violation of civil liberties – in some extreme cases death and civil war – undertaken in pursuit of energy fuels and technology, as well as the contribution of energy production to military conflict	Extractive industries transparency initiatives, energy truth commissions and inspection panels, improved social/EIAs for energy projects, availability of legal aid to vulnerable groups
Energy and due process	Procedural justice	Edward Coke, Thomas Jefferson, Jurgen Habermas	Due process: free prior informed consent (FPIC) for the siting of energy projects; fair representation in energy decision-making	Approaches to energy siting that ignore or contravene free, fair, and informed consent, and/or do not conduct adequate social and EIAs	Better information disclosure, broader community involvement and participation

Topic	Concept(s)	Major philosophical influence(s)	Applications to energy	Injustices	Solutions
Energy poverty	**Welfare and happiness** *a core theoretical foundation of this thesis.	John Rawls, Amartya Sen, Martha Nussbaum	Accessibility and subsistence: an energy system that gives people an equal shot of getting the energy they need, energy systems that generate income and enrich lives	Lack of access to electricity and technology, dependence on traditional solid fuels for cooking, and time intensive fuelwood and water collection and processing of food in emerging economies, borne mostly by women and children	Social pricing and assistance programs as well as pro-poor public private partnerships for microhydro units, solar home systems, improved cookstoves, biogas digesters, and small-scale wind turbines, mechanical energy for pumping, irrigation, and agricultural processing
Energy subsidies	Freedom	Robert Nozick, Milton Friedman	Libertarianism: energy decisions not unduly restricted by government intervention	Gross subsidies that involve an involuntary wealth transfer to recipients, essentially raiding the pocketbooks of the unwilling	Elimination of inappropriate subsidies, subsidy impact assessments, sunset clauses, and adjustment packages for those dependent on subsidies
Energy resources	Posterity	Ronald Dworkin, Brian Barry, Edith Brown Weiss	Resource egalitarianism: an obligation to minimize resource consumption and ensure adequate reserves for future generations	Exhaustion of depletable energy reserves and fuels	Improved energy efficiency, establishment of national resource funds, commercial-scale deployment of renewable electricity and biofuels
Climate change	Fairness, responsibility and capacity	Peter Singer, Henry Shue, Paul Baer, Stephen M. Gardiner, Dale Jamieson, Simon Caney	Intergenerational equity: an obligation to protect future generations from energy-related harms	A daunting suite of negative impacts from climate change including ocean acidification, food insecurity, climate refugees, and the increased frequency and severity of natural and humanitarian disasters	Greenhouse development rights (GDR), community-based adaptation, mitigation through stabilization wedges

This thesis builds on the modernist definitions of energy justice (see Table 1) to address energy poverty bounded by the welfare and capability-based rationale of equitable distribution of energy resources. It outlines the concept of distributive energy justice. Distributive energy justice relates to fairness in the distribution. In recent years, researchers have argues that energy poverty is 'fundamentally a complex problem of distributive injustice' (Walker and Day, 2012); and suggests that this is reinforced by further injustices in recognition and policy-making procedures. It provided a theoretical foundation for further studies that unpacked the philosophical and moral foundations for considering energy poverty to be a form of distributive injustice (Sovacool, Sidortsov and Jones, 2014; Sovacool, 2015; Sovacool *et al.*, 2016; Bouzarovski and Simcock, 2017a; Gillard, Snell and Bevan, 2017).

Fig 5 illustrates the high-frequency terms/words associated with current literature on ‘energy justice’ and ‘poverty’. Two hundred eleven relevant documents were filtered from the original corpus of 1818 documents, representing only ~11% of the documents explicitly mentioned the above two keywords in their ‘Title, Abstract, or/and Keyword’. The word cloud in Fig 5a shows most common words/terms in the current literature like ‘justice’, ‘poverty’, ‘sustainable’, ‘policy’, ‘climate’, ‘social’, etcetera. Fig 5b illustrates the keyword co-occurrence network of high-frequency words/terms clustered by the colour. Red cluster shows interconnections of ‘energy justice’ and ‘poverty’ around critical terms like ‘transitions’, ‘vulnerability’, ‘equity’, ‘climate change’, etcetera (see Fig 5b). It indicates the current paradigm in distributive justice research that focus on these themes to explore and shape the narratives around distributive injustices in poverty. A similar discourse on distributive injustices is framed around ‘health’, ‘housing’, ‘communities’, ‘sustainability’ and ‘policies’ that further illustrates the literature link between built environment, health and energy poverty. Table 2 presents critical literature establishing these links in the context of policy planning for distributive justice in poverty.



a. Word cloud of common terms

b. Term co-occurrence network constructed from titles, abstract and keywords

Fig 5. High frequency words/terms and their interconnections in the current literature on 'energy justice' and 'poverty' in their title, abstract, and/or keywords (n = 211).

Table 2. Critical theoretical discourses on distributive energy injustices in a just-policy design context (2021 – 2015)

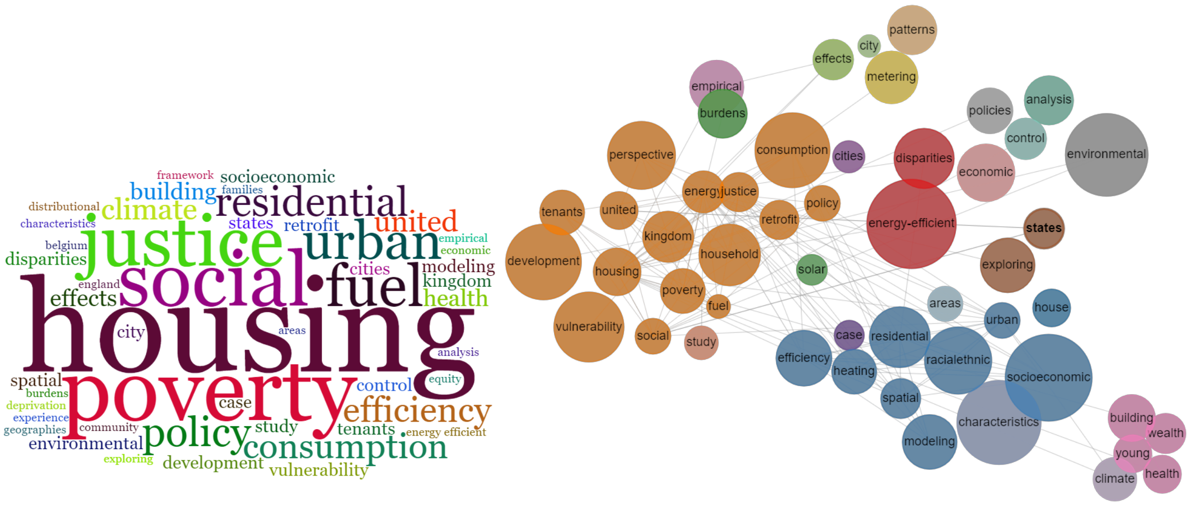
Theme	Distributive injustices discourse	Theoretical influence(s)	Policy implications for energy poverty alleviation	Study location/Reference
Low carbon energy transition/renewable (RE) integration at community-level	Micro-politics of RE project planning influences energy access interventions	Post-colonial micro-politics	Need of decentralised mentality and consideration of community-level politics	Indonesia (Fathoni, Setyowati and Prest, 2021)
Electrification planning	Lack of ethical and fairness considerations in the construction of energy infrastructure	Soft energy paths and capabilities approaches	Need of a justice-based electrification planning framework that revaluates the electrification planning and decision-making process at local-level.	Sub-Saharan Africa (Tarekegne, 2020)
Off-grid solar market	Reliance on poorly regulated solar RE market	Energy-ethnography	Deepening policy reliance on poorly regulated solar markets to address energy poverty is dangerous.	Malawi (Samarakoon, 2020)
Gender and energy poverty	Lack of recognition of women in energy poverty alleviation policies; Gender bias of energy and fuel usage and access to modern energy services	Post-modern gender theory	Need of analysing the gender-energy nexus to reveal its social dynamics and understanding non-technical dimensions of women's poverty.	Bangladesh (Moniruzzaman and Day, 2020)
Low-income housing, thermal comfort, fuel poverty	Poor design of social housing leading to increased cooling needs, energy poverty and health burdens.	Fuel poverty affects human health/social justice	Need of intersectionality between vernacular architecture and sustainable cooling practices to address distributive justices	Brazil (Mazzone, 2020)
Electricity scarcity and social injustice	Social scarcity of electricity abrogates social justice	Neoliberal and capitalism	Need of understanding that electricity availability does not mean access to all - scarcity can be experienced even when the resource is in abundance.	Zimbabwe (Chipango, 2020)
Fuel poverty, spatiality and well-being	Social housing planning and uneven access to fuel	Well-being and energy use	Essential to understanding the ways social housing tenants relate to uneven access to fuel is as an emotionally embodied home making and unmaking practice.	Australia (Waitt and Harada, 2019)
Well-being and energy services	Inaccessibility to energy services impacts well-being	Well-being: Eudaimonic vs Hedonic; The capability	Need of ethical imperative to ensure energy justice and well-being when provisioning energy services.	(Samarakoon, 2019)

Theme	Distributive injustices discourse	Theoretical influence(s)	Policy implications for energy poverty alleviation	Study location/Reference
		approach (Sen and Nussbaum); Human needs approach		
Non-western theory of energy justice	Heavy influence of western concepts makes it difficult to address temporal energy injustices in developing countries	Energy transition; temporal justice	Need of policy to focus on not only where and how the benefits and burdens of energy transitions are distributed, but also when and who experience the intra- and inter-generational nature of energy transitions. Need of contextualised understanding of temporal dimensions of energy justice.	India (Malakar, Herington and Sharma, 2019a)
Inclusive design; low-income housing; gender and energy poverty	Lack of open spaces and inclusivity in design of slum rehabilitation housing leads to energy poverty.	Energy practice; housing design	Gender inclusive design of low-income housing is critical to address energy poverty.	India (M. Sunikka-Blank, Bardhan and Haque, 2019)
Energy burden of low-income households	Energy inequality expand education inequity in low-income households	Building and energy modelling; appliance ownership	Leveraging weatherization funding to fund building energy retrofit in low-income households.	USA (Nelson and Gebbia, 2018)
Affordable heating as energy justice; low-income housing	Energy poverty is significantly associated with deprivation of many capabilities; Social stigma against energy poor; Household access to affordable warmth	The capability approach (Sen and Nussbaum)	Deprivation of capabilities regarding housing, health, mobility, access to cultural and recreational activities as the feeling of fulfilment and ontological security are critical to promote distributive, procedural and recognition justice.	Belgium (Bartiaux *et al.*, 2018a)
Low-income housing; urban densification; fuel poverty	Dwelling typology has causal links with the experience of fuel poverty	Urban form; densification	Fuel poverty alleviation policies must account for urban density and dwelling type.	Australia (Poruschi and Ambrey, 2018)
Spatial injustices in energy system	Geographic disparities and temporal differences in domestic energy demand lead to elevated energy poverty risks	Social inequality and energy access	Spatial understanding of energy inequality is critical for contextualised just policy design.	(Bouzarovski and Simcock, 2017a)
Spatial and temporal aspect of energy poverty	Historically poor thermal quality of housing stock; rising	Energy poverty; systemic	Need of recognising housing and demographic related vulnerabilities to	Hungary, the Czech Republic and Poland

Theme	Distributive injustices discourse	Theoretical influence(s)	Policy implications for energy poverty alleviation	Study location/Reference
	utility prices; falling real income	injustices; social theory	fight energy poverty and distributive injustices.	(Bouzarovski and Herrero, 2017)
Energy knowledge and experiences	Political economic influences spatial dimension of energy justice; Traditional discourse of energy services restricts the welfare goals of UN SDG-7	Green growth; energy poverty	Energy solutions need to shift away from simple technological fixes; Energy policy needs to be built on a holistic range of energy knowledges and experiences.	Sierra Leone (Munro, van der Horst and Healy, 2017)
Residential heating justice; low-income households	Racial/ethnic, spatial and socioeconomic disparity on residential heating EUI	Energy use intensity (EUI)	Need of identifying distinct forms of social inequality in residential energy efficiency to prevent broad-based energy policies that fail to serve the vulnerable and low-income households; Implementation of energy assistance programs with socio-culturally sensitivity; Modelling energy use intensity rather than total energy consumption provides more meaningful information for analysing disparities and targeting the most appropriate intervention to the appropriate location.	USA (Reames, 2016)
Energy poverty; well-being	Weak understanding on the conceptualisation of energy deprivation	The Capability Approach (Sen and Nussbaum)	Understanding energy use in the capabilities space also provides a means for identifying multiple sites of intervention	(Day, Walker and Simcock, 2016a; Walker, Simcock and Day, 2016)
Heating energy justice/policy evaluation	Poor housing design, energy efficiency impacts health of occupants, especially in winters due to lack of affordable heating.	Fuel poverty, energy efficiency and health	The overall health and welfare of British homes increases on energy efficiency upgrades under the Warm Front Program. Warm Front lessened the prevalence of fuel poverty, cut greenhouse gas emissions, and saved household money.	United Kingdom (Sovacool, 2015)

Table 2 lists critical literature around the theoretical discourse of distributive justice, and energy poverty alleviation approaches. The core discourse was in two parts. The first part catered to understanding contextualised injustices from around the globe. The second part was developing a methodological framework connecting energy demand with long term health and well-being measures. However, both these parts are in their early stages of exploration, and literature demands further and in-depth exploration of the pathways to distributive justice in poverty. Table 2 also shows that built environment design acts as a catalyst for distributive justice in low-income communities. This theoretical angle is a critical epistemology for this thesis. This thesis contributes to this research gap by developing a new methodology of distributive injustice exploration using grounded knowledge and experiences embedded in a low-income built environment.

2.4 Intersections in distributive energy justice and low-income built environment

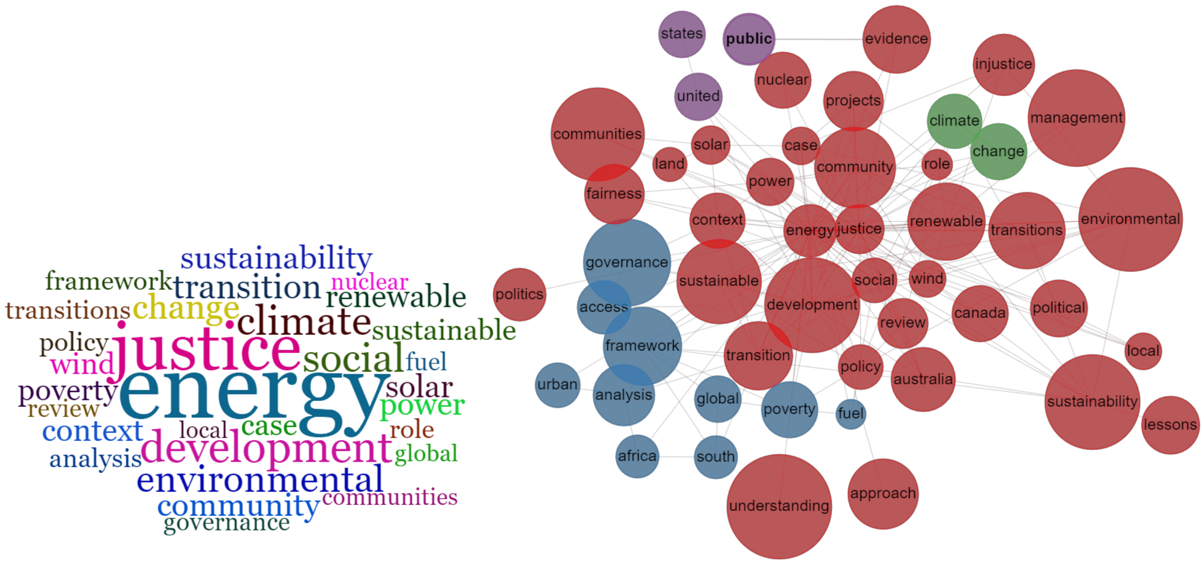


a. Word cloud of common terms b. Term co-occurrence network constructed from titles, abstract and keywords

Fig 6 High frequency words/terms and their interconnections in the current literature on 'energy justice' and 'built environment' in their title, abstract, and/or keywords (n = 61)

Fig 6a shows the most common words/terms associated with 'energy justice' and 'built environment'. The colour clusters in Fig 6b illustrate the related themes with the above search keywords. It can be seen here that the term 'energy justice' has higher interconnections in the orange cluster (see Fig 6b) with words/terms like 'vulnerability', 'social', 'poverty', 'household', 'retrofit', 'fuel' and 'consumption'. It empirically illustrates critical intersections between distributive energy justice and the built environment in poverty. It further shapes the narratives/discourse around equity and equitable distribution of energy infrastructure in low-income communities. The connection between social housing and energy poverty has been extensively studied in recent years (see Fig 6b), where discussions around the quality of the built environment and the demand for affordable energy services is regarded as a critical distributive justice (Walker, Simcock and Day, 2016; M. Sunikka-Blank, Bardhan and Haque, 2019; Samarakoon, 2019). More specifically, access to open spaces, daylight, clean air, sanitation and healthcare facilities are the externalities that frame the distributive justice narratives in poor communities (SPARC, 2015; Gillard, Snell and Bevan, 2017; Bardhan, Debnath, Jana, *et al.*, 2018b; Bartiaux *et al.*, 2018a; Waitt and Harada, 2019; Mazzone, 2020). Such externalities are systematically reviewed in-depth in the empirical chapters of this thesis (see Fig 1).

In this intersectional quest for factors that influence distributive justice discourse concerning built environment, recent studies have reported that lack of contextual understanding of energy injustices in the built environment (Bombaerts *et al.*, 2020; Johnson *et al.*, 2020; Lacey-Barnacle, Robison and Foulds, 2020; Tucho, 2020). The blue cluster in Fig 6b further illustrates the current research focuses on social and people-centric factors like 'racial ethnic', 'socioeconomic', 'spatial', etcetera. Such lack of contextualised viewpoint of energy injustices is even more critical for investigating the asymmetries in energy affordability and accessibility in the Global South, as the present literature on energy justice has a heavy influence on western viewpoints (Buchholz, 2014a; Malakar, Herington and Sharma, 2019a; Bombaerts *et al.*, 2020; Lacey-Barnacle, Robison and Foulds, 2020; Mazzone, 2020; Müller *et al.*, 2020).



a. Word cloud of common terms

b. Term co-occurrence network constructed from titles, abstract and keywords

Fig 7 High frequency words/terms and their interconnections in the current literature on 'energy justice' and context' in their title, abstract, and/or keywords (n = 259)

The word cloud in Fig 7a shows high-frequency word/terms associated with the literature on the need for contextualised understanding of energy justice/injustices at the community level. Fig 7b further illustrates the focal points to the epistemologies of 'contextualised energy justice'. A growing body of study demands a contextual understanding of energy justice with renewable integration and low-carbon transition policies (Johnson *et al.*, 2020; Sovacool and Griffiths, 2020a), need of gendered approach to energy justice (Govindan *et al.*, 2020; Lacey-Barnacle, Robison and Foulds, 2020; Moniruzzaman and Day, 2020) and extraction of local lessons and capacity-building toward energy injustices (Johnson *et al.*, 2020; Kovacic *et al.*, 2020; Lacey-Barnacle, Robison and Foulds, 2020; Scott and Powells, 2020; Tucho, 2020).

2.5 Energy affordability challenges in low-income communities of the Global South

This thesis's core focus is to explore the distributive injustices in the Global South, especially concerning urban poverty and low-income built environment. About a quarter of the world's urban population live in slums, and the redevelopment of the slum dwellers is one of the burning sustainable development challenges (Hutt, 2016; ourworldindata, 2020). Slum rehabilitation housing (SRH) refers to social housing building stocks that are developed with the sole aim of accommodating slum dwellers and fill the affordable housing deficits in rapidly urbanising countries of the Global South. It also serves as a poverty alleviation policy instrument designed with the broader goal of affordable housing for all (R. Bardhan *et al.*, 2015).

In India, SRH has been regarded as one of the most successful policies of slum redevelopment and urban rejuvenation. However, in recent years, post-occupancy evaluation has shown that the quality of life in the SRH is deteriorated by the low standard of the built environment (Kshetrimayum, Bardhan and Kubota, 2020b). In policy and planning perspectives, SRHs are envisaged as transitional homes for slum dwellers, but in real-world cases, they become the permanent residential structure for millions of citizens. Studies have shown that SRH in Mumbai, India, is transforming into vertical slums due to the inappropriate and non-contextual design of the housing communities (R. Bardhan *et al.*, 2015; M. Sunikka-Blank, Bardhan and Haque, 2019). Built environment design flaws include lack of daylighting in the living spaces, low indoor air quality and ventilation strategies, lack of sanitation and hygiene. At a community level, there are no open spaces, parks and green areas. The occupants must spend most of their time indoors as these 8-10 storey vertical apartment units do not have operational lifts, and garbage is dumped in-between the building units (see Fig 8). Recent literature also shows that occupants face a higher degree of discomfort and distress in the SRH built environment that is associated with higher healthcare-seeking behaviour (Vaid and Evans, 2017; Lueker *et al.*, 2019; Kshetrimayum, Bardhan and Kubota, 2020b; Sarkar and Bardhan, 2020b). It creates additional health and energy burden in the low-income households that illustrates the poverty penalty of living in the SRH (Chowdhury, 2009; Subbaraman *et al.*, 2014; Nijman, 2015; Vaid and Evans, 2017).

Fig 8. High-rise apartments of a slum rehabilitation housing (SRH) in Mumbai, India, demonstrating poor quality of the built environment (source: Author).

A recent study by Debnath, Bardhan and Sunikka-Blank, (2019) have reported that people living in an SRH community in Mumbai often pay more than 30% of their monthly income as electricity bills, shedding light on the poverty penalty of accessing a modern form of energy in such low-income transitional housing units. The same study further explored that occupant usually borrow loans at high-interest rates from informal lenders that significantly adds to their distress and financial hardship. Such chronic financial burden with sub-standard dwelling units often forces the occupants to move back from the SRH to horizontal slums. It further expands informality in urban areas, demonstrating a policy lacuna (Debnath, Bardhan and Sunikka-Blank, 2019a; Kshetrimayum, Bardhan and Kubota, 2020b; Sarkar and Bardhan, 2020b).

Similar observations concerning the low quality of social housing/SRH and prevalence of energy poverty are reported from the rapidly urbanising economies of the Global South like Brazil (Mesquita and Ripper Kós, 2017; Moreno, Morais and Souza, 2017; Mazzone, 2020), Ethiopia (Tesfamichael *et al.*, 2021), Argentina (Sosa, Correa and Cantón, 2018), Australia (Waitt and Harada, 2019), India (Minna Sunikka-Blank, Bardhan and Haque, 2019), Bangladesh (Moniruzzaman and Day, 2020), Nigeria (Bisu, Kuhe and Iortyer, 2016), Latin America (Santillán, Cedano and Martínez, 2020), Sub-Saharan Africa: Mozambique, Rwanda (Castán Broto *et al.*, 2018; Muza and Debnath, 2020), etcetera. Besides, a significant body of literature from the Global North provides strong empirical evidence on poor built environment design and the prevalence of energy poverty (Walker and Day, 2012; Day, Walker and Simcock, 2016a; Reames, 2016; Walker, Simcock and Day, 2016; Bartiaux *et al.*, 2018a; Sanchez and Reames, 2019), also see section 2.2. The most coherent policy implications drawn from these articles infer bottom-up and citizen-centric policymaking and urban planning to reduce the distributive injustices associated with household level's energy infrastructure.

The SRH/social housing building stocks and its effective built environment planning are even more critical in poverty alleviation efforts across the Global South. They aim to uplift citizens from extreme poverty through affordable housing and a decent quality of living. The literature evidence provided above shown that there are embedded injustices in the current built environment design and planning of the SRH in Mumbai, while the same SRH models are being replicated across sub-Saharan Africa, South-east Asia and Latin America. Thus, the embedded distributive injustices will also be duplicated in these areas that will significantly impact millions of occupants' quality of life. Just policies must include a context-specific built environment design that can, in turn, provide equitable and affordable access to clean energy in SRH.

2.6 Synthesis of theoretical intersectionality for this thesis

This section condenses the theoretical threads from the quantitative literature review in the previous sections and provides a synthesis of this thesis's theoretical grounding. This thesis's theoretical proposition of distributive energy justice is built on discussions around energy services and their welfare benefits after Sovacool and Dworkin (2014). It has its epistemological foundation in the work of distributive justice and human capabilities by John

Rawls, Martha Nussbaum, and Amartya Sen (see Table 2). Sovacool and Dworkin (2014), in Chapter – 7 of their books, expanded the applicability of justice theory in the energy space by stating that *'an energy system that gives people an equal shot of getting the energy they need, energy systems that generate income and enrich lives is a just energy system'*. It forms the basis of the distributive justice discussions in this thesis to understand the causes of affordability asymmetries in the SRH (as mentioned in Chapter – 1).

Translation of this theory into an empirical framework remains a challenge in the current literature (as discussed in section 2.3). The author has used an intersectional approach by overlapping Sovacool and Dworkin (2014) distributive justice interpretation with Sovacool (2011)'s urban energy service ladder framework. It defined energy services as an intersection of socio-technical and socio-cultural energy demand. It is distinct according to sectors, urban and rural areas, and direct and indirect uses. This hypothetical ladder finds that low-income households demand fewer energy services with a greater fuel mix and fuel stacking (firewood, dung, kerosene, electricity, etc.).

On the other hand, middle-income households demand a much broader range of services for comfort, convenience, and cleanliness (3Cs). There is always a constant struggle to balance the socio-cultural and socio-technical energy service needs in these households. The upper-class or wealthy households have access to the same energy fuels, carriers, and technologies as middle-income homes and families. However, they consume more energy (and more high luxury items). A broader picture of such energy service intersectionality with welfare, well-being and social dimensions is illustrated in Table 2. The latest literature addresses this intersectional attribute of human-scale energy services (HUSES) after Brand-Correa, Martin-Ortega and Steinberger, (2018).

Literature review showed that practice-based approaches and 3Cs had been epistemologically studied by social anthropologist Elizabeth Shove (2003), where she describes 3C-demand as a characteristic of social norms across the consumer classes. Shove (2012) further explored 3Cs and energy demand contexts through a practice-theoretic lens, stating that *'appliance ownership is more context-specific than merely a function of income, and not everyone may acquire appliances in the same way as income rises'*.

From the HUSES perspective, Shove's 3Cs can be interpreted as follows. "Comfort" is described as one's satisfaction with the immediate physical environment by controlling the built environment parameters of the indoor climate. "Cleanliness" is referred to as the energy services needed to maintain desired hygiene and sanitation conditions. It has a broader undertone of unique ideas of the built environment's display, disinfection, and deodorisation. "Convenience" refers to energy services that enable a smooth and effortless way of life. It is also associated with improving the quality of experience by using hyper-modern time-saving appliances (e.g., heating frozen food in microwave ovens rather than cooking every meal) in the modern world. Johnson, Gerber and Muhoza, (2019) further showed that the availability of 3Cs critically influences occupants' well-being. The demand for 3Cs is formed through specific energy practices, material reality, social norms, and aspirations, which is met through household appliances ownership.

It defined the boundary for the socio-technical system that investigated the change in household practice and 3C-demand through specific appliance ownership in poverty as a critical distributive justice parameter in specific material reality. In this thesis, this material reality was defined by the built environment characteristics of the SRH.

The change in household practices defined the temporal dimensions of energy demand in this thesis (also illustrated in section 1), which was used to build empirical models from practice-based approaches and appliance ownership in the SRH (i.e., the empirical Chapter – 4). Again, synthesising from Sovacool and Dworkin (2014) theory on distributive energy justice, temporality and spatiality have two critical components (discussed in detail in sections 2.3 and 2.4). First, as mentioned above, in this thesis, temporality was measured by changing household practices based on Shove (2003) 's practice-based lens. Second, the spatial dimensions of distributive justice were empirically instrumentalised using sociologist Janet Stephenson's energy cultures theory. This theory allowed expanding practice-based lens across spatial scales, i.e., through case studies of SRH and energy service demand in SRH of India, Brazil and Nigeria. Further methodological details, data structures and empirical approaches are presented in Chapter – 3.

A vital synthesis of the above theories guides the contextualisation of distributive justice and HUSES to the appropriation of low-income built environment design. This linkage is systematically explained in detail in Chapter 3. In addition, the practical problems associated with high electricity bills and the poor design of the SRH are evaluated using the theoretical constructs of distributive justice at a household and community level. For example, Sunikka-Blank, M, et. al (2019) have shown that to understand energy demand in the SRH, it is important to internalise the daily routines of women living in such communities.

Another critical element of the synthesis is establishing the boundaries of contextualisation using distributive justice's temporal and spatial characteristics in low-income communities. Finally, it conceptually embeds the discourses associated with energy cultures and HUSES literature to transform it into methodological tools. For example, Brand-Corea, L, et al. (2018) used participatory workshops to test their HUSES theory and its interpretation of energy poverty in Medellín, Columbia.

The analytical conversion of practice theory to evaluate changing practices and their causal linkages on household energy consumption in the SRH (see Chapter – 4) is built on hypothesises derived through the intersectionality presented in section 2.5. Similarly, as mentioned above, the translation of 3Cs and urban energy ladder into regression-based modelling framework in Chapter – 5 is built on the intersectional understanding of socio-cultural energy services with built environment parameters, as illustrated in section 2.4. In addition, the extension of the energy cultures framework into a nested natural language processing framework led to the development of the novel deep-narrative analysis framework and its empirical application in the study areas of India, Brazil and Nigeria (see Chapter 6 and Chapter 7).

In summary, the key points of the theoretical synthesis of the intersections of energy justice, built environment and poverty alleviation studies are:

- Built environment modulates the need for socio-cultural energy service, i.e., the demand for comfort, cleanliness and convenience, that can be studied through the lens of energy cultures and HUSES framework.
- Distributive energy justice theories embody the spatial and temporal dimensions of HUSES that can be studied through practice-based approaches (for exploring temporality) and cross-sectional participatory research design (for exploring spatiality), among many other approaches as discussed in section 2.4. It is further presented as this thesis's core analytical approach in Fig 11 and section 3.3.

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CHAPTER 3 Conceptual framework

A multi-system approach to contextualising distributive energy justice in poverty

3.1 Framing a socio-technical and socio-cultural system of energy service demand in slum rehabilitation housing

This thesis investigates energy injustices in the low-income transitional built environment, like slum rehabilitation housing (SRH), through the theoretical foundation of distributive energy justice for welfare and capability addition (as presented in Table 1 in section 2.2). The literature reported existing methodological challenges to just energy policy design at the grassroots level (see section 2.3). The most widely reported challenge is the need for contextualised understanding of existing inequality in affordability and accessibility to energy services in poverty (Sovacool and Dworkin, 2015a; Munro, van der Horst and Healy, 2017). The present conceptual development links essential energy services for cooling, heating and cooking to eudemonic well-being in low-income poverty, as 'human scale energy services (HUSES)' (Brand-Correa, Martin-Ortega and Steinberger, 2018). Though, such concepts are yet to be evaluated or applied in just policy design of energy systems.

Theoretically, the general aim of energy justice is to reduce instances of injustices related to energy systems. Its practical application has defined systemic boundaries that create bottlenecks in just policy design (Bouzarovski and Simcock, 2017a; Jenkins *et al.*, 2020). In energy research and social science literature, systemic boundaries are often defined as socio-technical and socio-cultural dimensions of HUSES (Shove, 2003b; Shove and Walker, 2014). The socio-technical dimensions of HUSES relate to the quantification of energy as a residential commodity. For example, energy consumption at a household level is principally viewed as a physical quantity measured in a standardised unit (kilowatt-hour (kWh)).

In contrast, the socio-cultural dimension of HUSES is driven by a complex interaction of energy use and built environment for deriving eudemonic wellbeing or household welfare (Brand-Correa, Martin-Ortega and Steinberger, 2018). This interaction with the built environment shapes the need for comfort, cleanliness and convenience (3C) as the socio-cultural energy services (Shove, 2003a). The impending factors that link energy justice and the built environment is discussed in detail in section 2.4. The central theoretical synthesis of this thesis is illustrated in section 2.6 in details.

This thesis adapts Shove (2003a)'s definition of 3C s with its implications for the urban household energy ladder after Sovacool (2011), as discussed in section 2.6. Sovacool, (2011) applied the 3Cs concept of energy services to construct a theoretical urban energy service ladder that illustrated poorer-household demand energy services for subsistence. Middle-income households demand energy services for comfort, cleanliness, and convenience, whereas high-income households demand energy services for increasing consumption and convenience (Sovacool, 2011). However, recent studies have shown that the urban poor exhibit a dichotomy in their consumption by portraying a middle-income consumption pattern that poses a challenge to objectively investigate distributive injustices (Khosla, Sircar and Bhardwaj, 2019; Mazzone, 2019; Muza and Debnath, 2020; Rahman *et al.*, 2020; Yawale, Hanaoka and Kapshe, 2021). It is further explored in detail through empirical modelling in Chapter – 5 of this thesis.

This research explores the interactions between the socio-technical and socio-cultural dimensions of HUSES in low-income built environment (i.e., slum rehabilitation housing (SRH), see section 2.3). The theoretical intersections between spatiality and temporality of distributive energy justice, HUSES-built environment design nexus, and energy cultures are explained in section 2.5, which informs this research's framework (see Fig 9). This framework was designed to empirically understand the meaning of contextualised just policy for SRH occupants.

It can be seen from Fig 9 that the grounded problem lies in the transition of the built environment from horizontal slums to SRH. It was also discussed in detail in section 2.5 on the problem of electricity affordability asymmetries in the SRH due to low built environment quality that is expanding distributive injustices. Building on the research objectives from section 1.1.2, this thesis systematically investigated two interacting systems (see Fig 9). As mentioned in the research scope in section 1.2, assumptions were made to establish boundaries for socio-technical and the socio-cultural system under empirical investigation. In this thesis, the socio-technical system comprised of quantification of a shift in household energy practices (in time scale – hours), quantification of change in built environment quality factors (i.e., perception of indoor air quality, thermal comfort, hygiene and sanitation) and appliance ownership numbers (i.e., change in appliance ownership before and after moving into SRH). Chapter – 4 and Chapter – 5 empirically explored the implications of this socio-cultural system on deriving a contextualised understanding of distributive injustices in the SRH built environment.

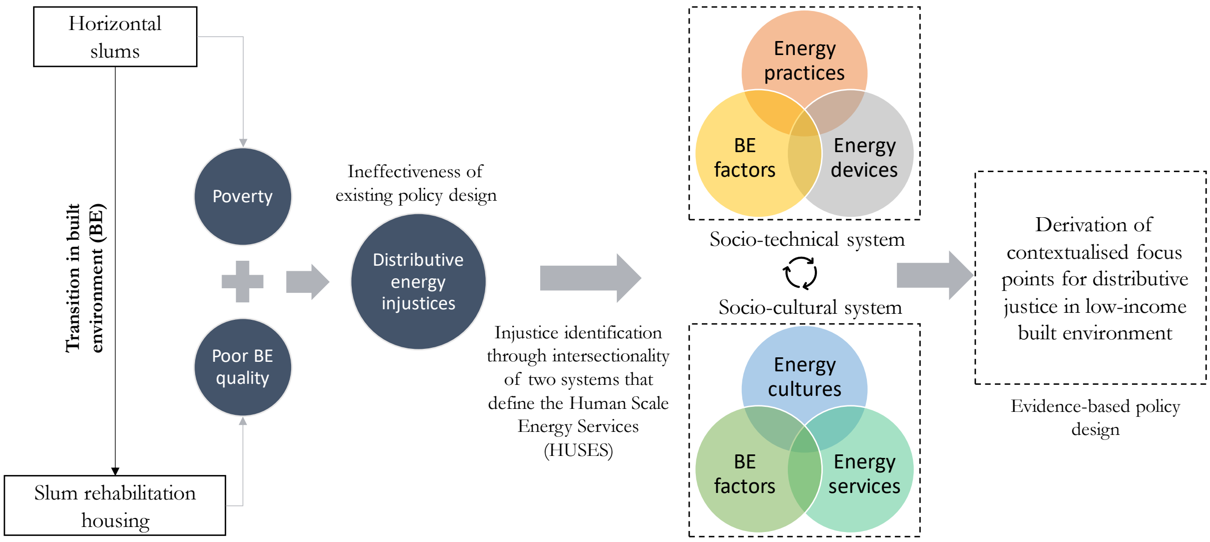

Fig 9. Foundational framework of this thesis

Similarly, the socio-cultural system in Fig 9 implies an interacting system of HUSES influenced by that place's energy cultures. This system essentially caters to exploring spatial dimensions of distributive injustices across SRH in India, Brazil and Nigeria. Here, Janet Stephenson (2011)'s theory of energy cultures was used to explore distributive injustices by understanding the social norms, practices and materiality of the built environment at the spatial scale. A deeper understanding of HUSES at this scale was gained by expanding the 3Cs-based conceptualisation of household energy service demand; however, physical quantification of energy services was also used based on the field-based narratives. This cross-sectional exploration of the socio-cultural and socio-technical system aided in deriving a context-specific understanding of distributive injustices for informing policy design at the local governance level (see Fig 9, and for scope section 1.2)

3.2 Research design and methodological framework

Methodologically, a systemic exploration of the socio-technical dimensions of HUSES in the slum rehabilitation housing would mean investigating the temporalities associated with energy use in this transitioning-built environment. For example, it is critical to understand the before and after-effects in household energy demand and practice are moving from horizontal slums to slum rehabilitation housing. Such time-based/temporal comparison is needed to track the changing landscape of distributive injustices in resource-constrained settings. Simultaneously, deriving metrics for quantifying shifts in energy intensity at the household level (Malakar, Herington and Sharma, 2019a). In this research, the temporal dimension associated with changing energy landscape in low-income built environment was investigated through the lens of social practice theory (SPT) (after (Shove, Pantzar and Watson, 2012; Shove and Walker, 2014)) and causalities were empirically derived using structural equation modelling (see Chapter – 4).

Similarly, drawing from the literature-based evidence in section 2.1, investigating the socio-cultural dimensions of HUSES need a context-driven understanding of the social norms, practices and material aspects of energy infrastructure/provisions (Brand-Correa, Martin-Ortega and Steinberger, 2018). The lack of methodological approaches to assess such socio-cultural energy services objectively remains a significant knowledge gap. Such systematic investigations are usually performed using qualitative methods like participatory surveys, narrative analysis, ethnography, energy journalism, etcetera (Moezzi, Janda and Rotmann, 2017a). Effective translation of qualitative evidence into just energy policy design remains an existing challenge, often overpowered by technocratic approaches. As mentioned in section 1.1.3, this thesis develops a novel methodology of quantifiable narrative analysis using a mixed-method approach for textual analysis using machine learning and grounded theory for energy policy applications. It contributes significantly to the knowledge gap by developing a methodology that aims to increase the layer objectivity to the energy system's socio-cultural analysis.

Concurrently, socio-culture investigation contributes to understanding distributive injustices' spatial dimensions (Bouzarovski and Simcock, 2017a). In this thesis, the 'energy cultures theory' (after (Stephenson *et al.*, 2010; Stephenson, 2018)) was used to investigate social norms, energy practices and materiality of the built environment in poverty. Energy cultures provide an interdisciplinary framework to understand the factors influencing energy consumption behaviour and help identify behaviour change opportunities. It takes a culture-based approach to behaviour lifestyle/consumption pattern and systems thinking (Stephenson *et al.*, 2010). The socio-cultural dimensions of energy services (i.e., 3Cs) were then connected with the built environment factors using narratives of distributive injustices in three distinct case studies of slum rehabilitation housing in India, Brazil and Nigeria (see Chapter 6 – Chapter 7).

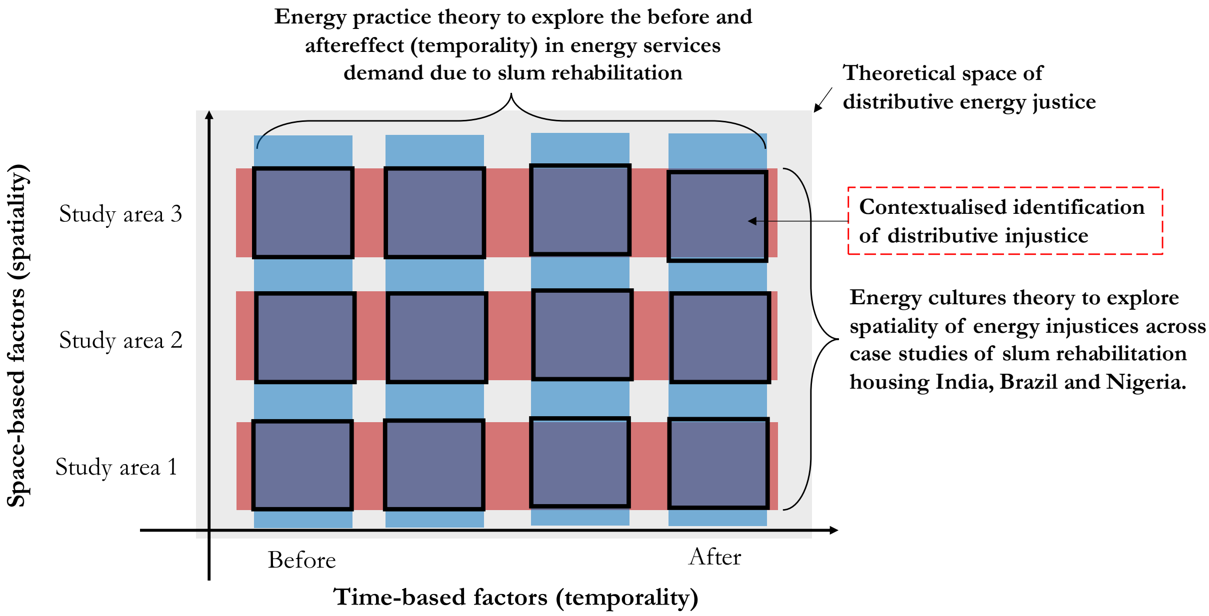

Fig 10. A conceptual framework for contextualised identification and analysis of distributive injustices from field study.

Fig 10 illustrates this study's conceptual framework that integrates both temporal and spatial dimensions of distributive energy justice (see section 2.2.). This framework was the foundation for the investigation of HUSES in the slum rehabilitation housing across India, Brazil and Nigeria. As mentioned above, this investigation was performed in two categories to extract context-specific instances of distributive injustices in poverty. The first category was assessing changing household energy practices (temporalities) associated with transitioning the built environment, i.e., from horizontal slums to slum rehabilitation housing. This investigation's scope was socio-technical that estimated direct and indirect effects of slum rehabilitation on household energy demand (see Fig 9 and Fig 10, and Chapter 4 – 5).

The second category was the exploration of distributive injustices embedded in the socio-cultural fabric of slum rehabilitation housing. It focussed on investigating the spatial dimensions of distributive injustices in slum rehabilitation housing through three field studies in India, Brazil and Nigeria. Here, in-depth focussed group discussions were conducted in the study areas to extract grounded narratives of energy poverty associated with slum rehabilitation housing. It shaped this thesis's socio-cultural scope (see Fig 9 and Fig 10), while a new methodology was designed to analyse these narratives for energy policy design applications (see Chapter 6 – 7). Table 3 further illustrates the assumptions and methodological specifications of this thesis with respect to the socio-technical and socio-cultural system.

Table 3. Assumptions and methodological specification of this thesis

System	Quantifiable/ descriptive parameters	Methodology	Data	Broad assumptions	Chapters
Socio-technical	Energy practices shift (time/temporal dynamics)	Practice theory; built environment (BE) design evaluation; structural equation modelling (SEM)	*Survey 1:* Socio-economic survey of 1224 households in Mumbai, India *Survey 2:* Built environment and energy service demand survey in 200 households of Joao Pessoa, Brazil and Mumbai, India (See Appendix for the survey questionnaires)	Time/duration of use of specific appliances in household is an indicator 'of changing practices. Ownership of specific appliances denotes higher energy intensity in the households, an indicator of changing practices.	See the Chapter 4 and Chapter 5 for detailed assumptions and analysis.
	Built environment (BE) design factors				
	Household appliance ownership/energy devices				
Socio-cultural	Energy cultures (social norms, practices and materiality)	Energy cultures theory-driven focussed group discussion (FGD); Constructivist grounded theory; Machine learning based textual analysis using topic modelling and Latent Dirichlet Allocation (LDA) algorithm	Narrative on energy poverty and distributive injustices: affordability and availability issues Case studies in Mumbai (India), Abuja (Nigeria) and Rio de Janiero (Brazil)	Poor BE quality is assumed to be consistent problem. The questions around social norms and practices are kept open ended.	See the Chapter 6 and Chapter 7 for detailed assumptions and analysis.
	Built environment design factors				
	Availability of the type of energy services				

3.2.1 Describing the socio-technical system using a practice theoretic lens

Table 3 presents the assumptions of this thesis's socio-technical system that outlines built environment-driven domestic energy demand and appliance ownership in the SRH. A theoretic approach based on practice theory was used to capture the time-based changes in energy demand (temporalities) moving from horizontal slums to SRH units. Practice-related research demand examinations of broader social processes that place the onus on the practices and how they are performed by households instead of individuals as energy consumers or appliance users (Foulds, Powell and Seyfang, 2016). Social practise theory (SPT) is a tool to study such social processes. It states that practices are entities made of material arrangements (i.e. materials, technologies, and tangible and physical entities), know-how and routines, institutionalised rules and teleoaffective structures (domains of symbols, meanings, beliefs and emotions) (Labanca and Bertoldi, 2018).

The conceptualisation of SPT into energy research through the combination of materials, meaning and competencies that together make up the social practice and shape the practice in their interaction process was done by (Shove, Pantzar and Watson, 2012). In SPT, individuals act as carriers of a practice which ultimately leads to decision-making rather than just behavioural attributes. A change of built environment on moving from horizontal slums to SRH represents a change in occupants' social processes. However, the influences of such change on the broader physical systems like household energy demand remains understudied in the distributive justice literature (as seen in section 2.3 and section 2.4).

Understanding the social processes that influence the change in energy practice can help contextualise energy justice in poverty as it reveals the latent processes associated with energy accessibility and affordability within a specific material-reality (here, it is the SRH built environment). Building on Fig 10, Chapter – 4 investigates the temporalities associated with energy intensity on the transition from slums to SRH by capturing change in time spent performing household activities like cooking, cleaning, and washing. Causality was established between change in practices with change in appliance ownership pattern using structural equation modelling. The analytical approaches are discussed in detail in section 3.3.

While SPT-based approaches have their strength in capturing the temporal changes in social processes at greater granularity, it is limited by its replicability and reproducibility across spatial scales, primarily when used inform energy policy (Brand, 2010; King, Both and Lamond, 2014; Labanca and Bertoldi, 2018). It is due to SPT's inherent characteristics of prioritising qualitative and structural reorganization of systemic outputs and associated shared meanings and competencies (Shove and Walker, 2014). In an original analysis, Chapter – 4 shows the use of structural equation modelling in quantifying shifting energy practices with energy demand indicators for policy modelling applications (the variables and parameters are listed in Table 3).

The limitations of SPT to evaluate spatiality in energy demand was addressed by adopting energy cultures theory after Stephenson (2018). It is explained in the next section.

3.2.2 Describing the socio-cultural system using energy cultures theoretic lens

Section 3.2.1 described the assumptions and methodological approach towards handling this thesis's socio-technical system using a practice theory-based lens. It was also reported that practice theory has limitations in spatial scales as it dives deeper into the temporalities of a social process and tracks its structural changes qualitatively (Labanca and Bertoldi, 2018). However, this thesis conceptually demanded (see Fig 10) spatialising distributive energy justice across the SRH in India, Brazil and Nigeria to generate comparative contexts of injustices.

Energy cultures theory was adopted after Stephenson (2018) to investigate energy justice's spatial dimensions and its associated human scale energy services (HUSES) in the study areas. Energy cultures theory explores the interaction between energy practices, socio-cultural norms and material reality that shapes the need for certain energy services. It is an extension of SPT that enables spatialising energy research by systematically accounting for the effects of socio-cultural norms in a specific material-reality. In this thesis, the material-reality is the built environment characteristics of SRH in study areas. The energy cultures approach provides a theoretical tool to map the cultural barriers associated with HUSES. Objective accounting of the cultural barriers in energy justice studies remains a research gap (as mentioned in section 2.1). Its knowledge is required for accurate contextualisation of the injustices, which is addressed in this thesis.

In this thesis, the theoretic transition from SPT to energy cultures theory was not done abruptly. Instead, a systematic approach was adopted to define this socio-cultural system using insights from energy cultures theory. While Chapter – 4 illustrated a methodology for objectively analysing qualitative markers of SPT in household energy demand studies in the SRH of Mumbai, Chapter – 5 demonstrates the spatial dimensions of energy demand in the transitioning-built environment of Brazil and India. The spatialisation was performed by investigating the demand for socio-cultural and socio-technical energy services that create the need for comfort, cleanliness, and convenience (3Cs) in poverty. It was applied from the theoretical synthesis presented in section 2.6.

Deeper insights into the socio-cultural system of energy demand across the SRH cases in India, Brazil and Nigeria was obtained through in-depth participatory interviews and its textual analysis using advanced natural language processing techniques (see Chapter – 6 and Chapter – 7). The detailed analytical procedures and the data structure is illustrated in section 3.3.

3.3 Analytical framework

The research gap presented in Chapter – 2 showed that current literature on energy justice is limited by a lack of context-specific knowledge of distributive outcomes of energy policy in the marginalised communities (Lee and Byrne, 2019; Bombaerts *et al.*, 2020; Tucho, 2020; Initiative for Justice, 2021). This thesis's conceptual framework intended to address this methodological gap in the energy justice literature by developing a methodological tool to extract context-specific information on distributive injustices (see Fig 10). Section 3.3 established the theoretical basis for adopting a practice theory-based approach on identifying the temporalities of energy justice and the energy cultures theory-based approach for spatialising distributive energy justice in low-income communities of the Global South.

It illustrates the theoretical synthesis from state-of-the-art literature on energy justice and poverty alleviation (see section 2.3 and 2.6) while expanding it by considering built environment design as a critical component of distributive justice. As presented in section 2.4, the literature review showed that appropriate design of the built environment provides welfare opportunities through HUSES for the occupants living in low-income communities that translate into equitable distributional outcomes of health and well-being (SPARC, 2015; Gillard, Snell and Bevan, 2017; Bartiaux *et al.*, 2018a; Samarakoon, 2019; Waitt and Harada, 2019; Mazzone, 2020). Fig 9 illustrates this systematic integration of the built environment as the foundational problem of distributive injustice in this thesis.

Fig 10 and Table 3 show the methodological assumptions of this thesis that aims to derive an original investigative framework for contextualising distributive energy justice in the slum rehabilitation-built environment of the Global South. Expanding on them, Fig 11 illustrates the analytical framework of this thesis. It illustrates the analytical steps and the data typology of this thesis based on the assumed classification of a socio-technical (see section 3.2.1) and a socio-cultural system (see section 3.2.2) of domestic energy service demand in study areas.

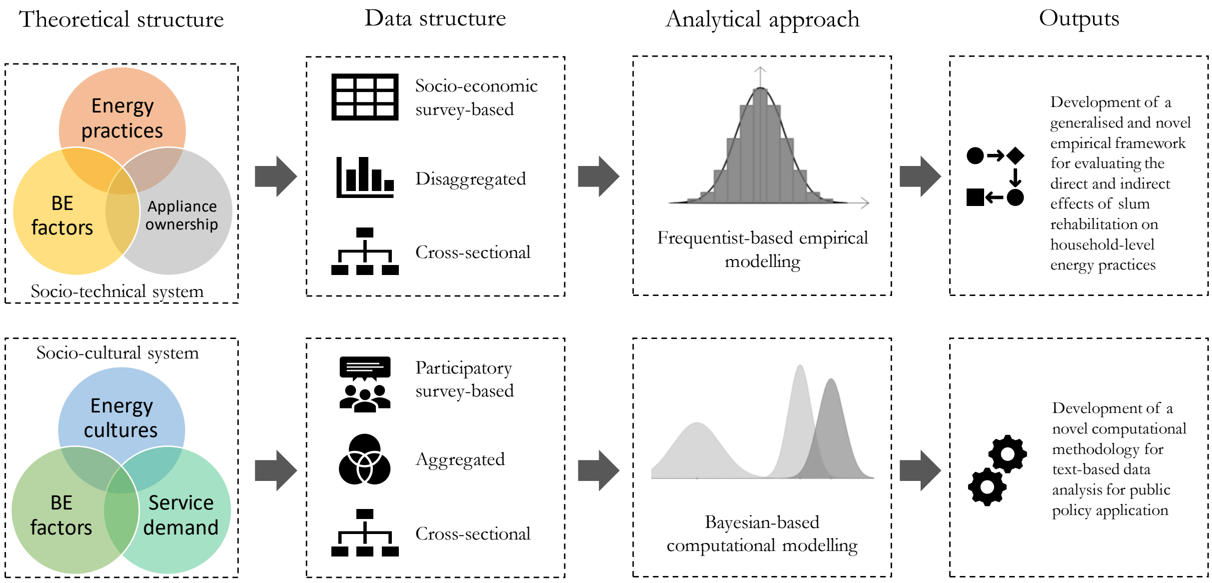

Fig 11. The analytical structure of this research with complex data typologies

The socio-technical system comprises the accounts of shifting in energy practices using 'time spent on household activities' as a variable, built environment design variables and specific appliance ownership as the indicator of energy service demand in the SRH. Theoretically, an SPT-based approach was used to construct a structural equation model (SEM) of non-income drivers of energy demand on the transition from horizontal slums to the SRH in India, using a 1224 household socio-economic survey-based dataset (see Table 3). This analytical procedure investigated the temporal scale (i.e. temporalities) of energy service demand in the study area, see Fig 10. It provided an original modelling-based approach to quantify SPT for policy application, limited in the existing literature. The steps for SEM and causality identification is presented in detail in Chapter – 4.

As mentioned in section 3.2.1, SPT is limited by its transferability and reproducibility at spatial scales (Brand, 2010; King, Both and Lamond, 2014; Labanca and Bertoldi, 2018). Here, the analytical boundary was expanded to include a spatial comparison of appliance ownership and energy intensity in the SRH of India and Brazil using a socio-economic survey-based dataset of 200 households. Logistic regression was used to compare energy demand and built environment design impacts in the study areas. It involved contextualisation of energy demand as a social energy service of comfort, cleanliness, and convenience (3Cs) using energy cultures theory (see section 3.2.2).

A similar analytical approach was used to gather deeper-insights into 3Cs and energy cultures in the SRH of India, Brazil and Nigeria. It represented the core socio-cultural system that involved robust spatial contextualisation of distributive injustices. It involved data collection through participatory surveys and focus group discussions (FGDs). The data typology was cross-sectional and aggregated as it was collected as occupants' energy cultures narrative (see Fig 11). The narratives were collected through audio files, which was transcribed accordingly into text format for further analysis.

A Bayesian-based computational modelling approach was adopted for the text-based narrative analysis. Natural language Processing (NLP) and machine learning (ML) was used to analyse the narratives objectively. In contrast, a nested application of the constructivist grounded theory was used to extract latent information on energy injustices in the study areas (mentioned in detail in Chapter 6 – 7). Here, a novel deep-narrative analysis methodology was created for contextualising energy justice using narrative-based data. The deep-narrative analysis approach facilitated contextualisation across spatial scales by 'zooming-in' and 'zooming-out' of the problem statement. For example, in Chapter – 7, 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 (zoom-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 (zoom-in) investigation of the case-specific energy narratives in poverty and the demand for human-scale energy services (HUSES). The zoom-out and zoom-in approach were to discover the commonalities and contrast the injustices in the study areas.

The output structure in Fig 11 represents the output from the empirical models concerning this thesis's socio-technical and socio-cultural system (see Fig 11 and Table 3). For example, the socio-technical investigation's output comprises empirical models connecting built environment design parameters with appliance ownership factors. It mathematically explores the direct and indirect effects of change in household practices on appliance purchasing behaviour due to the built environment's transition (see Chapter – 4). It used a covariance-based SEM model through IBM SPSS AMOS v25.0 while theoretically adopting a practice-based approach (see section 3.2.1).

Similarly, following the conceptual framework in Fig 10, Chapter – 5 illustrates the thesis's systemic shift from a socio-technical domain to a socio-cultural domain. In this chapter, the core methodology involved in the empirical handling of social energy services (3Cs) as an appliance ownership factor in specific built environment conditions across spatial scales (i.e., SRH in Brazil and India). It used an advanced-binary logistic regression method with embedded small-bias correction, called Firth's binary logistic regression in R-programming languages. Theoretically, it adapted energy cultures theory to addresses the limitations of practice-based approaches across spatial scales (see section 3.2.2)

The socio-cultural system was further explored through participatory surveys to collect granular context-specific data of distributive injustices in the study areas. It demanded objective treatment of narratives without losing their richness. Here the output structure was the methodological development of the 'deep-narrative analysis' framework, as mentioned above. The zooming-in and zooming-out capability of this methodological further enabled contextualisation of energy injustices in the SRH of India, Brazil, and Nigeria. It contributes significantly to the methodological gaps in energy justice literature described in section 2.1, especially relating to the lack of methods for developing grounded energy justice theories using grounded data from the marginalised communities of the Global South (Jenkins, McCauley and Forman, 2017; Bombaerts *et al.*, 2020; Tucho, 2020). Current literature demands novel methodologies to enable contextualising energy justice theories that are built mainly on western philosophies.

3.3.1 Survey design and data collection

The data collection was done in parts, focussed group discussions (FGDs) were organised by the author and the data was collected by the author, the survey data from Mumbai was collected by commercial company but the author had access to the primary data. In Brazil, the data was collected by the co-author, but the survey questions were set together with the author who has also access to the primary data. Covid-19 significantly affected the plans for data collection and site visits; hence, several structural changes were made to accommodate the data collection objectives.

Based on the data structure presented in Fig 11, two data collection approaches were employed. The first approach involved an in-depth questionnaire survey conducted across 1224 SRH households in Mumbai to fulfil Chapter 4 (see Appendix 1 for the detailed questionnaire). In addition, a parallel questionnaire survey was conducted for Chapter 5 in Mumbai (n = 100) and Joao Pessoa (n = 100) that captured the socio-cultural dimensions of energy demand in the study areas.

The second approach involved detailed FGD for gathering grounded narratives of energy injustices in the study areas. It involved in-person conduct of FGD in the respective local languages that involved seven participants in Rio de Janeiro, eleven in Mumbai and seven in Abuja. This section further specifies the details of chapter wise survey design and data collection methodologies.

The dataset used in Chapter 4 was collected through socio-demographic surveys across 1,224 households in Mumbai, which were selected using a stratified random sampling method across the four SRHs in the M-Ward. The M-ward was specifically chosen as it had the highest number of SRH units in the city (Bardhan, R. et al. (2015)). Close to 6000 households lived in these four SRH clusters, and the 1224 household sample represented ~20% of the population. The socio-demographic details of the 1224 surveyed households are illustrated in Appendix -1.

A survey questionnaire was developed comprising three segments that recorded the change in household practices on moving to SRH from the horizontal slums, perception of the built environment and household appliance ownership criteria. A detailed rationale for survey design and its theoretical basis for this research is presented in Chapter – 4 (see Appendix 1 for the survey questionnaire). The author conducted a pilot survey across 75 households as a scoping exercise (see here), then used it to improve the questionnaire to remove any directional bias and leading questions. The full-scale door-to-door survey was conducted using a commercial survey company in mid-2018. Face-to-face data collection assured that respondents answered the questions with due attention and mutual trust was built. The questionnaire prepared was initially prepared in English and then translated to Marathi and Hindi for dissemination. The author carried this translation with one of the team members from the survey company to ensure accurate translation. Ethical clearance was obtained through the Department of Engineering (Division - D), the University of Cambridge for the pilot survey (Proposal no: DebnathMay18) and the Institutional Ethics Committee of Indian Institute of Technology Bombay (Proposal no: IITB-IEC/2020/016). All the participants provided a verbal consent at the beginning of the survey in which they were assured their responses would be treated confidentially and they could withdraw from the research at any stage. The participation was entirely voluntary, and all participants were over 18 years old.

The surveys for 100 households in both Natwar Parekh Complex (NPC, Mumbai) and Gadanho and Timbó Social Housing (GTSH, João Pessoa) (Chapter - 5) was performed similarly. However, while the Joao Pessoa case study had a response rate of over 50% because of a low number of housing units (~181 units) in the study areas, the Mumbai case (~ 800 units) was restricted to a response rate of less than 10% due to lack of resources to conduct a larger-scale survey during the Covid-19 onset in India.

For the focussed group discussions, a bilingual moderator was hired from within the surveyed communities. This decision was taken considering the sensitivity of working in vulnerable communities that are usually cautious about external interference in their day-to-day lives. In addition, pre-training was provided to reduce directionality in the participatory interviews. Sampling for participants was done per the best practices presented by (Morgan David (1997)). The focus group is characterised by homogeneity but with sufficient variation among participants to allow for contrasting options. By homogeneity, they shared the same energy service-related problems in the slum rehabilitation housing in the study areas. Other homogeneity factors included gender (women only) and occupation (participant in the informal labour market). A detailed explanation of the selection criteria for the three study areas is presented in Chapter 6 and Chapter 7.

While recruiting participants, this research followed the 'ideal size' argument by Morgan, David (1997, p 68) that stated that an ideal size focus group is usually between five and eight participants. However, if the topic is stated that 'if they have little experience with the topic, then a group size of 10 could be productive' (Morgan, David (1997)). The topic of human-scale energy services was somewhat familiar to the participants and at a different scale. For example, in Mumbai and Abuja, occupants were familiar with high electricity bills caused by poor billing cycles by the DISCOMs. However, they were unaware of how high bills can be related to the built environment.

Similarly, for the Rio de Janeiro case, occupants were unaware of possible links between their housing design and its impact on the energy bills. Therefore, the FGDs for this research encouraged participation between 7 – 11 people. An additional determinant was the complexity of the topic and the extraction of 'energy cultures' in the study areas that further shaped the participant recruitment through nominations from the women-led community associations. This route of recruiting FGD participants was most effective in community studies (Morgan, David (1997, p 69)). As incentives, the participants were provided with non-financial incentives like snacks and tea/coffee to encourage participation and a comfortable environment for discussions.

The FGDs were recorded using an audio device, then transcribed in English by bilingual co-authors and the moderator. The transcription process is further explained in detail in Chapter -7. In Mumbai, the translation was done from Hindi – English; in Rio de

Janeiro, Portuguese – English; and Abuja, Hausa – English. The moderators were part of the community, and they obtained verbal consent from each participant before starting the FGD. In addition, they facilitated open, uninhibited dialogues during the FGD through a non-prescriptive and semi-structured interview schedule. The Mumbai participant was fluent in both Hindi and Marathi, so our choice of Hindi did not affect the results.

As mentioned above, the FGDs were conducted with a certain degree of homogeneity. The familiar trust was built during the interview process by encouraging the moderator to bring her friends. We were conscious of the selection bias this may have caused by inviting participants familiar with the moderator. However, given the sensitive nature of the community structure, this was the best option to encourage uninhibited participation in the discussion. A rigorous pre-training was given to the moderator to prevent leading questions and remove any directionality biases. In addition, the participants were informally pre-briefed about the objective of the event to encourage open conversation.

Another potential source of selection bias was the homogeneity in the female-only nature of the FGDs. At the same time, it stands true that a separate FGD based on only the male occupants could have been a more representative case of the study areas, and it remains a limitation of this study. However, due to the socio-cultural construct of such communities, the female members are the ones who spend most of their time interacting with the slum rehabilitation built environment. The male members are the usual participants in the labour force, so they spend more than 12 hours out of home, while the female members stay at home and are most instrumental in shaping the energy cultures of the place. Therefore, it led to the choice behind female-only FGDs for the energy cultures study in Chapter 7. Representation bias was also observed in the age distribution of the participants as the older women (>60 years) were more cautious about the event and did not consent to participate in the FGDs. Nonetheless, the familiarity of the moderator with the community encouraged equal participation from across the working-age group.

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CHAPTER 4 Empirical – 1

Changing energy practices on slum rehabilitation: Temporal effects of transitioning-built environment on energy demand

4.1 Chapter Summary

This chapter explores the effect of slum rehabilitation on appliance ownership and its implications on residential electricity demand. The low-income scenario makes it unique because the entire proposition is based on the importance of non-income drivers of appliance ownership that includes effects of changing the built environment (BE), household practices (HP) and appliances characteristics (AC). This study demonstrates quantitatively that non-income factors around energy practices influence appliance ownership, and therefore electricity consumption. The methodology consists of questionnaire design across BE, HP and AC based on social practice theory, surveying of 1224 households and empirical analysis using covariance-based structural equation modelling. Results show that higher appliance ownership in the slum rehabilitation housing is due to change in household practice, built environment and affordability criteria. Change in HP shifts necessary activities like cooking, washing and cleaning from outdoor to indoor spaces that positively and significantly influences higher appliance ownership. Poor BE conditions about indoor air quality, thermal comfort and hygiene, product cost, discounts and ease of use of the appliances also trigger higher appliance ownership. The findings of this study can aid in designing better regulatory and energy efficiency policies for low-income settlements.

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4.2 Introduction: Non-income drivers of residential energy demand

Residential electricity demand will increase in the Global South with its accelerated economic growth in the coming decades. The International Energy Agency (IEA) states that OECD countries account for 65 per cent of the total residential electricity consumption globally. In contrast, electricity demand in non-OECD countries, especially in the Global South, has grown twice the rate compared to the OECD countries (IEA, 2009). It is expected that non-OECD countries will exceed OECD countries' demand by up to 25 per cent in 2030 (Cabeza *et al.*, 2014). Global climate and energy scenario estimate future appliance penetration using income (average national GDP), electrification and urbanisation-driven logistic curves (Farsi, Filippini and Pachauri, 2007; McNeil and Letschert, 2010; Daioglou, van Ruijven and van Vuuren, 2012; McNeil *et al.*, 2013). This method is rooted based on the assumption that all households would have the same appliances globally at a certain income level, which oversimplify reality (Rao and Ummel, 2017). However, factors like market accessibility, affordability, household characteristics, wealth and income levels together better explain appliance ownership (Rao and Ummel, 2017).

Everyday activities of occupants shape their need for household appliances which influence energy consumption. These activities represent practices, which are a routinised behaviour of everyday life (Reckwitz, 2002). Whether consciously or not, these practices drive the 'practical rational' behind individuals and households' appliance purchase decisions (Røpke, 2009). Practice-related research demand examinations of broader social processes that place the onus on the practices and how they are performed by households instead of individuals as energy consumers or appliance users (Foulds, Powell and Seyfang, 2016). Social practise theory (SPT) is a tool to study such social processes. It states that practices are entities made of material arrangements (i.e. materials, technologies and tangible and physical entities), know-how and routines, institutionalised rules and teleoaffective structures (domains of symbols, meanings, beliefs and emotions) (Labanca and Bertoldi, 2018). Shove et al. (Shove, Pantzar and Watson, 2012) conceptualised this idea for energy studies by combining material, meaning and competencies that make up the social practice and shape the practice in their interaction process. In SPT, individuals act as carriers of a practice which ultimately leads to decision-making rather than just the behavioural attributes. Shove et al. (Shove, Pantzar and Watson, 2012) elucidation on the material dimension (i.e. objects, infrastructure, tools, hardware and the human body) of SPT establishes connecting theories around energy consumption in households. However, the causations are yet to be studied. A change of built environment in low-income communities is linked with a change in their social processes. However, this change on the broader physical systems like energy remains understudied in the literature.

Known drivers of residential energy use at a macro-level are income, climate, demographic characteristics, along with energy price dynamics, dwelling type and technology evolution, including information and communication technologies (ICT) (Ekholm *et al.*, 2010; Cabeza *et al.*, 2014; Rao and Ummel, 2017). In India, macro-level studies have revealed a hierarchy in which goods are acquired (Daioglou, van Ruijven and van Vuuren, 2012). Both rural and urban households have been shown to follow complex energy transition trajectories. They tend to rely on more than one energy source, contrary to the idea of climbing the hypothetical energy ladder (Van Der Kroon, Brouwer and Van Beukering, 2013). With the rise in household income, improved solutions become more accessible; there is a tendency to stack multiple energy/fuel sources, termed as 'energy/fuel stacking' or 'energy staircase' (Kowsari and Zerriffi, 2011; Van Der Kroon, Brouwer and Van Beukering, 2013; Bisaga and Parikh, 2018). The accessibility of an 'improved solution' is shaped by the occupants' social practices, which adds meaning and competence to their daily life through appliance purchase (Bisaga and Parikh, 2018). As the improved solution complies with the household practices of a social class, appliance ownership increases, as occupants find value in owning that appliance. Practice theory suggests that appliance ownership is more context-specific than merely a function of income, and not everyone may acquire appliances in the same way as income rises (Shove, Pantzar and Watson, 2012).

In the study presented in this chapter, we investigate whether the change of the built environment of slum dwellers to slum rehabilitation housing (SRH) affect their residential electricity use. In doing so, we investigate the number of appliance purchase in the slum rehabilitation housing after shifting and assume it as an indicator of end-user demand for residential electricity. This system boundary defines this work's novelty, where we link change in the built environment, household practice and appliance characteristics as essential drivers of appliance ownership in low-income settlements.

The policy of 'Slum Rehabilitation Housing' was adopted in 1995 by the Government of Maharashtra to redevelop the slums into high-rise social housing by incentivising the private sector to participate in the redevelopment of slum communities. The process mandated to re-house the slum dwellers onsite in high-rise buildings that includes legal entitlement to a stipulated 269-square-foot apartment, including a bathroom with tap water and a kitchenette. This policy provided the slum dweller access to a cross-subsidised, free of cost house without burdening their time or economic poverty (Debnath, Bardhan and Jain, 2017; Nutkiewicz, Jain and Bardhan, 2018). The housing units, though, provided the slum dwellers with a permanent shelter. The units lack basic design guidelines, energy efficiency or socio-cultural considerations (M. Sunikka-Blank, Bardhan and Haque, 2019). How housing units are used determines the dynamics of social practices that influence appliance ownership vis-à-vis energy use.

We base this study on an SRH community in Mumbai that comprises occupants living here for more than six months. Previous studies have shown that these SRHs often resemble 'vertical slums' characterised through the hyper-density of occupants, sub-standard dwelling quality and inadequacy to provide basic amenities (Zhang, 2016; Bardhan, Debnath, Jana, *et al.*, 2018a; Bardhan, Debnath, Malik, *et al.*, 2018a; Debnath, Bardhan and Sunikka-Blank, 2019a). These sub-standard conditions compel the occupants to move back to horizontal slums. A recent study has shown that about 40% of that occupants move out (Nair, 2018). A similar study found that higher appliance ownership in the SRH causes economic distress that causes broader psychological and social discomfort (Debnath, Bardhan and Sunikka-Blank, 2019a). However, none of these studies investigated household practice's effect on occupants' energy service demand (or human-scale energy services (HUSES)) in the SRH. The present study contributes to this gap in energy research and presents empirical evidence on household practice and built environment on appliance ownership. The contribution of this study is twofold. First, it empirically links household practice, built environment and appliance characteristics to appliance ownership in low-income settlements under urban transition (slums to slum rehabilitation housing). Second, this study's policy implications can guide in designing better subsidy and energy efficiency plans for such low-income communities.

The study's primary hypothesis is that higher appliance ownership in the slum rehabilitation housing is due to a change in household practice triggered by the change in the built environment from the horizontal slums to SRHs. Six sub-hypotheses (H1 to H6) were developed based on a conceptual model of appliance ownership in the rehabilitation houses. It is discussed in detail in Section 4.4.2 and Fig 12. A questionnaire survey was developed to allocate the built environment, appliance characteristics and household practice-based questions to empirically test this hypothesis using a latent-variable modelling approach (see Section 4.4.1). The empirical analysis findings are illustrated in Section 4.5.2, preceded by a detailed presentation of the data descriptive (see Section 4.4.1). Conclusion and policy implications drawn from this chapter towards just energy transition and distributive justice is presented in section 4.6.

4.3 Background: Appliance ownership and energy practices in low-income built environment

Appliance ownership has mainly been discussed or predicted using empirical research based on societal trends, while very few studies examined determinants of appliance ownership at a household level (Rao and Ummel, 2017). Macroeconomic studies have estimated the household appliance penetration based on logistic curves driven by income, electrification and urbanisation (Daioglou, van Ruijven and van Vuuren, 2012; McNeil *et al.*, 2013; Batih and Sorapipatana, 2016). However, these estimates do not explain historical appliance diffusion or investigate the household-specific factors that arise from coordinated and independent 'homely' practices that a household performs. Recent studies that describe household appliances' growth in urban India and China are also skewed by only using the demographic characteristic data (especially the household size) and not considering the effect of household-level drivers in appliance ownership decisions (Cabeza *et al.*, 2014; Bhattacharyya, 2015). Studies that examined the effect of income elasticity on appliance purchasing capability discussed heavily between income and energy growth (Wolfram, Shelef and Gertler, 2012; Auffhammer and Wolfram, 2014).

Among the few household-level determinants, most of the studies have reported household size to be a significant non-income determinant, along with housing type and age (O'Doherty, Lyons and Tol, 2008; Leahy and Lyons Sean, 2010). In rural China, Rong and Yao (Rong and Yao, 2003) found that more education, public services and a higher number of female members in a household increase the likelihood of appliance ownership. In rural India, Kemmler (Kemmler, 2007) found that critical non-income drivers were household characteristics, the degree of community electrification, and the quality of the electricity supply. In urban India, Tiwari (Tiwari, 2000) found that household size has a positively affects residential electricity consumption. It was recognised that a five-member family in Bombay (now Mumbai) would have 23% more electricity expenditure than a two-member family. The addition of an extra member increases the usage by 7.7%. Contrary to this study, Filippini and Pachauri (Filippini and Pachauri, 2004) determined a negative correlation with electrical energy consumption in urban Indian households, stating that houses with more than six members had lower electricity consumption than those with fewer numbers. A study by Louw et al. (Louw *et al.*, 2008) in a low-income household in South Africa had established that the number of household members did not affect the electricity consumption as most of the electrical end-uses (like cooking or watching TV) were shared simultaneously between the occupants.

A significant effect of family composition (i.e. presence of children, teenagers, adults and older adults) and the age of the household responsible person (HRP) has been widely acknowledged in the literature as a crucial non-income driver of energy consumption (Jones, Fuertes and Lomas, 2015). However, these studies do not specifically comment on the drivers of appliance purchase but rather comment on the effect of household energy consumption and the age of HRP. Tenure type of the house is also identified to impact the total residential electricity consumption significantly, but it remains a local-effect and differs widely with the study area (Wyatt, 2013; Jones, Fuertes and Lomas, 2015). The relationship between dwelling type and higher appliance ownership remains unclear. In general, the literature suggests that the influence of dwelling type on electricity consumption is related to the differences in floor area (Wyatt, 2013). Similarly, for dwelling age, it is reported that newer homes have higher energy consumption despite owning higher energy-efficient appliances; it is primarily attributed to the rebound effect of energy efficiency [33], [35], [36]. However, most of these studies were conducted in developed countries and may be entirely different for India, where culture-specific practices matter in driving the electricity demand (M. Sunikka-Blank, Bardhan and Haque, 2019).

Other commonly discussed built-environment elements that influence energy consumption are the number of rooms, bedrooms, floors and the floor area in addition to the presence of electric space heating, ventilation, electric hot water heating systems and air-conditioning systems (Larsen and Nesbakken, 2004; Jones, Fuertes and Lomas, 2015). As mentioned earlier, these studies report the findings from developed economies, in our study area, i.e. the slum rehabilitation housing, the presence of these elements (like mechanical cooling, ventilation, hot water system and space heating) is highly unlikely as the general population belong to the lower to middle-income demographic characteristics.

Rao and Ummel (Rao and Ummel, 2017), in their cross-country and micro-level study of Brazil, India and South Africa, have shown a significant variation in appliance penetration at income levels, implying that country-specific factors matter. Upfront purchase cost that determines the affordability of an appliance matters most in low-income households across these countries. Appliances like television and refrigerators have a higher penetration in all three countries, whereas the penetration of washing varies widely across the nations. Higher penetration of television and refrigerators can be explained by the influence of social practices with these appliances. While television (an Information and Communication Technology (ICT) equipment) provides a medium for entertainment and knowledge sharing, a refrigerator provides extra utility time, especially to the women of the house (Dhanaraj, Mahambare and Munjal, 2018). These devices are purchased for use in households in order to contribute to customers' well-being by creating value in the form of knowledge or entertainment (in the case of ICT devices) or by saving time from daily grocery shopping (in case of refrigerators) (Pothitou, Hanna and Chalvatzis, 2017). Studies have reported that occupants tend to own the appliance, which complements their social practices, which influences their social practices (Røpke and Christensen, 2012; Pothitou, Hanna and Chalvatzis, 2017). These appliances enable users to save time from their day-to-day activities to derive greater utility from their usage. This extra time is crucial for the low-income population as they often use it for income generation activities, especially in emerging economies (M. Sunikka-Blank, Bardhan and Haque, 2019). Therefore, 'time-saved' from ICT usage for economic activities is a primary cause behind its higher penetration rate in the emerging economies than the OECD nations (IEA, 2009).

In another study by Dhanaraj et al. (Dhanaraj, Mahambare and Munjal, 2018) examining the reason behind low refrigerator ownership in India, the authors found that lack of female education and decision-making capability in the households significantly affect refrigerator purchasing behaviour in the household. The authors suggest that income is not a sufficient condition behind refrigerator ownership; the duration of electricity for more than 17 hours a day has more significance. They also mention that as the households' females tend to derive greater utility from refrigerator usage, their role in purchasing decision-making is vital. Refrigerator lowers the household burden of work and eases women's entry into the labour market (Dhanaraj, Mahambare and Munjal, 2018). Thus, appliances in such low-income settings have a dynamic role in changing practices and household welfare. Additionally, non-income drivers include household size, years of education of the HRP, number of rooms, dwelling quality, affordability, automobile ownership, female to male ratio, rural-urban migration, race and tenure type (Rao and Ummel, 2017).

While these drivers represent the material aspect of Social Practice Theory (SPT), the meaning and skills represent the abstract element of the occupants' socio-cultural dynamics that drives their energy stacking behaviour. A study by (Khalid and Sunikka-Blank, 2017) in middle-class households in Pakistan have reported that material and social constructs of 'homely' household practice related to comfort, lighting, cleanliness, cooking and ICT were critical in driving 'uncanny' residential electricity demand. The modernistic prefiguration of spaces and electrical appliances shapes occupants' social practice, which shapes everyday energy practices (Khalid and Sunikka-Blank, 2017). A similar work by Bisaga and Parikh (Bisaga and Parikh, 2018) in South Africa has reported that social practices change dramatically and depend on the appliances' availability. They found that appliance ownership does not increase linearly with time. Instead, the change in practices by using an appliance motivates occupants to purchase solar energy appliances. Foulds et al. (Foulds, Powell and Seyfang, 2016) investigated the trend in appliance purchasing amongst occupants who changed home to energy-efficient houses in the UK have found that moving home can change the appliance requirements. The social-meaning of specific appliance-using practices (e.g. stylishness, convenience, thermal comfort, cleanliness) were significant in motivating occupants to purchase appliances. However, skills and competence to perform appliance-using practices were less prominent in influencing appliance ownership changes. They suggested that change in the built environment of occupants change appliance ownership based on appliance-using practices.

Rao and Ummel's (Rao and Ummel, 2017), Bisaga and Parikh's (Bisaga and Parikh, 2018), and Foulds et al.'s (Foulds, Powell and Seyfang, 2016) studies provide critical clues for this work as the occupants living in the slum rehabilitation housing have heterogeneity in all the above drivers. These inhabitants are part of one of the world's biggest informal economy (Debnath, Bardhan and Jain, 2017). They are rural to urban migrants, and they tend to restore their rural identity and social practices (Nijman, 2015). They live in low-income settlements, yet they have middle-income household characteristics (Zhang, 2016). These occupants own their houses which is a significant fulfilment of the middle class (Ronita Bardhan *et al.*, 2015).

Moreover, these housing units are characterised by sub-standard living conditions in a vertical and high rise building fabric (Debnath, Bardhan and Sunikka-Blank, 2019a). A study by (Debnath, Bardhan and Sunikka-Blank, 2019a) have reported that these occupants tend to move out of these houses and rebound to their original horizontal slums. At present, it is estimated that nearly 40% of the inhabitants rebound by either selling or renting their SRH flats to a third person (Nair, 2018). The reason behind such a rebound behaviour was found out to be increased discomfort and distress in the slum rehabilitation households (SRH) owing to a mismatch between social, cultural and architectural design requirements of the occupants (Debnath, Bardhan and Sunikka-Blank, 2019a). It was also due to higher appliance ownership among the rehabilitated occupants as they feel SRH is an avenue of getting out of poverty. They buy appliances as soon as they move in to fulfil their aspirations (Debnath, Bardhan and Sunikka-Blank, 2019a). The transition of the built environment from slums to a permanent vertical housing structure (SRH) was found to influence their social practices that may have had a considerable impact on the appliance purchasing decisions, leading to higher electricity usage. However, Debnath et al. (Debnath, Bardhan and Sunikka-Blank, 2019a) were inconclusive regarding the influence of changing the built environment on social practices that can lead to higher electricity consumption. In this study, we investigate these linkages and derive critical inferences from informing policies for sustainable low-income built environment and energy transitions in the Global South.

4.4 Data and methods

4.4.1 Survey design

Mumbai has an estimated population of 12.4 million as per 2011 Census data, out of whom 42 per cent (i.e. 5.2 million) of the population lives in the slums (Zhang, 2016). Over the past two decades, 0.15 million slum dwellers have been rehabilitated into slum rehabilitation housing (SRH) by a state-owned body, Slum Rehabilitation Authority. Four slum rehabilitation housing (SRH) societies in the 'Ward-M' of Mumbai were selected for conducting the household surveys. It is estimated that more than 6,000 families live in these four SRHs.

The surveys spanned 1,224 households which were selected using a stratified random sampling method across the four SRHs. A survey questionnaire was developed comprising three segments that recorded the change in household practices on moving to SRH from the horizontal slums, perception of built environment and household appliance ownership criteria. The questions on the change in household practices were drawn after (Khalid and Sunikka-Blank, 2017) which investigated the connections between 'homely' practices and their impact on Pakistan's high electricity demand. This study was explicitly referred to because of its similarity to the socio-cultural context of our study area.

A recent study by (M. Sunikka-Blank, Bardhan and Haque, 2019) in Mumbai's SRHs had demonstrated the importance of women as critical household energy-decision makers. It guided our questionnaire formulation of household practices that can influence appliance ownership (see Table 1). A dichotomous variable *(1= Male, 0 = Female)* was included to understand the gender dynamics in the appliance-purchase decision. The interviewees were asked, *'Who usually makes the appliance purchase decisions?'*. Other variables in this segment included documentation of the time-related mandatory household activities[1] like cooking, washing and cleaning, and ICT usage activities that included time spent watching TV and time spent in economic generation activities (i.e. work from home). These variables were reported on an ordinal scale *(1= Less than 1 hour, 2= 1-2 hours, 3= More than 2 hours)*. Other narratives were collected based on the methodology (M. Sunikka-Blank, Bardhan and Haque, 2019) to get a subjective overview of the household practices concerning energy usage in the horizontal slums and the SRH.

Additionally, based on appliance ownership in the current housing, a dichotomous variable was introduced to report the change in energy-intensive practices. It was assumed that if the household bought energy-intensive appliances like TV, washing machine, microwave, refrigerator, computer, laptop/tablet computers and clothing irons, then there was a significant shift in energy-intensive practices, and it was coded as *'Yes = 1' or else 'No = 0'*. A continuous variable on the increase in the number of activities performed indoors was also reported (See Table 1). Mandatory household activities like cooking, cleaning and washing were mostly performed by female household members during the day, as the male (working-age) members remain out-of-house for work (M. Sunikka-Blank, Bardhan and Haque, 2019). It characterises these low-income settlements' critical social norm that the working-age male member spends the daytime out of the house (12-18 hours/day). Therefore, household practice-related questions were directed to the female members of the household.

Questions relating to the built-environmental attributes were derived from the recent study of Bardhan et al. (Bardhan, Debnath, Jana, *et al.*, 2018a), (Bardhan, Debnath, Malik, *et al.*, 2018a) that indicated indoor air quality (IAQ), hygiene and thermal comfort to be a crucial driver of occupant dissatisfaction in low-income tenement houses (see Table 1). The occupants were asked to rate their IAQ using a Likert-like scale consisting of five *parameters (Very poor = 1; Poor = 2; Average = 3; Good = 4; Very good = 5)*. Similar scale was used to report the occupant's perception of the thermal comfort in their present rehabilitation *houses (Very*

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[1] Mandatory activities are those household activities that are compulsory for daily living. This nomenclature is borrowed from activity-based approach studies (Chikaraishi *et al.*, 2017).

cold = 1; Cold = 2; Slightly cold = 3; Neutral = 4; Slightly hot = 5; Hot = 6; Very hot = 7). Additionally, an ordinal variable was added to report the change in thermal comfort conditions compared to the horizontal slums from the occupant's perspective and coded as *(Same= 0; Less comfortable = 1; More comfortable = 2*).

Variables related to appliance characteristics were based on the consumer culture of appliance ownership in India, as shown in (Eckhardt and Mahi, 2012). Six dichotomous variables *(1 = Yes, 0 = No)* defining product characteristics was used that included size, brand, product cost, quality, availability of discount and the ease of using the appliance (see Table 4). These product variables cumulatively indicate the affordability criteria; however, 'affordability' is not explicitly analysed as a separate indicator in this study.

To link drivers of appliance ownership with the built environment and household practices, an observed continuous variable was introduced in the survey questionnaire that recorded the number of appliances purchased after shifting into the SRH. This indicator was treated as the endogenous variable for the analytical model (see Fig 12) and is discussed in detail in Section 4.4.2. The variables and descriptive statistics are illustrated in Table 4 (see Appendix – I for more details).

Table 4. Descriptive statistics of the variables

Survey variables	Parameter	Variable type	Mean	Std. dev	Min	Max
Number of appliances purchased after shifting	V1	Continuous	2.26	1.63	0	10
Household Practice						
Gender dynamics in appliance purchase decision making	P1	Dichotomous (Male = 1; Female = 0)	0.41	0.49	0	1
Hours spent in performing mandatory activity - Cooking	P2	Ordinal (Less than 1 hours=1; 1 - 2 hours = 2; More than 2 hours = 3; Not performing the activity = 4)	1.93	0.61	1	4
Hours spent in performing mandatory activity - Washing	P3	Ordinal (Less than 1 hours=1; 1 - 2 hours = 2; More than 2 hours = 3; Not performing the activity = 4)	1.56	0.67	1	4
Hours spent in performing mandatory activity - Cleaning	P4	Ordinal (Less than 1 hours=1; 1 - 2 hours = 2; More than 2 hours = 3; Not performing the activity = 4)	1.95	0.62	1	4
Hours spent in subsistence activity	P5	Ordinal (Less than 1 hours=1; 1 - 2 hours = 2; More than 2 hours = 3; Not performing the activity = 4)	3.71	0.73	1	4

Hours spent in ICT use including Television	P6	Ordinal (Less than 1 hours=1; 1 - 2 hours = 2; More than 2 hours = 3; Not performing the activity = 4)	2.58	0.85	1	4
Increase in number of activities performed indoors after shifting	P7	Continuous	0.49	0.71	0	4
Increase in energy intensive activities	P8	Dichotomous (Yes = 1; No = 0)	0.45	0.50	0	1
Built environment						
Perception of Indoor Air Quality	BE1	Likert scale (Very poor = 1; Poor = 2; Average = 3; Good = 4; Very good = 5)	3.26	0.90	1	5
Concern regarding hygiene	BE2	Dichotomous (Yes = 1; No = 0)	0.73	0.44	0	1
Perception of thermal comfort in rehabilitation house	BE3	Likert scale (Very cold = 1; Cold = 2; Slightly cold = 3; Neutral = 4; Slightly hot = 5; Hot = 6; Very hot = 7)	4.16	1.41	1	7
Perception of thermal comfort in comparison to the horizontal slums	BE4	Ordinal Likert (Same= 0; Less comfortable = 1; More comfortable = 2)	1.28	0.69	0	2
Appliance characteristics						
Size	A1	Dichotomous (Yes = 1; No = 0)	0.73	0.44	0	1
Brand	A2	Dichotomous (Yes = 1; No = 0)	0.81	0.39	0	1
Product cost	A3	Dichotomous (Yes = 1; No = 0)	0.88	0.33	0	1
Quality	A4	Dichotomous (Yes = 1; No = 0)	0.86	0.35	0	1
Discount available	A5	Dichotomous (Yes = 1; No = 0)	0.84	0.37	0	1
Ease of use	A6	Dichotomous (Yes = 1; No = 0)	0.67	0.47	0	1

4.5 Hypothetical model development

Six hypotheses were formulated based on the evidence from the literature on social practice and residential electricity use, built environment and its effect on energy demand and appliance ownership characteristics in low-income tenement housing. Additionally, increased appliance ownership after shifting to SRH was considered as an endogenous variable. These hypotheses are illustrated in the conceptual framework in Fig 12. They are represented as H1, H2, H3, H4, H5 and H6, respectively.

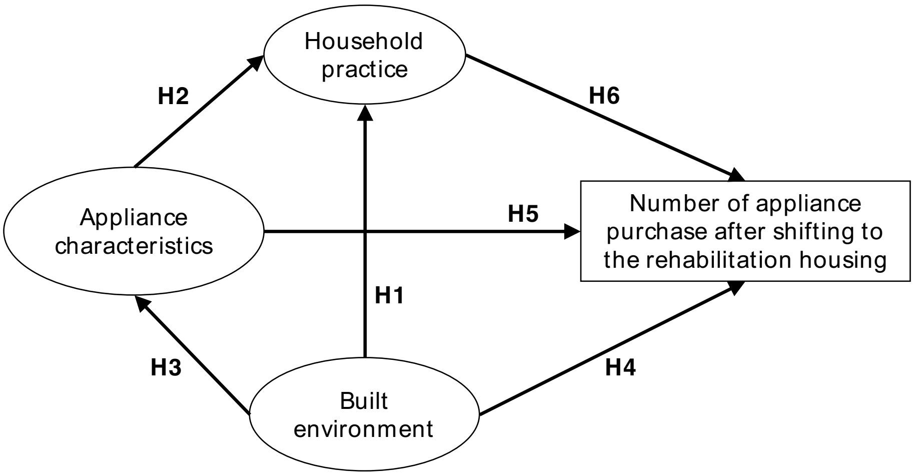

Fig 12. Conceptual model of the study indicating possible linkages between the variables.

H1: *Shifting of occupants from horizontal slums to vertical slum rehabilitation housing positively affects household practice change.*

This hypothesis is based on recent studies in Lahore, Pakistan (Khalid and Sunikka-Blank, 2017) that showed a change in the occupants' built environment design had a positive impact on high residential electricity consumption through a change of household practice. It is further supported by Rao and Ummel's (Rao and Ummel, 2017) derivation of non-income drivers of appliance ownership in India, Brazil and South Africa that listed dwelling type and the number of rooms as critical built environment variables affecting practices that in turn influence appliance ownership. Policy insights from social practice theories on energy conservation by Labanca and Bertoldi (Labanca and Bertoldi, 2018) also support this hypothesis.

This hypothesis tests that when occupants move from horizontal slums to vertical slum rehabilitation houses, it positively affects household practice change. In horizontal slums, the social practices are mostly associated with the outdoor social spaces, like, cooking, washing clothes, cleaning and social interactions with neighbours (M. Sunikka-Blank, Bardhan and Haque, 2019). Such communal spaces are missing in the vertical slum rehabilitation housing that may influence household practices.

H2*: Appliance characteristics have a positive effect on the change in household practices.*

H2 is supported by (Bisaga and Parikh, 2018) that showed that the change of practice of rural households in Rwanda had a positive non-linear influence on solar home system adaptation due to an increase in the households' energy demand. The author's mentioned that change of practice due to specific solar appliance ownership further motivated the occupants to invest in solar energy solutions. In another study by (Dhanaraj, Mahambare and Munjal, 2018), the effect of refrigerator ownership in low-to-middle income households in India was presented. The authors showed that the introduction of the refrigerator contributed to the welfare of female household members through a change of household practices.

H3: *Transition of the built environment from horizontal slums to vertical slum rehabilitation housing positively affects on choosing specific appliance characteristics.*

H3 is supported by a recent study by (Foulds, Powell and Seyfang, 2016) that showed that shifting house influences appliance ownership. This study was conducted for recent Passivhaus (energy-efficient homes) owners in the UK. It showed that the houses' high energy efficiency status influenced higher appliance ownership, which in turn resulted in higher usage time and energy demand. Ample evidence can be found in a review paper by Janda (Janda, 2011).

In the case of the slum rehabilitated households, the shift from the slums entails the idea of climbing up the social ladder. The shifting of the occupants from a temporary slum to the permanent SRH may instil the aspiration to purchase more appliances, as permanent housing is associated with the notion of moving out of poverty. This aspirational component influences the occupants to choose specific characteristics that complement the perception of climbing up the social ladder like the brand, size, product cost and quality (Eckhardt and Mahi, 2012). Contrastingly, in horizontal slums, occupants preferred to purchase unrated appliances to save on upfront cost (Khosla and Bharadwaj, 2015). Additionally, the space constraint in the slums restricted the uptake of appliances which was relieved in the SRH.

H4: *Change in the built environment positively affects on the number of appliance purchases after shifting to SRH.*

It is a further extension of H3. The change of the built environment represents the transition of the slum dwellers from the informal shacks to permanent high-rise apartments in the slum rehabilitation houses. As mentioned earlier, aspiration and the feeling of climbing up the social ladder play a crucial role in determining new appliances' purchasing decision with specific lifestyle characteristics (like the brand, size, cost and quality). The hypothesis H4 examines the quantitative aspect of built environment transition on the appliance ownership in the SRH. The change of the built environment in the SRH is marked by the lack of outdoor social spaces that compels the occupants to spend more time indoors, contrary to living in horizontal slums. Literature shows that such transition also influences household practices that can, in turn, affect the household electricity demand (Foulds, Powell and Seyfang, 2016).

H4 has its basis on (Foulds, Powell and Seyfang, 2016), where they established a positive influence of energy efficiency house on the appliance ownership. However, the setting of the study was in a higher income group, unlike this study. Similar inferences were also drawn by Rao and Ummel (Rao and Ummel, 2017) on dwelling type as a positive influencer of occupants' appliance purchase on a macro and regional level dataset of India, Brazil and South Africa. (Khalid and Sunikka-Blank, 2018) showed that the change of the built environment in middle-income households in Lahore, Pakistan increases energy demand due to the change of practice. It is a close representation of our case study in the SRH of Mumbai, India and forms a critical lead for the conceptualisation of H4.

H5: *Appliance characteristics have a positive effect on the number of appliance purchase after shifting to SRH.*

Hypothesis 5 (H5) is built on classical macroeconomic and consumer theory assumptions that appliance characteristics like quality, brand, size, cost and discount available significantly influence appliance ownership across all socio-economic classes (Filippini and Pachauri, 2004).

H6: *Change in the occupants' household practice has a positive effect on the number of appliance purchase after shifting to SRH.*

H6 is assumed based on the recent advancement in the sociological consumption studies based on the practice-theory approach. Practices are meaningful to people, and people are influenced by the practices they are engaged in everyday life (Røpke, 2009). Consumption comes in as an aspect of practices (discussed in detail in Section 4.4). This hypothesis adds to the merit of the study. For the first time, we are saying that appliance ownership is influenced by household practices and changing the built environment in low-income households. Other literature-based evidence supporting H6 can be found in (Foulds, Powell and Seyfang, 2016; Sunikka-Blank, Galvin and Behar, 2017; Khalid and Sunikka-Blank, 2018).

Structural Equation Modelling (SEM) was conducted to identify each path of the hypothetical model (see Fig 1) and verify the suitability of the conceptual model. Covariance-based SEM (CB-SEM) is the most common SEM approach, and it follows the maximum likelihood (ML) estimation procedure. It aims to minimise the difference between the observed and estimated covariance matrix (Astrachan, Patel and Wanzenried, 2014). AMOS is widely used for CB-SEM estimation. As the questionnaire data with a large sample size fits the normal distribution, this study chose this SEM estimation method using IBM SPSS AMOS v25.0. CB-SEM was performed to explain the relationship between household practices, built environment and appliance characteristics with the observed variable of increase in appliance ownership after shifting in the slum rehabilitation housing. Global fit indices were reported as per the work of Fu et al. (Fu *et al.*, 2019) to check the model's reliability (Model fit results are shown in Table 5 in Section 4.5.2).

4.6 Results and discussion

4.6.1 Descriptive of appliance ownership and household practice

The occupants' socio-economic conditions remained the same despite whether they lived in horizontal slums or the vertical apartment of the slum rehabilitation housing (SRH). It remains a salient feature of this study that the effect of low-income built environment transition can influence household electricity demand through a change of household practices. The typical appliance layout of horizontal slums and SRH apartment units are illustrated in Fig 13a and 13b, respectively. In horizontal slums, the occupants had access to electricity and appliances like TVs and refrigerators, just like that of the SRH housing. However, smaller floor area in the horizontal slums (~80 sq ft/~ 7.5 sq m) restricted higher uptake of the appliance, and their household practices were performed outdoors in a communal way. Common practices like washing clothes, cooking, cleaning and socialising with neighbours were all performed in outdoor community spaces in the slums. As they moved into vertical SRH apartments, they were provided with a relatively higher floor area (~265 sq ft/ ~24 sq m) that may have influenced household appliances' purchasing decisions. It is further influenced by occupants' aspirations to climb up the social ladder, as a permanent housing structure in Mumbai is a social-status indicator (M. Sunikka-Blank, Bardhan and Haque, 2019).

The current status of appliance ownership is illustrated in Fig 14, indicating ceiling fan (98.61%), television (TV) (92.89%) and refrigerator (61.11%) to be the most common household appliance in the study area. Washing machines (27.78%) and cloth irons (38.07%) were present in almost one-third of the surveyed households. In this study, appliances like washing machines, TVs and refrigerators were categorised as energy-intensive devices (see Section 4.4). It can be seen from Fig 15 that most of these energy-intensive devices were purchased after shifting to the SRH. It supports our general hypothesis that the transition of the built environment from horizontal slums to vertical apartments (SRH) influences household appliances that increase the electrical energy intensity of the households.

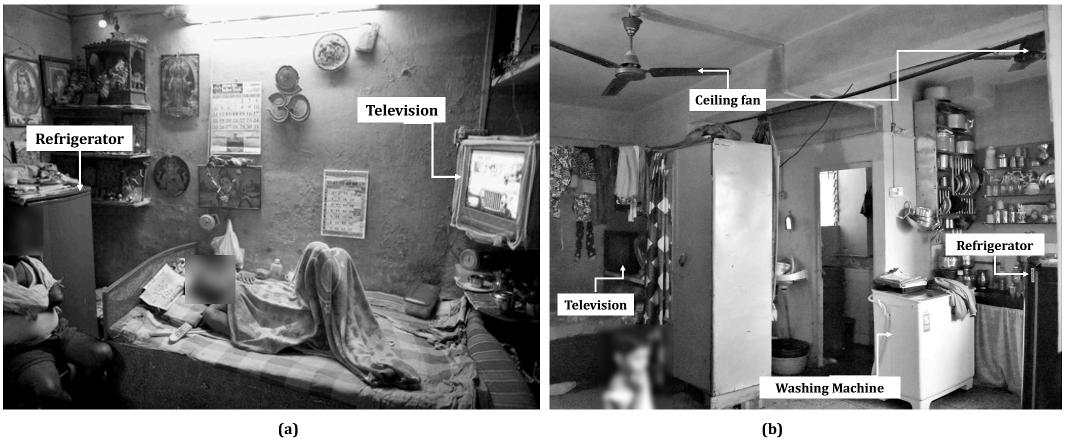

Fig 13. Household appliances in a typical (a) horizontal slum house (80 sq ft);
(b) slum rehabilitation house (265 sq ft)
Source: (a) Daniel Berehulak/Getty Images Europe (b) Authors'

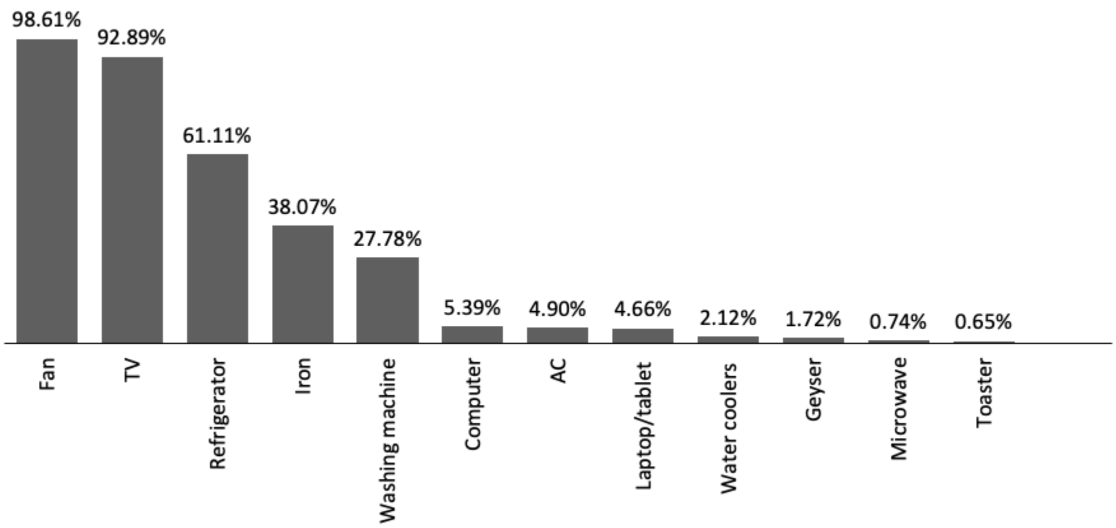

Fig 14. Share of household appliances in the sample size (n= 1224)

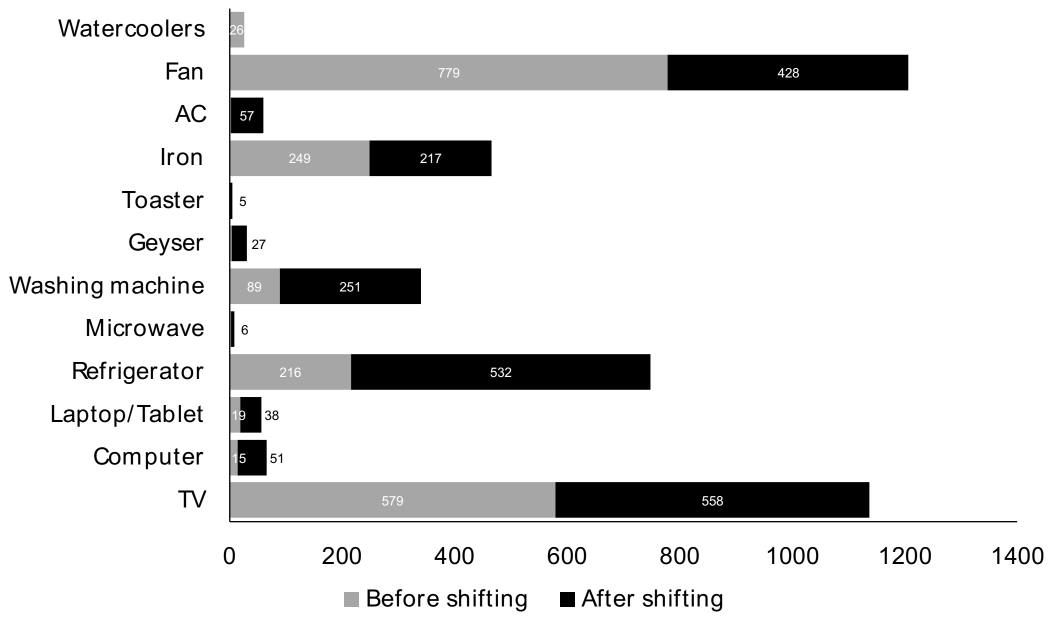

Fig 15. Household appliance ownership before and after shifting to the slum rehabilitation houses (n = 1224)

Based on Fig 15, appliance ownership rise after shifting to SRH is significantly substantial for refrigerators and washing machines. Almost 72% of the refrigerators and 75% of the washing machines were bought after moving into the rehabilitation house (see Fig 15). Television ownership almost doubled (49%) on moving to SRH, and similar numbers are recorded for an increase in clothing iron ownership (47%). Contrastingly, ownership of air conditioning units (AC) rose by 100% (see Fig 15), even though AC units represented only 4.90% of total appliance ownership in the study area (See Fig 14). It is an indicator of growing middle-class and energy-intensive behaviour among the residents.

While almost 99% of the surveyed households had ceiling fans (see Fig 14), there was a 35.45% increase in its ownership upon shifting to SRHs. A ceiling fan is the only 'cooling' devices available to occupants in the SRHs used in the regulation of the occupants' thermal comfort. An increase in ownership can indicate increased discomfort through the built environment and is further discussed later in this section concerning the SEM results (see Fig 16). An increase in ICT device ownerships like computer, TV, laptop/tablet computers can influence household practices. Fig 15 shows a significant rise in the computer (up by 77%), laptop/tablet (up by 67%) ownership among the occupants along with other devices like a toaster (up by 100%), microwave (up by 100%) and geyser (up by 99%) for hot water. These devices account for less than one-tenth of the total appliance ownership (see Fig 14), but their rise in ownership point towards rising energy demand in these low-income areas.

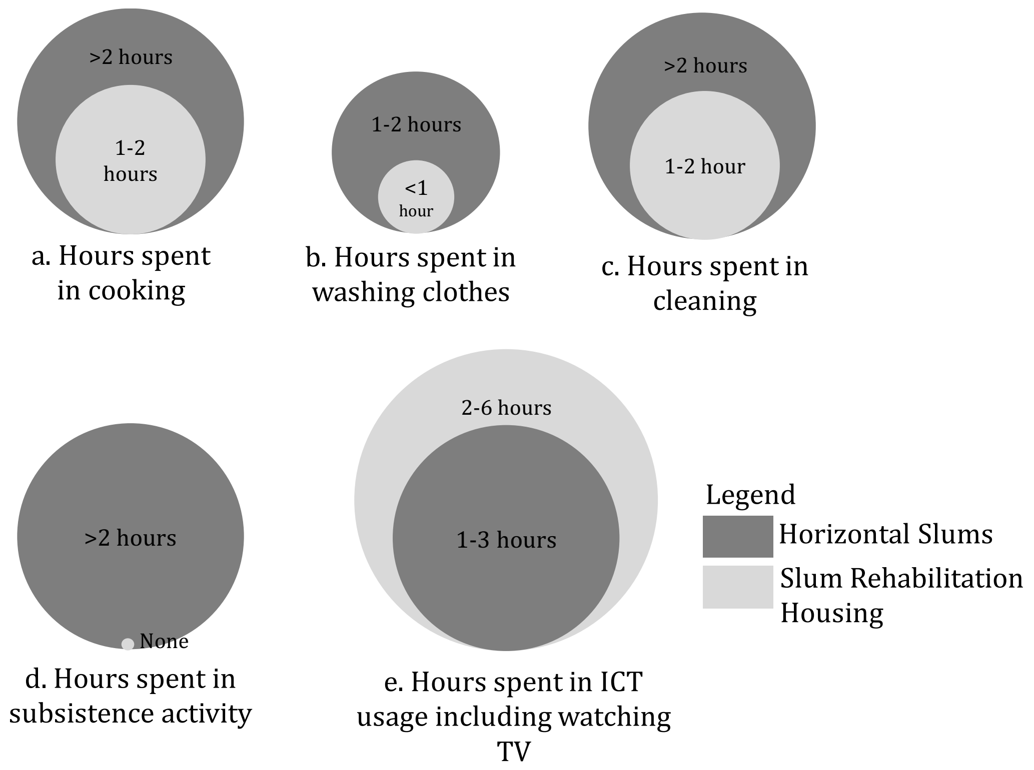

Fig 16. Average time spent in household activities in horizontal slums and slum rehabilitation housing

Fig 16 shows the average time spent in the household activities that constitute the occupants' social practices in the slums and the SRH. The average time spent in household activities in horizontal slums and SRH has contrasting differences in the spaces' organisation, as mentioned earlier. Life in the horizontal slum was communal; therefore, activities like cooking, cleaning and washing clothes used to take a more significant share of time (see Fig 16). On moving to the SRH, life became more private, and household practices reoriented around it. The washing time reduced due to the shifting of practices to washing machines, the cooking time went down as they had to cook for only the family members, and not as a communal meal. Indoor and private cooking also influenced the higher adoption of refrigerators in the households as they could store a larger quantity of cooked meal for days. It was absent in the horizontal slums because the community preferred readily cooked meals, which eliminated the refrigerator's requirement. Lack of space in the horizontal slums was also contributed to the low refrigerator ownership.

The cleaning time also reduced as the occupants had to cater to their own 265 square feet (~24 sq m) of rooms rather than cleaning several slum houses and the collective social spaces as in the horizontal slums. This shifting of household practices to private and indoor life in the SRH due to the built environment's architectural design encouraged the adoption of energy-intensive appliances like washing machines and refrigerators. It is discussed in detail in section 4.5.2.

A stark difference is in the time spent in subsistence activities (see Fig 16d), wherein horizontal slums used to be a significant component of their social and household practices. These subsistence activities were informal activities that the occupants used to perform in groups to support their livelihood, and they required a considerable amount of social spaces. In the SRH, lack of social spaces restricted this activity which is a significant cause of discomfort and distress, as mentioned in (Debnath, Bardhan and Sunikka-Blank, 2019a; M. Sunikka-Blank, Bardhan and Haque, 2019). Additionally, indoor and private living is evident from the increase in time spent watching TV and ICT usage in the SRH compared to the horizontal slums (see Fig 16e). The increased TV and ICT usage have a strong influence on the total increase of indoor energy-intensive activities in the SRH, contributing to increased residential electricity bills. This descriptive evidence supports our initial observation that household practices change contributes to higher appliance ownership, where household practices are changed as the slum dwellers are moved from informal shacks to formal apartments in the SRH. The next section quantitatively demonstrates this nexus and confirms the significant influence of such non-income drivers in determining the residential energy demand in such low-income settlements.

4.6.2 Empirical model estimation

The final SEM model and model fit indices for all data (n = 1224) are shown in Fig 17 and Table 5, respectively. The model fits well as per the indices and their satisfaction criteria (see Table 5). Overall, the model establishes the latent connections between the effects of the low-income built environment under transition from informal structures to permanent vertical apartments (slum rehabilitation housing (SRH)) on changing household practices, ultimately influencing higher appliance ownership in slum rehabilitated occupants. The SEM model in Fig 17 demonstrates quantitatively that non-income factors around energy practices influence appliance ownership, and therefore affect electricity consumption in low-income settlements.

Table 5. Model-fit indicators of the final model of this study

	Indicators		Criteria	Results
Absolute fit measures	χ^2/df (cmin/df)	Chi-square/degree of freedom	<3.00	2.735
	RMSEA	Root Mean Square Error of Approximation	<.08	.038
	AGFI	Adjusted Goodness of Fit Index	>.80	.956
	GFI	Goodness of Fit Index	>.80	.972
	SRMR	Standard Root Mean-square Residual	<.08	.018
Incremental fit measures	NFI	Normed Fit Index	>.90	.932
	CFI	Comparative Fit Index	>.90	.955
	IFI	Incremental fit index	>.90	.956
	TLI	Tucker Lewis Index	>.90	.935
Parsimonious fit measures	PGFI	Parsimonious Goodness of Fit Index	>.50	.690
	PNFI	Parsimonious Normed Fit Index	>.50	.643
	PCFI	Parsimonious Comparative Fit Index	>.50	.659

Non-income factors chosen for this study was represented through six hypotheses illustrated in Fig 12. Hypothesis H1, H2 and H3 constituted the structural model linking the influence of built environment on appliance characteristics and changing household practices (see Fig 17). Model results show that change of built environment from horizontal slums to vertical SRH apartments positively influenced household practices (0.16). At the same time, it significantly accentuated specific appliance characteristics (0.20, $p < 0.01$) to be central in purchase decision making (see Fig 17). The appliance characteristics have a significant positive influence on the changing household practices in the SRH (0.47, $p< 0.01$).

Specific appliance characteristics that have a significant positive effect on the household practices of the occupants are brand (0.63, $p<0.01$), product cost (0.68, $p<0.01$), quality (0.59, $p<0.01$), discount available (0.58, $p<0.01$) and ease of use (0.67, $p<0.01$) (see Fig 6). As mentioned in section 4.4, these variables became important for the occupants on moving to the permanent houses in the SRH because they strongly consider the shift as a step up the social ladder. It further encourages the purchase of rated appliances with these specific characteristics to suit their aspirational element of 'owning permanent housing in the city'. In the horizontal slums, the occupants preferred buying unrated appliances to save on the upfront cost (Khosla and Bharadwaj, 2015). While it is a good indicator of energy efficiency policies' perspectives, consumers voluntarily move towards rated appliances. However, this segment of consumers has the added burden of poverty as slum rehabilitation did not change their socio-economic conditions. Therefore, these characteristics do not significantly influence a high number of appliance ownership (0.03) on shifting from slums to SRH (see Fig 17). Instead, these appliance characteristics strongly influence household practices that affect appliance purchase decision in the SRH.

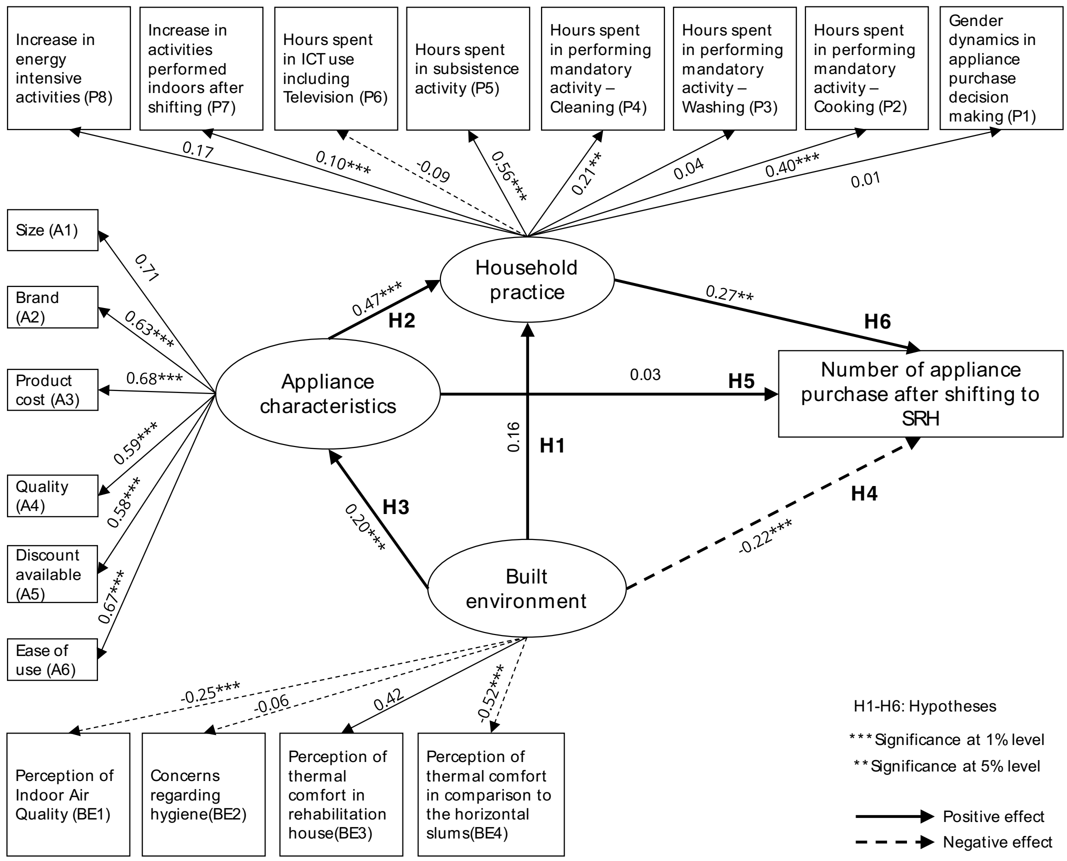

Fig 17. Model estimation using all data (n = 1224).
[Note: The numbers in the arrows represent factor loadings]

The change of the built environment influences changes in household practices (see Fig 17), supporting hypothesis H1. The change in the built environment is characterised by the difference in architectural designs between horizontal slum communities and the SRH apartments. As described in section 4.3, this change is primarily characterised by the lack of outdoor social spaces in the SRH. Household practices in the horizontal slums revolved around these outdoor spaces where mandatory activities like cooking, cleaning and washing clothes used to be performed communally. The current design of the SRH restricts such as social spaces (M. Sunikka-Blank, Bardhan and Haque, 2019), which is shifting these activities indoors and is altering the household practices. An increase in indoor activities is increasing the activities' energy intensity, translated into higher electricity bills for these low-income households (Debnath, Bardhan and Sunikka-Blank, 2019a). It points toward the critical nexus between housing design and energy choices in such low-income settlement programs that help derive effective energy policies for people living in poverty.

Model results show that there is a significant increase in indoor household activities upon moving into the SRH that significantly influences the household practices (0.10, $p<0.01$) that in turn strongly influences higher appliance ownership (0.27, $p<0.05$) (see Fig 17). An increase in energy-intensive activities on shifting to the SRH has a sizable factor loading on the household practices (0.17). It is due to the private usage of appliances in contrast to that of the slums.

The hypothesis H4 relates to the relationship between the built environment and uptake of appliances (see Fig 17 and section 4.4.2). The significant negative factor loading (0.22, $p<0.01$) can be interpreted as certain aspects of the built environment deteriorate upon moving into rehabilitation housing which influences the purchasing of appliances to compensate for this loss in home comfort. Poor built environment condition in the SRH is a factor of its inefficient design that negatively affects the thermal comfort (0.52, $p<0.01$) and indoor air quality (0.25, $p<0.01$). As the household practices have moved indoors in the SRH, low thermal comfort and indoor air quality further contribute to occupants' discomfort and distress (Debnath, Bardhan and Sunikka-Blank, 2019a). In turn, it leads to the uptake of appliances that can relieve them from the added discomfort.

Considering the direct and indirect effects on the appliance purchase after shifting, each factor's total estimated effect is shown in Table 6. Appliance characteristics (0.158) and household practice (0.265) had a more substantial total effect on appliance ownership after shifting to the SRH. The built environment had a more significant indirect effect (0.75) on the increased appliance ownership after shifting.

Table 6. Effect of each factor on the number of appliance ownership after shifting

	Total effect	**Direct effect**	**Indirect effect**
Built environment	-.149	-.224	0.75
Appliance characteristics	.158	.033	0.125
Household practice	.265	.265	0.000

4.6.3 Inference of the causal linkages

The empirical results presented in section 4.5.2 demonstrates the significant linkages between household practice and appliance characteristics with increased appliance ownership in the study area (see Fig 16). Change of practices like confining daily activities indoors was found to have a significant association with the increase in energy-intensive activities (see Fig 17) like washing clothes in washing machines, indulging in more ICT usage and increased refrigerator usage and ownership as compared to the horizontal slums (see Fig 15). In addition, built environment elements like lack of social spaces was a critical confounding factor that mediated higher appliance ownership through a change of practices.

The household practices mainly performed by women in the horizontal slums were an open system where spatially unbounded multitasking activities occurred. For example, women cooked and washed clothes outdoors while socialising with their neighbours. The traditional practice of preparing fresh meals and the ease of fresh vegetables from the local 'bazaar' dismissed refrigerators' needs. The ineffective design of SRH with low accessibility made the activities individualistic compared to community-based in horizontal slums, triggering energy-intensive indoor living. Presently, refrigerators and TV are the most common appliance purchased after shifting to the SRH (see Fig 15) to compensate for the distress associated poor standard of the housing units (Debnath, Bardhan and Sunikka-Blank, 2019a). The low indoor air quality, thermal discomfort, and lack of hygiene in the SRH are eased through higher appliance ownership, leading to higher electricity demand. If appliance ownership is assumed to have a linear association with energy demand, this evidence suggests that energy demand will rise multi-fold with the future building stock. Understanding such built environment-induced energy demand becomes more important as 70% of India's low-middle income building stocks is yet to be built (Bardhan and Debnath, 2016).

The higher time spent using ICT devices (smartphones) than the horizontal slums (see Fig 16e) can be mainly attributed to the individualistic living and the breaking of the social network. As mentioned above, household practices used to be shared communally in horizontal slums due to the availability of open spaces. However, it was lost in the SRH built environment due to the lack of open spaces that forced indoor living. Therefore, it triggered higher smartphone usage as a coping mechanism for the lost social network. During the survey, informal conversations with the occupants revealed that smartphones had become a critical part of their lives, especially for women who miss their social life in the horizontal slums. The narratives are discussed in detail in Chapter – 7.

Another causal link for higher ICT usage can be the loss of avenues for subsistence activities in the SRH, as illustrated in Fig 16d. Informal subsistence activities like tailoring, garland making, spice grinding, etcetera were common in horizontal slums due to the abundance of communal spaces and a physical, social network. However, these spaces were lost in the SRH that stopped such informal income-generating activities. Therefore, the allocated time in such practices has been converted to watching more TV and higher smartphone usage. It further shows the influence of built environment design in regulating household practices and its temporality effect on energy usage as the invisible drivers.

The study’s results are particularly relevant in designing better energy policies for the low-income housing sector through regulatory changes. The policies should be in tandem with the quality of the built environment and appliance purchase behaviour of appliances like refrigerators and washing machines that contribute sufficiently to household welfare by reducing the female burden in these low-income habitats. Dhanaraj, Mahambare and Munjal, (2018) regarded these appliances as ‘welfare appliances’. Thus, a ‘good’ energy policy for such low-income houses should use these welfare appliances through built environment design regulations or by providing economic incentives for owning them.

4.7 Chapter conclusion

We have examined the drivers of higher appliance ownership in low-income settlements that is undergoing transition. This study demonstrates quantitatively that non-income factors around energy practices influence appliance ownership, and therefore electricity consumption. We find that appliance ownership increases when household practices shift indoors. We also find that low indoor air quality, hygiene, and thermal comfort compensate for higher appliance purchases. Sub-standard design of social housing like the slum rehabilitation housing poses health hazards to the occupants. However, our empirical findings indicate the possibility of an energy burden on the occupants through higher electricity bills. The study's findings are crucial for quantifying a practice-based approach to make 'good' energy policies. In this context, a good energy policy should drive better-built environment design and higher inclusion of welfare appliances to deliver energy efficiency inherently in changing household practices. For example, better-designed SRH can be prefitted with energy labelled welfare appliances that naturally embed relative energy savings in changing practices. This study opens a new dialogue on the inclusion of changing practices searching for contextualised energy policy for the Global South.

The significant implications of this study lie in contributing to the energy demand forecasting for growing megacities like Mumbai. It is primarily because the occupants of low-income housing are assumed to belong to the lowest strata of the energy ladder, i.e. consuming the least energy. However, this study has shown that non-income factors like a change in household practices and built environment characteristics can significantly increase the energy demand despite low-income status. This finding emphasises the need for designing policies by considering the effects of housing and energy choices of people living in low and middle-income social classes. It remains a significant gap in the current policy discussions as the low-income population are assumed to consume the least energy, and resources are allocated accordingly. If not addressed, such a gap can threaten India's energy security, especially when two-thirds of the building stocks are yet to be built. While India will pull out millions of its citizens from extreme poverty in the coming decades, the future of urbanisation will primarily belong to the low-income strata. Hence, understanding their practices and energy choices will be critical in determining future energy sustainability.

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CHAPTER 5 Empirical – 2

Empirical links between built environment and socio-cultural energy service demand: Mapping distributive energy justice

5.1 Chapter summary

The interaction of energy and buildings institutes a complex socio-technical system that influences the occupants' eudemonic well-being. Understanding these drivers become even more necessary in impoverished areas where occupants struggle to avail essential energy services. Literature indicates that energy injustice can be addressed by providing comfort, cleanliness, and convenience (3Cs) as critical cultural energy services in low-income. This chapter investigates the socio-architectural influence of slum rehabilitation housing (SRH) on cultural energy services that promote distributive justice. The methodology adopts an empirical route using 200 household survey data of SRH in Mumbai, India and João Pessoa, Brazil. A model between the 3Cs and socio-architectural elements was established using Firth's binary logistic regression. Survey results showed that the SRH in Brazil had twice the appliance ownership than the Mumbai SRH. There were distinct energy service preferences in the study areas, despite common poverty burdens. The empirical results showed that the lack of socio-architectural design elements like open spaces, privacy and walkability in the study areas demanded specific comfort and convenience appliances as a counter-response. A critical policy implication drawn was the need for socio-architectural inclusive energy planning for distributive justice in poverty. Mitigating rising energy demand through appropriate built environment design of slum rehabilitation housing can fulfil UN SDG 7 (clean and affordable energy) and SDG 11 (sustainable cities and communities) goals.

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5.2 Introduction: Intersectionality between cultural energy services (3C) and low-income built environment

An energy-just world is believed to promote happiness, welfare, freedom, equity and due process for producers and consumers (Sovacool and Dworkin, 2014) (pp 13). Energy justice is a critical element of current energy policies addressing climate change mitigation and sustainable development goals. Energy justice frameworks have been designed to investigate and restructure energy supply and enhance equity (Mebratu *et al.*, 2018). Parallel to this approach, it is also essential to understand the human dimensions of energy that determine a place's energy culture (National Research Council, 1984). Understanding energy culture can help design 'just' policies in a bottom-up targeted manner for equitable distribution of energy resources, especially poverty alleviation (Sovacool, 2012; Sovacool and Dworkin, 2015b).

Energy cultures are derived from everyday energy practices, norms and the material reality of the built environment that drive specific energy services (Stephenson, 2018). Energy culture translates everyday energy consumption into household welfare which promotes energy justice. It is the responsibility of an energy just system to increase welfare by improving individuals' capabilities for maximising utility (Day, Walker and Simcock, 2016a). Distributive energy justice entitles people to a basic set of minimum energy services which enhance their long term well-being (Samarakoon, 2019). However, the current literature lacks evidence on the thresholds of a minimum of energy services as energy consumption at a household level is principally viewed as a physical quantity that is measured in a standardised unit (kilowatt-hour (kWh)) (Walker, Simcock and Day, 2016).

Besides, at the individual level, energy is consumed in the form of 'cultural energy services', driven by a complex socio-technical system of energy and built environment interaction (Wilhite and Lutzenheiser, 1998; Shove, 2003a; Stephenson, 2018). This complex system is collectively referred to as human-scale energy services (HUSES) (Brand-Correa, Martin-Ortega and Steinberger, 2018). Anthropologist Elizabeth Shove, (2003) (Shove, 2003a) aptly describes the socio-technical forces behind socio-cultural energy services as comfort, cleanliness and convenience (3Cs). 'Comfort' is described as one's satisfaction with the immediate physical environment by controlling the indoor climate parameters. 'Cleanliness' is referred to as the energy services needed to maintain desired hygiene and sanitation conditions. It has a broader undertone of unique ideas of the display, disinfection, and deodorization of the built environment. 'Convenience' refers to energy services that enable a smooth and effortless way of life. In the modern world, it is also associated with improving the quality of experience by using hyper-modern time-saving appliances (e.g., heating frozen food in microwave ovens rather than cooking every meal). The 3Cs are discussed in detail in section 2.1.

Sovacool, (2011) applied the 3Cs concept of energy services to construct a theoretical urban energy service ladder that illustrated poorer-household demand energy services for subsistence. Middle-income households demand energy services for comfort, cleanliness and convenience. At the same time, high-income households demand energy services for increasing consumption and convenience (Sovacool, 2011). However, in reality, urban poor exhibit a dichotomy in their consumption by portraying a middle-income consumption pattern (Debnath, Bardhan and Sunikka-Blank, 2019a; Khosla, Sircar and Bhardwaj, 2019). We argue that this dichotomy is due to a cross-fertilisation of fulling aspirations of middle-income consumption pattern and improving convenience through cultural energy services in poverty.

Owning a house is an aspirational element in the urban poor that shapes the cultural norms (Nijman, 2015). Slum rehabilitation aims at improving the quality of life and eudemonic well-being of the urban poor by enabling slum dwellers to own a house (Jones, 2017). However, low-quality slum rehabilitation can negatively impact energy sustainability and health, well-being, and socialization of the urban poor (Bardhan, Debnath, Jana, *et al.*, 2018a; Debnath, Bardhan and Sunikka-Blank, 2019a; Lueker *et al.*, 2019). A recent study on slum rehabilitation housing in India shows that a low-quality built environment pushes occupants towards energy poverty by increasing their household energy bills (Debnath, Bardhan and Sunikka-Blank, 2019b). In the same study, the lack of open spaces has disrupted the social network of the occupants. We argue that the poor design of SRH built environment is a distributive injustice restricting the welfare benefits of cultural energy services (3Cs) in the study areas. Therefore, the slum rehabilitation-built environment's influence is investigated to deliver comfort, cleanliness, and convenience in poverty through appliance ownership.

The study's focus is at the intersection of energy policy and built environment policy of the Global South's hyper-dense cities. It aims to solve the broader problem of identifying distributional benefits and energy systems' costs in rapidly urbanising cities under spatial complexities of built environment typologies, as described in this thesis's research framework in Fig 10 and Fig 11. The study's novelty lies in the empirical establishment of the socio-architectural needs and appliance ownership as critical 3C components that can be utilised for distributive justice-based policymaking. This study contributes significantly to the sparse literature on policy interaction for distributive justice from utility-side (electricity) and urban planning. It also contributes to the growing literature on the socio-technical understanding of architecture and energy systems in the Global South's rapidly urbanising cities (Basu *et al.*, 2019). The case of India and Brazil presented here aptly represents the complex urbanising scenarios where poverty alleviation efforts must be supported by just energy and climate policies (Ozawa *et al.*, 2019). Understanding energy consumption as 3Cs in poverty can help policymakers and utility companies customise tariff mechanisms and ease the injustices due to the poverty trap. As Global South prospers economically throughout this decade, millions of citizens will be moved out of extreme poverty through slum rehabilitation programs. Therefore, it is critical to improving its welfare effects, and the distributive energy justice perspective can guide future slum rehabilitation and energy sustainability policies.

To realise the research question presented above, this chapter addresses the following objectives, a) to examine the variation in appliance ownership and energy practices in slum rehabilitation housing of Brazil and India as a description of cultural energy services. b) to investigate how socio-cultural energy services (comfort, cleanliness and convenience) are derived through appliance ownership in the study areas' socio-architectural context; c) to empirically examine the role of socio-architectural variables of slum rehabilitation in the energy service demand for 3Cs through specific appliance ownership. The objective (c) binds this chapter to the broader research framework illustrated in the chapter – 3. A binary logistic regression is used to empirically answer the objective (c) using a 200-household sample survey on appliance ownership and socio-architectural amenities of the SRH in Brazil and India.

We vary two variables in this study - first, the typology of slum rehabilitation housing (SRH) (low-rise and high-rise buildings). Second, the occupants' socio-cultural background living in SRH (Brazilian SRH and Indian SRH) defines their energy service needs. By varying these variables, we examine 'how do socio-architectural elements like access to open spaces, walkability and comfort strategies influence the demand for comfort, cleanliness and convenience (3Cs) through specific appliance ownership?' We assume that the material manifestation of the 3Cs is through household appliance ownership, and just policies should enable low-income occupants to avail these services through appropriate socio-architectural design provisioning.

This chapter is structured as follows. Section 5.3 illustrates the applied energy concepts of cultural energy services and literature evidence on built environment – energy justice nexus. Section 5.4 presents the methodology with a detailed description of the study area and the study variables. Section 5.5 illustrates the results and discussion into two subsections. Section 5.5.1 describes the exploratory results of energy culture in the study areas. Section 5.5.2 illustrates Firth's binary logistic regression's empirical result examining the influence of lack of socio-architectural compatibility on cultural energy service demand. Finally, section 5.6 presents the chapter conclusion and policy implications of this study towards distributive energy justice.

5.3 Background

5.3.1 Cultural energy services (3C) and appliance ownership

People do not consume energy in real life; they consume cultural energy services (Wilhite and Lutzenheiser, 1998). The energy services can be specified through the conventions of comfort, cleanliness and convenience (3Cs) that drive the energy consumption culture in society (Shove, 2003a). It is the cultural energy services that convert energy into well-being (Samarakoon, 2019). In a recent study, Brand-Correa et al. (2018) explored the connection between well-being and energy use. They called it human-scale energy services (HUSES). Authors found that household appliances act as critical transducers of energy to well-being conversion, such that HUSES are manifested through specific appliance ownerships. Here, we synthesise 3Cs as an applied energy concept (see Table 7) through the lens of socio-cultural definitions of 3Cs by Shove, (2003) and urban energy service ladder by (Sovacool, 2011).

Johnson, Gerber, & Muhoza (2019) showed that energy services' availability critically influences occupants' well-being. The demand for energy services is formed through specific energy practices, material culture, norms and aspirations, met through the household appliances ownership. It is referred to as the 'energy culture'(Stephenson, 2018). It establishes a logical link between appliance ownership and the demand for energy services, which cater to the socio-cultural need for comfort, cleanliness, and convenience (3Cs). Both Shove (2003) and Sovacool (2011), in their interpretation of social energy services, converge their arguments on the welfare implications of appliance ownership especially in fuel-poor and energy-poor households (see Table 7). Empirical studies from the Global South have also provided evidence on this association in low-income households. Like, Dhanaraj, Mahambare, & Munjal, (2018) have found that welfare appliances like refrigerators and washing machines reduce drudgery women and children in doing activities like cooking, washing and cleaning in low-income households of India. Reduction of drudgery saves time and improves convenience, which is, in turn, used for income generation contributing to household welfare (Dhanaraj, Mahambare and Munjal, 2018). Sovacool and Dworkin, (2014) in Chapter 7 provides its epistemology which establishes the regimes of distributive energy justice through household welfare in poverty based on Amartya Sen and Martha Nussbaum's *Capability Approach* theory. We add another layer to this epistemology by including socio-architectural design variables for just energy policymaking in poverty.

Table 7 Comfort, cleanliness and convenience for appliance ownership as an applied energy concept

Cultural energy services	**Shove, (2003)'s description of 3Cs as domains of energy consumption in daily life**	**Sovacool, (2011)'s interpretation of 3Cs as drivers of urban energy consumption in daily life**	**Appliance ownership as material manifestation of energy culture (3Cs) in the slum rehabilitation housing (Authors' assumption)**
Comfort	A socio-technical system that co-evolved with the industrialisation of indoor climate and increasing energy intensity. It led to a worldwide standardisation of technologies, building styles and conventions, which now dictate the energy culture and the ownership of household appliances. For example: like owning cooling appliances, air conditioners, practices of opening/closing windows, etcetera.	The 3Cs are interpreted as one's satisfaction with the immediate physical environment, strongly associated with the ability to control indoor climate. It is a critical factor behind the global rise in air conditioning, especially among middle-income consumers. In low-income households, comfort has more economic connotations as income decides comfort outcomes. For example, poor households usually cater to natural ventilation, open spaces or fans for thermal comfort than energy-intensive mechanical cooling devices.	Thermal comfort: Fans and natural ventilation are the most common strategy (Malik, Bardhan and Banerji, 2019). Social comfort: Community areas and open spaces for socialising in the built environment. It is crucial for well-being (Debnath, Bardhan and Sunikka-Blank, 2019a). Mental comfort: Community-feeling and preserving the social network in the built environment (Debnath, Bardhan and Sunikka-Blank, 2019a).
Cleanliness	A co-evolutionary socio-technical and socio-cultural system that emerged from an identity-defining bathing and laundering practices to energy-intensive cleaning and laundering services. For example, change of bathing	The social aspect of energy services that encompasses unique ideas of the display, disinfection, and deodorization. It also represents the energy need to maintain aesthetics, hygiene	Electrification of cleaning regimes at a household-level. For example, Aspirational uptake of washing machines as a 'modern' device; vacuum cleaners and clothing irons.

Cultural energy services	Shove, (2003)'s description of 3Cs as domains of energy consumption in daily life	Sovacool, (2011)'s interpretation of 3Cs as drivers of urban energy consumption in daily life	Appliance ownership as material manifestation of energy culture (3Cs) in the slum rehabilitation housing (Authors' assumption)
	and hand-washing practices to a washing machine and hot-shower driven energy-intensive practices. It represents the change of cleanliness as a household practice to an industry-driven system of using detergents, washing machines, bathroom-fixtures, ironed-clothes, etcetera, for pleasure and duty. At a neighbourhood/societal scale, cleanliness-services is represented as the maintenance of hygiene and sanitation.	and sanitation in a household or a neighbourhood.	Better hygiene, safety and sanitation in the built environment as a crucial need.
Convenience	Describe arrangements, devices, or services that helped save or shift time. A consumption culture where commodities and services are sold as being convenient or as making life more convenient for those who use them. There are modern and hypermodern forms of convenience devices that provide people with greater flexibility over their daily schedule that promotes 'ease of life' or 'welfare'. For example, freezer, coffee maker, juicer, blender, smartphones, microwave ovens, computers/laptops/tablets, etcetera are categorised as hypermodern devices. Convenience devices help in the branching of daily tasks through multi-tasking or in reducing the time of daily tasks that in turn, increases the demand for further convenience through the purchase of additional appliances.	Convenience can refer to reducing the effort needed to do a job as well as improving the quality of experience, such as watching a recorded show on a smartphone than on a tight television schedule. Lower-cost and enhanced services in today's age have put paramount importance on the 'convenience' factor of owning an appliance. Services are needed round the clock and in an 'instant'. This demand for energy services is a primary reason for the rapid rise of energy demand in emerging economies like China and India, especially among middle-income consumers.	Uptake of hyper-modern appliances that saves time. It adds to the household welfare, especially to the women of the household by saving time from their daily chores (Dhanaraj, Mahambare and Munjal, 2018). For example, refrigerators, washing machine, microwave oven, coffee machine, mixer grinder, juicer, vacuum cleaners, etcetera Information and communication technology devices (ICT) like smartphones, TVs, Wi-Fi, laptops, computers, tablets, etcetera.

5.3.2 Built environment and its influence on cultural energy services

The literature on Social Practice Theory (SPT) has established critical theories between the material reality of the built environment and energy culture (Shove, 2003a; Shove and Walker, 2014; Khalid and Sunikka-Blank, 2017). In SPT, individuals act as carriers of a practice which ultimately leads to decision-making rather than just the behavioural attributes. Shove, Pantzar, & Watson, (2012) (Shove, Pantzar and Watson, 2012)'s elucidation on the material dimension (i.e. objects, infrastructure, tools, hardware and the human body) of SPT established connecting theories around human-energy interactions in the built environment.

Energy culture is one of the theories that connect energy practices with socio-cultural norms and built environment's material reality (Stephenson, 2018).

A change of built environment in low-income communities is linked with a change in their social processes. However, its energy implications are understudied. Identified drivers of residential electricity use include income, climate, demographic characteristics, energy price dynamics, dwelling type and technology (Ekholm *et al.*, 2010; Cabeza *et al.*, 2014; Rao and Ummel, 2017). However, in the context of the Global South, energy studies have revealed a hierarchy in which appliances are acquired (Daioglou, van Ruijven and van Vuuren, 2012). It is due to reliance on more than one energy sources, causing a complex energy transition trajectory across the socio-economic domains. With the rise in household income, improved solutions become more accessible; there is a tendency to stack multiple energy sources, termed as 'energy stacking' or 'energy staircase' (Kowsari and Zerriffi, 2011; Van Der Kroon, Brouwer and Van Beukering, 2013). Energy stacking is shared among the urban poor in the Global South, the reasons for which are not entirely known yet. However, empirical studies have shown the influence of energy culture on energy stacking practices which point towards understanding the socio-cultural (i.e., non-income drivers) of energy demand in low-income communities (Bhide and Monroy, 2011; Kowsari and Zerriffi, 2011; Bisu, Kuhe and Iortyer, 2016; Choumert-Nkolo, Combes Motel and Le Roux, 2019). The above studies have investigated energy services as a socio-technical system that demands lighting, heating, cooling, entertainment, cooking, etcetera. It restricted the investigative boundary of the energy system as a physical quantity in these studies. This study expands this boundary by exploring human-scale energy services that demand comfort, cleanliness and convenience in the built environment. Therefore, contributing to the growing literature on non-income drivers of energy service demand and appliance ownership.

Besides, built-environment quality, household size, automobile ownership, appliance characteristics, education level, gender dynamics and household practices are also reported as critical non-income drivers of appliance ownership that drives energy consumption (Tiwari, 2000; Pothitou, Hanna and Chalvatzis, 2017; Rao and Ummel, 2017; Bisaga and Parikh, 2018). For example, Rao & Ummel, (2017), in their cross-country and micro-level study of Brazil, India and South Africa, have shown that penetration of appliances like television and refrigerators are highly driven by social practices, norms and material culture across the social groups. Similarly, Debnath et al., (2019b) have shown that slum rehabilitation in India influences high appliance ownership due to changes in household practices. The change in the household practices is due to the change of the built environment from horizontal slums typology to vertical rehabilitation housing typology. It indicates a possible influence of building typology in appliance uptake practices which is investigated in this study.

In the rapidly urbanising Global South, the social impacts of the built environment and energy interaction in poverty were reported from Mexico. It was found that making energy efficiency retrofits in social housing would reduce the case of their abandonment by the overall improvement of occupants' 'thermal comfort' (Medrano-Gómez and Izquierdo, 2017). Studies also showed that Brazil's infamous 'My house, my life' national social housing program could have been made more effective and energy-efficient through appropriate built environment design that can connect occupants to the community and improve the overall well-being. It involved providing access to open spaces, improving walkability and setting up community terraces (Mesquita and Ripper Kós, 2017). Similarly, bioclimatic design strategies at a neighbourhood level in Argentina's social-housing showed a lowering of outdoor temperatures, which in turn improved thermal comfort and reduced cooling energy demand (Sosa, Correa and Cantón, 2018). In India's social housing, Bardhan, Debnath, Malik, & Sarkar, (2018) have shown that effective geometric and spatial arrangements of these housing units can improve the overall quality of life. The authors investigated the role of socio-architectural elements that improve indoor comfort and air quality. Thus, in low-income communities, built environment design acts as a critical catalyst of shaping the energy culture, which, in turn, determines the demand for cultural energy services.

5.3.3 Built environment and energy justice: Intersectionality of sustainable urban planning and energy systems

The built environment plays a critical role in realising energy justice-based policies' distributional benefits through inclusive land use and urban planning (Poruschi and Ambrey, 2019). However, distributional benefits of energy systems are often overlooked in urban planning narratives as land-use zoning for infill and high rise developments become a policy priority (Burton, 2003; Poruschi and Ambrey, 2019). This approach has a similar effect in the planning of slum rehabilitation programs, where the developers aim to maximise occupancy and fill the housing deficit (Ronita Bardhan *et al.*, 2015). In the slum rehabilitation housing of Mumbai, India, the high rise development policy has severe negative ramifications in the quality of life of occupants as they get restricted fresh air, daylight, open spaces, sanitation and hygiene conditions (Bardhan, Debnath, Jana, *et al.*, 2018a; Lueker *et al.*, 2019). It accentuates some of the injustices of built environment planning that has a spillover effect in energy use and appliance ownership in such low-income houses (Debnath, Bardhan and Sunikka-Blank, 2019b, 2019a).

Energy justice-driven urban planning is a contemporary topic in energy research and social science. A recent study showed that the current focus on urban planning and energy justice policies was determining the spatial scope of energy systems in cities. For example, Poruschi & Ambrey, (2019) investigated solar PV technology's spatial distribution as a distributive energy justice measure to rising cooling and heating demand in Australian cities. They used dynamic socio-economic panel data and geospatial dataset to determine the spatial location of solar PV panel installation for energy equity. Similarly, Byrne et al. (2016) (Byrne *et al.*, 2016) examined urban greening's potential in reducing thermal inequality in Australia. The authors used a practice-based lens to understand occupants' disposition towards green infrastructure to combat heat stress. In the US, Zhou & Noonan, (2019) used green building and smart meter roll-out programs across racially diverse neighbourhoods to investigate energy injustices. In doing so, the authors derived new energy justice exploration and policy perspectives (Zhou and Noonan, 2019). From a city planning standpoint, the concept of economic and social justice, along with energy sustainability, was used by Chatterton (2013) to develop an agenda for post-carbon affordable communities in the UK.

Similarly, Sanchez & Reames, (2019) have used a socio-spatial analysis in justice-based policy design to mitigate urban heat island using green roofs in Detroit, US. One of the very few recent studies that have used energy justice as an urban planning philosophy. It indicated the need for justice-based pathways for addressing future cooling demands, especially in low-income and vulnerable communities.

Josa & Aguado, (2019) provided an in-depth review of cross-fertilising themes across economic, environmental and social aspects in civil engineering, infrastructure planning and society. They find energy-justice in the urban transportation and mobility segment to have a broader social transformation effect at a city scale and derive a framework for holistic decision-support for planners and policymakers Heffron, McCauley, & de Rubens, (2018) conducted a critical methodological study that developed an energy justice metric as a research and policy decision-making tool to tackle inequality. It used an environmental subparameter, 'Cost of Loss of Amenity to Local Communities', that connected local built environment variables (amenity) with the direct and indirect energy sources' effect. The process of derivation of this energy justice metric provided a critical methodological clue to this study.

Similarly, from an urban sprawl mitigation perspective, Wilson & Chakraborty, (2013) found that the current paradigm of planning research demands multidisciplinary considerations of resilience and environmental, energy and climate justice for tackling urban sprawl/slum formation. Our study expands on it by exploring the socio-architecture needs in poverty with the demand for specific energy services. This understanding can enhance justice-driven policymaking capabilities.

5.4 Data and Methods

5.4.1 Data collection and survey design

Data was collected in the slum rehabilitation housing (SRH) of Mumbai, India and João Pessoa, Brazil-based on comfort, cleanliness and convenience (3C) appliance ownership survey. The survey questionnaire was designed based on the theoretical background of energy cultures to examine the socio-cultural factors influencing the demand for the 3Cs (after (Stephenson, 2018)). We specifically interviewed women of the household as they spend most of the time in their built environment. This occupancy pattern is distinct to low-income households in the Global South (M. Sunikka-Blank, Bardhan and Haque, 2019). The classification of appliances based on the 3C category is done as per Table 7. The survey variables are illustrated in Table 8. The data was collected in August 2019.

The questionnaire design and the surveys were conducted based on UN-DESA (2005)'s best practice guidelines. The question frames were designed as per the energy cultures categorisation. We can map the social process involved in the demand for 3Cs through energy practices, norms, and material culture in the surveyed households. In doing so, we capture the time spent in the SRH during weekends and weekdays, thermal comfort perception at home compared to living in the horizontal slums, what drives the use of cooling devices, and the appliance ownership in the households. The surveys spanned across 200 housing units in Mumbai (n=100) and João Pessoa (n = 100), who were selected using a stratified random sampling of the SRH units.

Table 8. Survey variables to explore energy cultures in the slum rehabilitation built environments

Sl. No	**Survey variables**	**Classification Category**	**Variable type**	**Interconnected energy-cultures domains and descriptions**
A1	Total appliance ownership	Energy use	Continuous	Material reality
A2	Appliances owned	Energy use	Dichotomous (1 = Yes, 0 = No)	Norms and aspirations Comfort (thermal): *Fan, air conditioners, air coolers, etcetera.* Cleanliness: *Vacuum cleaners, geysers, clothing irons, etcetera.* Convenience: Welfare appliances: *Washing machine and refrigerators* Hyper-modern appliances: *Microwave ovens, coffee machine, juicer, mixer-grinder, food mixer, DVD players, Smartphones, TVs, laptop, computer, tablets, etcetera.*
A3	Time spent at home in weekdays	Socio-cultural	Ordinal (1 = less than 12 hours; 2 = 12-18 hours; 3 = more than 18 hours)	Practice
A4	Time spent at home in weekends	Socio-cultural	Ordinal (1 = less than 12 hours; 2 = 12-18 hours; 3 = more than 18 hours)	Practice
A5	Thermal comfort perception at home as compared to horizontal slum	Built environment	Ordinal (1 = very cold; 2 = cold; 3 = slightly cold; 4 = neutral; 5 = slightly hot; 6 = hot; 7 = very hot; 8 = cannot answer; 9 = depending on the time)	Material reality
A6	Strategies to improve thermal comfort	Socio-cultural and built environment	Dichotomous (1 = Yes, 0 = No)	Practice
A7	Fan usage time at home	Socio-cultural	Ordinal (0 = Do not use/ there is not, 1 = less than 12 hours; 2 = 12-18 hours; 3 = more than 18 hours)	Practice
A8	Window opening schedule (Day/ Night)	Socio-cultural	Dichotomous (1 = Yes, 0 = No)	Practice
A9	Reasons for keeping the windows closed	Built environment	Dichotomous (1 = Yes, 0 = No)	Material reality Lack of privacy; Risk of burglary; Entry of insect/dust; Used as storage; Noise; Rain; Solar gains; Broken windows

5.4.2 Study areas

Mumbai, India: Slum Rehabilitation Housing (SRH)

The study area chosen in India is the slum rehabilitation houses in Mumbai in the state of Maharashtra. These houses are built under the 'Slum Rehabilitation Housing' policy that redevelops slums into high-rise social housing by incentivising the private sector to participate in the redevelopment of slum communities. It provides legal entitlement to slum dwellers to a stipulated 25 square meters apartment, including a bathroom with tap water and a kitchenette. In the past two decades, close to 0.15 million tenements have been rehabilitated using this model (Zhang, 2016). This policy provided the slum dweller access to a cross-subsidised, free of cost house without burdening their time or economic poverty (Ronita Bardhan *et al.*, 2015). Recent studies have shown that these housing units lack basic guidelines design, energy efficiency or socio-cultural considerations (M. Sunikka-Blank, Bardhan and Haque, 2019) that imposes energy and health burden on the occupants (Zhang, 2016; Bardhan, Debnath, Jana, *et al.*, 2018a). Households pay around 30-40% of their monthly income to electricity bills, making them vulnerable to energy poverty (Debnath, Bardhan and Sunikka-Blank, 2019b).

The specific survey location of SRH in this study is the Natwar Parekh Complex (NPC). The NPC, an SRH in the 'M-ward' of Mumbai, was selected for this study. It is a high-rise SRH building with 15 floors and has 800 apartments (see Fig 18).

Fig 18. Slum rehabilitation housing of Natwar Parekh Complex, Mumbai, India (Source: Authors)

João Pessoa, Brazil: Gadanho and Timbó Social Housing (GTSH)

The study area in Brazil is in the city of João Pessoa, Paraíba State, northeast Brazil. Two social housing settlements were surveyed: Gadanho and Timbó, built-in 2013 (see Fig 19). The Gadanho Social Housing has 45-row house units with one floor, whereas the Timbó Housing is two-storeyed houses with 136 units. These houses were built through a partnership between the City Council of João Pessoa and the Federal Government to mitigate the housing deficit for the poor (MaisPB, 2014). The GTSH rehabilitated slum and disaster-struck occupants from temporary shelters around the city. Each house in the GTSH scheme had a floor area of approximately 37 square meters, distributed across a living/dining room, one kitchen, one bathroom and two bedrooms. Previous studies have shown that there were post-occupancy refurbishments in most of the houses to maximise the living area (Simoes and Leder, 2018). Occupants added terrace in many houses through frugal construction methods that further poor natural ventilation, leading to increased thermal discomfort. The GTSH built environment was designed with sidewalks and roads that improved walkability and access to communal spaces, which improved compared to the slums (Simoes, 2018; Simoes and Leder, 2018). These houses were also built in the same neighbourhood where the resident lived previously, which makes them distinct from the slum rehabilitation houses in Mumbai.

However, existing literature also shows these houses' overall quality was of low standards (Simoes, 2018; Simoes and Leder, 2018). There was no consideration for thermal comfort and energy efficiency in the indoor design, making GTSH uncomfortable (Simoes and Leder, 2018). As a compensatory measure, occupants perform frugal refurbishment of these dwelling units, which further deteriorates the indoor air quality by blocking natural ventilation (Simoes, 2018; Simoes and Leder, 2018). Frequent refurbishments include adding a bedroom, increasing the kitchen size or adding a terrace (like a *verandah*). These frugal refurbishments deteriorate the indoor thermal conditions and daylight conditions of the dwelling, decreasing or completely stopping the natural ventilation and daylighting (Simoes and Leder, 2018). The built environment and socio-economic characteristics of the surveyed households in both the study areas are illustrated in Table 9.

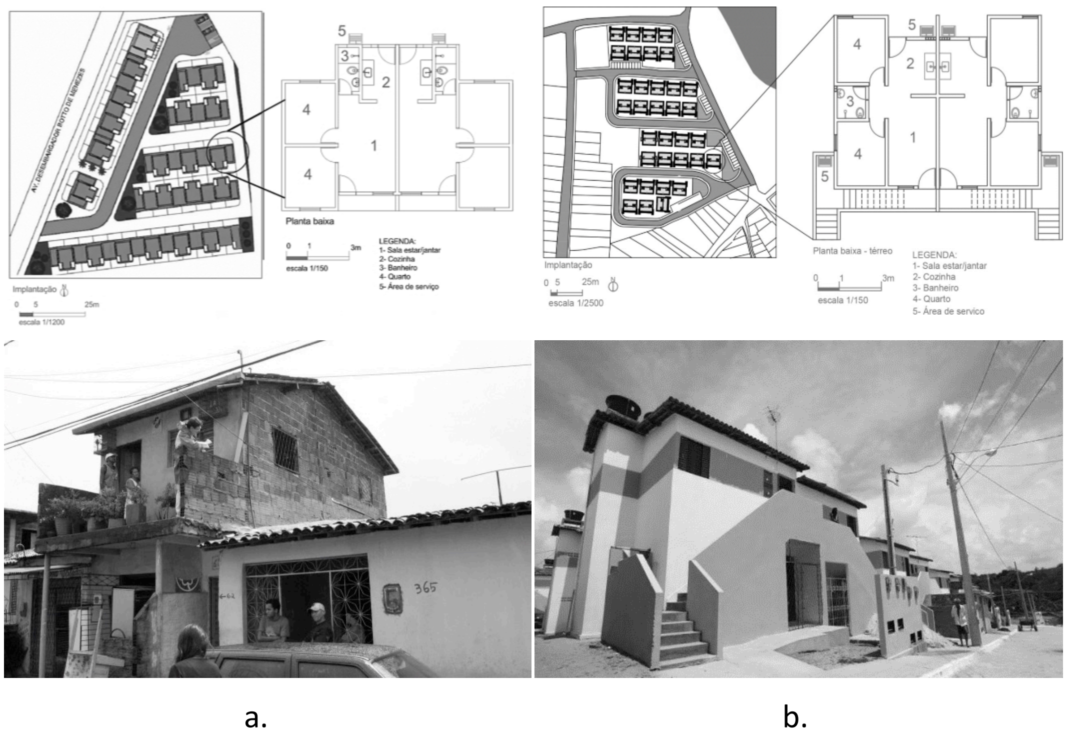


Fig 19 (a) Gadanho and (b) Timbo Social Housing, João Pessoa, Brazil. (Source: (PMJP, 2014))

Table 9 Built environment, socio-economic and energy use characteristics of the study areas

Characteristics	**SRH, Mumbai, India**	**GTSH, João Pessoa, Brazil**
Building typology	High-rise (8 floors)	Low-rise (1-2 floors)
Built environment	Stacked buildings in a 'shoe-box' like manner. Poor provisioning of sidewalks and open spaces. Lack of hygiene and sanitation. Safety remains a problem.	Housing design was homogenous placed in an industrial manner. Well-defined sidewalks and roads. Safety remains a problem.
Floor area (m^2)	~ 25	~37
Spatial placement of rehabilitation houses	Away from slum location	On the same location as the slums
Average household income	USD 70-140 per month	USD 93.5 – 180 per month
Primary occupation of head of household (HoH)	Labourer in construction industry.	Labourer in waste-recycling industry.
Average number of people per household	~ 5	~ 4
Average education level of HoH	Middle-school	Middle-school
Average household electricity bill	USD 6 – 10 per month	USD 20 - 30 per month
Average household energy consumption (kWh)	135	192
Low-income electricity tariff program	None	Electricity Social Tariff (ENEL, 2019)
Typical electricity demand drivers	Cooling (fans only), lighting and entertainment	Cooling (fans only), lighting, leisure and entertainment
Cooking fuel	Liquefied Petroleum Gas (LPG), kerosene	Liquefied Petroleum Gas (LPG)

5.4.3 Empirical analysis: cultural energy services and built environment design elements in slum rehabilitation housing

A binary logistic regression modelling approach was used to empirically estimate the influence of lack of essential built environment design elements in the slum rehabilitation housing understudy with the demand for specific cultural energy services through specific appliance ownership. The essential built environment design variables that contributed to reducing distress and discomfort of the occupants in such low-income communities were adapted from Debnath et al., (2019a) (Debnath, Bardhan and Sunikka-Blank, 2019a). We modelled five key variables concerning appropriate low-income built environmental design and planning, i.e., lack of privacy, lack of safety, walkability during daytime and night-time and access to open/ventilated spaces in the neighbourhood (see Table 10). These dependent variables were collectively called socio-architectural components (Bardhan, Debnath, Malik, *et al.*, 2018a). Besides, the demand for comfort, cleanliness and convenience were empirically represented by the ownership of specific appliances, as per Table 7.

Table 10. Variable list for empirical modelling

Dependent variable	**Data type (Binary: 1 =Yes, 0= No)**
Cultural energy service type in the study areas [E] (by specific appliance ownership)	[1] Comfort (ceiling fan, table fan, air-conditioners, air-coolers ownership) [2] Cleanliness (vacuum cleaners, geysers, clothing irons) [3] Convenience (Washing machine and refrigerators; Microwave ovens, coffee machine, juicer, mixer-grinder, food mixer, DVD players; Smartphones, TVs, laptop, computer, tablet)
Independent variable	**Dummy variable (Binary: 1 =Yes, 0= No)**
Lack of socio-architectural built environment elements that are crucial for the well-being of occupants in slum rehabilitation housing (after [13]).	[BE1] Privacy
	[BE2] Safety
	[BE3] Open space/ventilated space access during night-time
	[BE4] Walkability during daytime
	[BE5] Walkability during night-time

The estimated value of specific cultural energy service demand (E, 1 = yes, 0 = no) was interpreted as the probability of the demand for comfort [E1], convenience [E2] and cleanliness [E3] (3Cs) in the respective slum rehabilitation housing neighbourhoods. The estimated model is illustrated in eq.1,

$$E_i = b_0 + \beta_1 BE1 + \beta_2 BE2 + \beta_3 BE3 + \beta_4 BE4 + \beta_5 BE5 + u_i \qquad (1)$$

$$\{E_i = 1, \text{ if appliances for 3C were present;}$$
$$E_i = 0, \text{ if appliances for 3C were absent}\}$$

where, E_i indicated a binary variable corresponding to appliance ownership for specific cultural energy services, termed as Comfort (Model 1), Cleanliness (Model 2) and Convenience (Model 3), respectively}. Dummy variables were assigned (1 = Yes, 0 = No) for the dependent variables to match 3C-driven energy demand (see Table 10). Beta coefficients were represented through β_1 to β_6. And, u_i represented the error term of the model, and b_0 was the intercept. The eq. 1 tested whether the lack of a specific socio-architectural design variable (BE1 to BE6, see Table 10) influences the energy service demand for 3Cs.

Maximum likelihood (ML) based binary logistic regression often fails to converge in a small sample (Allison, 2008). The two most common concerns that arise from it are the loss of statistical power and bias and trustworthiness of standard errors and model fit tests (Newsom, 2016). Statistical power refers to the probability of finding significance when the alternative hypothesis is true in the population. It depends on the sample size, the variance of the independent and dependent variables, and effect size (e.g., odds ratio, proportional difference), among a few other things (e.g., number of predictors, the magnitude of the correlation among them, alpha level). A detailed review of power and sample size estimation methods can be referred from Bush (2015) (Bush, 2015).

ML estimation is known to have a small sample bias and produces an odds ratio that is too large for small samples (Nemes *et al.*, 2009). Nemes et al., (2009) (Nemes *et al.*, 2009)'s estimation showed that the bias appears to be about 10-15% for the log odds ration when n= 100, and nearly entirely disappears as n = 1000. Thus, it concluded that smaller samples could be expected to have a larger bias. Standard errors and significance tests require caution for smaller sample sizes in ML estimations(n < 100) (Newsom, 2016). The Wald test also performs poorly for small sample sizes (Hauck and Donner, 1977). To overcome these problems associated with small sample size in ML-estimates of binary logistic regression, (Firth, 1993) introduced a penalised log-likelihood method. Firth's penalisation (Firth, 1993) has garnered significant attention to reduce the small-sample bias of ML coefficients. Mathematically it can be represented as (Rahman and Sultana, 2017),

Let Y_i, $(i = 1, 2, \ldots, n)$, be a binary outcome (0/1) for the ith subject which follows Bernoulli distribution with the probability $\pi_i = \Pr(Y_i = 1)$. The logistic regression model can be defined as eq.2,

$$\text{Logit}[\pi_i \mid \boldsymbol{x}_i] = \eta_i = \boldsymbol{\varphi}^T \boldsymbol{x}_i \tag{2}$$

where $\boldsymbol{\varphi}^T$ is a vector of regression coefficients of length (k+1), and $\boldsymbol{x}_i$ is the ith row vector of the predictor matrix $\boldsymbol{x}$ which has order n x $(k+1)$. The term $\eta_i = \boldsymbol{\varphi}^T \boldsymbol{x}_i$ is called the risk score or 'prognostic index'. In standard ML, the model is fitted by maximising the log-likelihood denoted by $l(\boldsymbol{\varphi})$.

Whereas in penalised methods, $l(\boldsymbol{\varphi})$ is maximised subject to constraints on the values of regression coefficients. The penalised regression coefficient is obtained by maximising the penalised log-likelihood denoted by *l(φ)* – pen*(φ)*, where pen*(φ)* is the 'penalty term'. The penalty term is the functional form of constraints.

Firth (Firth, 1993) removed the first-order bias in the ML estimations of the regression coefficient by using the penalty term $\frac{1}{2}\, trace \left[I(\varphi)^{-1} \frac{\partial I(\varphi)}{\partial \varphi_j}\right]$ in the score equation $U(\varphi_j) = \frac{\partial I(\varphi)}{\partial \varphi_j} = 0$. The modified score equation is then represented as (see eq.3),

$$U(\varphi_j)^* = U(\varphi_j) + \frac{1}{2}\, trace \left[I(\varphi)^{-1} \frac{\partial I(\varphi)}{\partial \varphi_j}\right] = \mathbf{0}, j = 1, \ldots, k \quad (3)$$

where $I(\boldsymbol{\varphi})^{-1}$ is the inverse of information matrix evaluated at $\boldsymbol{\varphi}$**.** The corresponding penalized log-likelihood function for the above-modified score function is $l(\varphi) + \frac{1}{2}\log|I(\varphi)|$. It is known as Jeffreys invariant prior, and its influence is asymptotically negligible. The Firth type penalised ML estimator of φ is thus $\hat{\varphi} = argmax \left\{l(\varphi) + \frac{1}{2}\log|I(\varphi)|\right\}$**.** This method is bias preventive rather than corrective (Rahman and Sultana, 2017). We fitted the binary logistic regression model (see eq. 1) using Firth's bias reduction method, as illustrated above. It was proposed as an ideal solution to separation in logistic regression, especially with a small sample (Puhr *et al.*, 2017). The *logistf* package in R v3.3.3 was used for Firth's reduced-biased regression computations (Heinze *et al.*, 2018).

5.5 Results and discussions

5.5.1 Appliance ownership and energy culture in slum rehabilitation housing of João Pessoa, Brazil and Mumbai, India

Results show the distinction between the appliance ownership pattern in Joao Pessoa, Brazil and Mumbai, India households. Descriptive data shows that the total appliance ownership in Brazilian households is twice that of the Indian households (see Fig 20). Welfare appliances like washing machine and refrigerator occupy a significant portion of total appliance ownership in both the case studies (see Fig 20). Welfare appliance ownership contributes to improved convenience in low-income households (Dhanaraj, Mahambare and Munjal, 2018). However, there are more refrigerator per households in the Brazilian case study (111/100) than in Indian households (61/100). This pattern continues in the washing machine ownership as well [Brazil (53/100); India (35/100)]. Televisions (TVs) and fans are the most common household appliances in both the study areas. There are 152 fans in 100 surveyed households in Brazil, whereas in the Indian case, there are 99 fans in 100 households. Most of the fans in Indian case are ceiling fans, and the Brazilian households have both ceiling and table fans.

Similarly, for the TVs, Brazilian households had 132 TVs out of 100 samples, the Indian households had 97 TVs out of 100 samples (see Fig 20). Higher TV ownership can indicate a more substantial demand for convenience-driven energy services in Brazilian households. Besides, higher ownership of hyper-modern appliances in GTSH may indicate a higher demand for convenience-related energy services (see Fig 20 and Table 8). However, higher appliance ownership in Brazil may be attributed to lower costs of appliances than the Indian market or even point towards the welfare effects of special energy tariff programs for low-income households in Brazil (see Table 9). It is beyond the scope of this paper to report such comparative energy market analysis results.

Higher ownership of fans indicates a comfort-based energy culture of mitigating thermal discomfort due to the hot and humid climate of both the study areas (see appendix-I). The study area's built environment design is also reported to cause significant thermal discomfort (see section 5.3). The exact reasons for higher TV ownership are not known; studies have shown the popularity of 'soap opera' act as cultural drivers of TV-ownership in Brazil (McAnany and La Pastina, 1994; Ghisi, Gosch and Lamberts, 2007). However, it indicates a media-consumption culture which is often interpreted as a compensatory response towards low mental well-being (Scott and Woods, 2019; Werneck *et al.*, 2019). In Mumbai, a recent study has shown that women feel lonely in slum rehabilitation housing (SRH) which motivates them to watch more TV and purchase more appliances as a compensatory mechanism (Debnath, Bardhan and Sunikka-Blank, 2019a).

Besides, survey results show that appliances like blenders, DVD players, coffee machines, juicer, microwave ovens, toasters, food mixers and radios were exclusively present in the Brazilian case compared to Indian survey households (see Fig 20). These appliances are categorised as hypermodern devices and are solely created for improving the convenience factor (see Table 8). Results also show the ownership of freezer, sewing machine, printer, air-fryer, video game consoles, bedside lamps and home theatre system in the Gadanho and Timbo Social Housing (GTSH), which were absent in the SRH case (see Fig 20). Although the ownership of such hypermodern devices was low or even singular in some cases, it demonstrates the possibility of a more substantial convenience-driven energy culture in the GTSH as compared to the SRH. In the SRH, freshly ironed clothes have a significant social notion (Debnath, Bardhan and Sunikka-Blank, 2019b). They are embedded deeply into the energy culture through higher ownership of clothing irons than the GTSH case (see Fig 20).

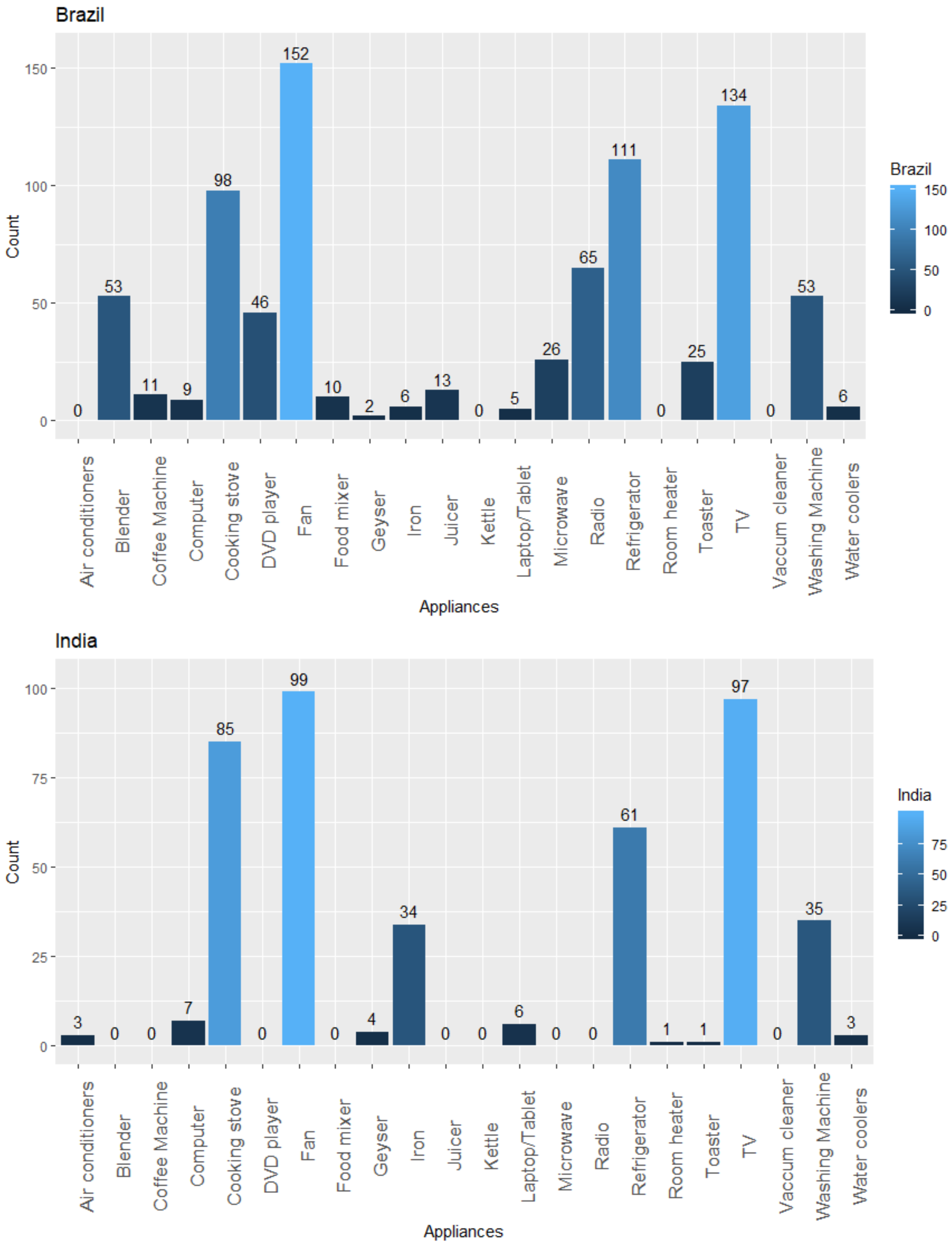


Fig 20 Household appliance in the slum rehabilitation housing of João Pessoa, Brazil (n = 100) and Mumbai, India (n = 100)

The electrification of cleanliness was not clear from the survey results as both GTSH and SRH households performed manual cleaning of households; no vacuum cleaners were found (see Fig 20). There were no electric showers[1] in both the survey areas, though GTSH had more washing machines than SRH, as illustrated in Fig 20. In both cases, washing machines were kept in either kitchen or the living room due to a small floor area of the housing units, which creates severe space constraints. Occupants usually expand their rooms by frugal refurbishments in the GTSH to accommodate such appliances, which cause thermal discomfort and lack of daylight. Simoes & Leder (2018) reported that such refurbishments forced the occupants to buy additional fans and always use artificial lighting. It increased the overall energy intensity of these households. Such refurbishments are widely performed due to the low-rise building typology across Brazil (Sullivan and Ward, 2012). However, such refurbishments were absent in the high-rise typology of the SRH. These houses were still affected by reduced daylighting and ventilation conditions due to poor design (Debnath, Bardhan and Sunikka-Blank, 2019a).

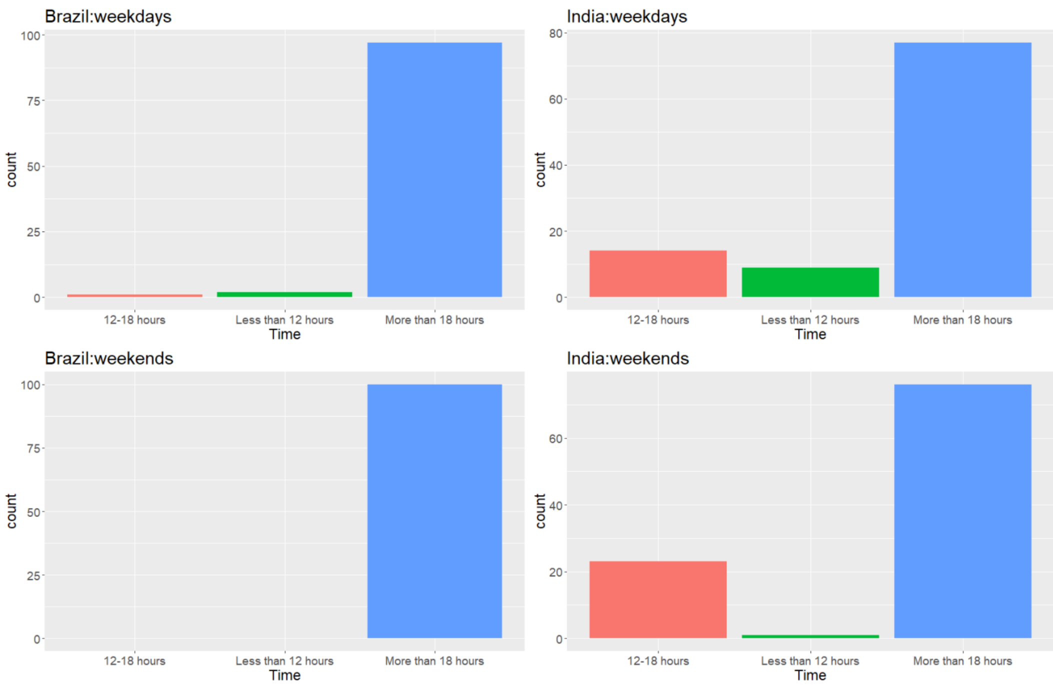


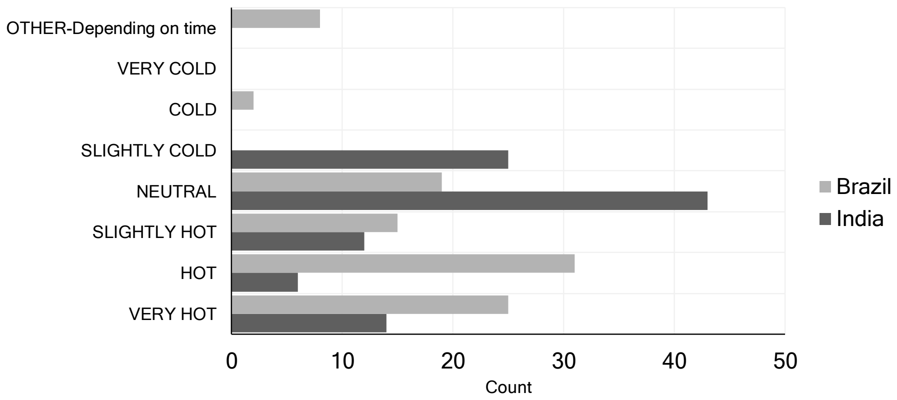
Fig 21 Time spent indoors in weekdays and weekend depicting occupancy norms in the study areas.

Occupancy pattern is a critical indicator of energy culture in households. Fig 21 illustrates the occupancy pattern in the GTSH, Brazil and SRH, India during the weekdays and weekends. In both areas, most of the surveyed occupants tend to stay indoors for more than 18 hours a day which is a noticeable characteristic of low-middle income housing (Bardhan and Debnath, 2016; Malik, Bardhan and Banerji, 2019). This level of occupancy is

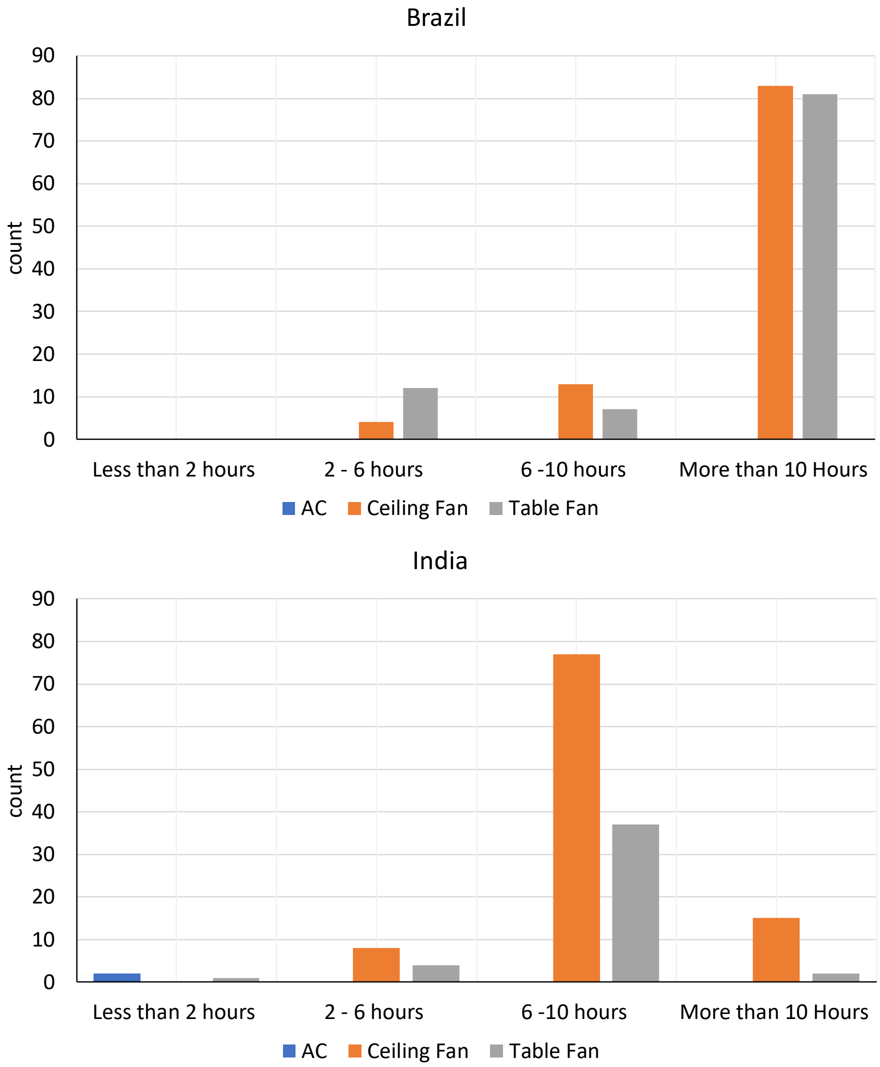
[1] An electric shower is a standard appliance in middle-income households in Brazil and India.

due to the strong cultural norm that at least one member (mostly women) of the family stays at home to take care of children and the elderly (also reported in (Bardhan and Debnath, 2016) for low-middle income housing in Mumbai). Such extended occupancy demands cultural energy services concerning TV-viewing and indoor energy-intensive practices (Ghisi, Gosch and Lamberts, 2007; Debnath, Bardhan and Sunikka-Blank, 2019b). For example, it can be seen in Fig 4 that both in Brazil and India, most of the surveyed occupants have indoor occupancy of more than 18 hours at the weekends and weekdays. Therefore, it is crucial to make indoors comfortable to balance discomfort with energy-intensive cooling practices. A rise in indoor energy intensity is linked with higher indoor discomfort due to poor ventilation and thermal comfort levels in low-income households (Sarkar and Bardhan, 2020a).

The thermal comfort perception of the surveyed social housing in Mumbai and João Pessoa revealed high thermal discomfort (see Fig 22a). The GTSH occupants responded that their current homes are either 'hot' or 'very hot', then 'neutral' by the SRH occupants. The cooling device usage time is shown in Fig 22b, which shows the ceiling fan as the most operated device in India and Brazil. Climatologically, João Pessoa is less hot and humid than Mumbai (see appendix). Physiologically, occupants of SRH may have higher temperature tolerance than GTSH; it is beyond the scope of this study to investigate this aspect. However, as discussed above, GTSH occupants perform extensive refurbishment of their low-rise housing units that block the windows, causing thermal discomfort (Simoes and Leder, 2018). To mitigate this discomfort, occupants in the GTSH used table fans in addition to ceiling fans as primary cooling devices (see Fig 22b). Thus, discomfort caused by frugal refurbishments of the built environment in GTSH is shaping the energy culture of high fan ownership.



(a)



(b)

Fig 22 (a) Thermal comfort perception and (b) use of cooling devices (fans, table fans and ACs) in the Brazilian (n = 100) and Indian (n =100) surveyed households

Common strategies associated with maintaining thermal comfort in GTSH and SRH is illustrated in Fig 23. It highlighted the energy culture associated with thermal comfort in the study areas. The most common thermal comfort practices in both the case studies were opening/closing doors and windows and fans' use (see Fig 23). Comfort measures that differed like 'taking a bath' and 'adjusting clothing levels' were governed by distinct socio-cultural norms of the study areas (see Fig 23). For example, bathing was not a standard thermal comfort response in the Indian case because it had a vital religious significance. Bathing as a practice in SRH households was done as a part of a religious routine, followed by wearing 'freshly ironed clothes' (therefore, iron ownership was more in SRH than the GTSH, see Fig 20). However, in the Brazilian case, the survey showed that bathing directly responded to thermal discomfort, so it stood out as a standard thermal comfort measure in GTSH (see Fig 23).

Similarly, the practice of adjusting clothing levels as a thermal comfort practice varied in SRH and GTSH, possibly due to the cultural norm of wearing distinct clothing styles. In the Indian case, 'saree' was the most common women wear. It is a traditional piece of long cloth draped around the body. The clothing insulation (clo) values differ based on the time of the year, a typical winter ensemble of saree provides 1.10 – 1.39 clo, and summer and monsoon ensembles provide 0.62 - 0.96 clo. While the clothing adjustment values have high variability between summer and winter months, adjusting sarees to thermal discomfort was also governed by the degree of convenience (Indraganti *et al.*, 2015). On the contrary, Brazilian clothing norms were distinctively 'western' (clo-value varies between 0.5 to 0.7), which were more convenient to adjust to the thermal comfort (Vecchi, Lamberts and Candido, 2017). Therefore, survey response showed that 'adjusting clothing levels' was more common in Brazilian households than the Indian households (see Fig 23).

Besides, Fig 23 also showed built environment driven thermal comfort measures that were distinct to the study areas' socio-architectural characteristics. Strategies like 'going out to the street during the day and evening' were common in the Brazilian case compared to the Indian case. It can be attributed to the low-rise typology of GTSH with walkable roads, dedicated community and open spaces[1] (see Table 9).

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[1] It does not mean GTSH has better roads and open spaces in terms of urban design. It is relatively better than the SRH context of Mumbai.

Walkability was reduced in the high-rise built environment of SRH, which forced the occupants to remain confined in their housing units even during hot summer days. Besides, the lack of open and community spaces in the SRH also disturbed the occupants' community-cohesion, and it affected their eudemonic well-being (also reported in (Debnath, Bardhan and Sunikka-Blank, 2019a)). Shifting of household practices to indoor and lack of open spaces was a significant reason behind the increase in the occupants' energy intensity. It leads the households in SRH to higher energy bills and poses greater vulnerability towards energy poverty (Debnath, Bardhan and Sunikka-Blank, 2019b).

The GTSH in Brazil was built on the same site as slums. Owing to its low-rise typology, families feel more connected as their social network remains intact (also reported in (Simoes and Leder, 2018)). It is one of the plausible reasons for the occupant to walk on the streets during day and night to mitigate thermal discomfort (see Fig 23). It provides further evidence on the influence of built environment design on households' energy culture, which influences the comfort – convenience regimes of that place. Thus, space planning is slum rehabilitation housing is critical to the eudemonic well-being of the occupant. It indicates a planning-derived route to energy justice in such low-income communities.

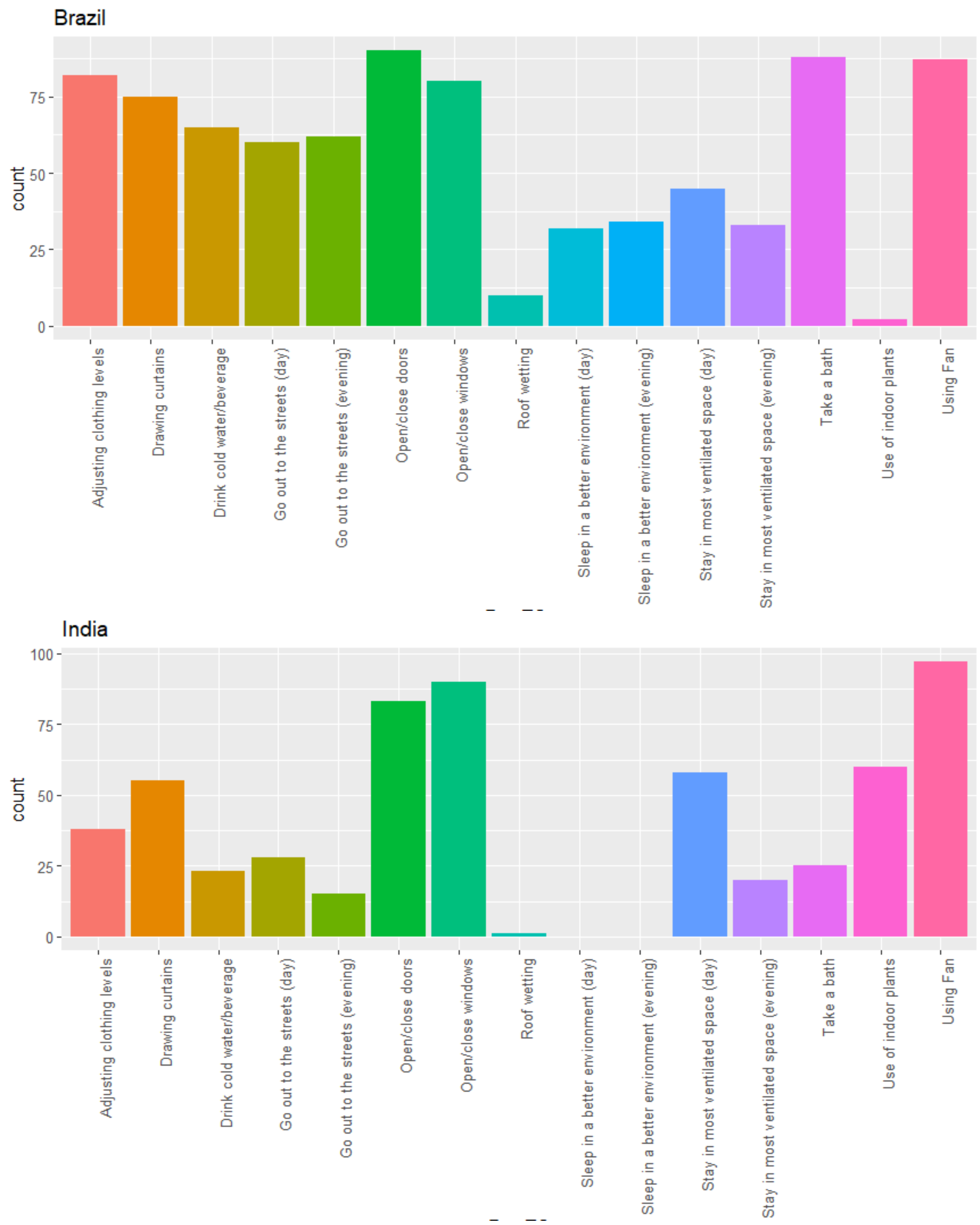

Fig 23 Practice and norms in GTSH, Brazil (n= 100) and SRH, India (n = 100) to restore thermal comfort in the built environment

Safety, hygiene and sanitation of the built environment are critical planning components essential for the occupants' eudemonic well-being (Vaid and Evans, 2017). These variables were often overlooked in slum rehabilitation housing planning that contributed significantly to occupants' distress and discomfort (Vaid and Evans, 2017; Bardhan, Debnath, Jana, *et al.*, 2018a; Debnath, Bardhan and Sunikka-Blank, 2019a). In doing so, we investigated the window operating schedules, as these were the only mean of natural ventilation in both the study areas. Fresh air exchanges are critical in maintaining comfort, cleanliness and convenience in low-income houses (Debnath, Bardhan and Banerjee, 2016; Bardhan, Debnath, Malik, *et al.*, 2018b; Kshetrimayum, Bardhan and Kubota, 2020b; Sarkar and Bardhan, 2020a). Fig 7 illustrates the windows opening and closing schedule in the study areas. Besides, it also demonstrates the built environment governed reasons for keeping the window closed.

In both the SRH, it was common to keep windows open during the day (see Fig 24). A few households were found to keep their windows open at night. It was surprising because, at night, all the family members were at home, which increased the occupant density of these housing units that increased indoor temperature. It was a source of thermal discomfort in these housing units. The socio-cultural norms associated with privacy and the cleanliness component of the built environment motivated window closure at night in the Indian case.

Windows were kept closed during the night due to the high concentration of dust and insects in the SRH, Mumbai (see Fig 24). A high concentration of insects and dust were present due to a lack of hygiene and sanitation (see Fig 18). Occupants threw garbage in the narrow space between the SRH buildings, that posed severe health and hygiene challenge (see Fig 18). Survey responses showed that lack of open-spaces and hygiene regulations in this built environment contributed to such practices. Similar observations were also reported by Kshetrimayum et al. (2020) (Kshetrimayum, Bardhan and Kubota, 2020b).

On the contrary, survey results showed that the neighbourhood hygiene conditions were comparatively better in the Brazilian case. It was contributed to its low-rise building typology and regular access to social spaces (see Fig 19). Therefore, insect infestation and dust's influence in keeping the windows closed in GTSH was small (see Fig 24). Lack of safety was a significant issue in both the study areas, such that occupants closed windows at night to prevent burglary (see Fig 24). These were some of the socio-architectural factors that influence the closure of windows at night when the occupant's density was the highest. The closure of windows at night caused thermal discomfort (Debnath, Bardhan and Sunikka-Blank, 2019a) that demanded energy-intensive cooling devices in both the study areas.

Such socio-architectural variables were empirically tested with demand for cleanliness, comfort and convenience in section 5.5.2.

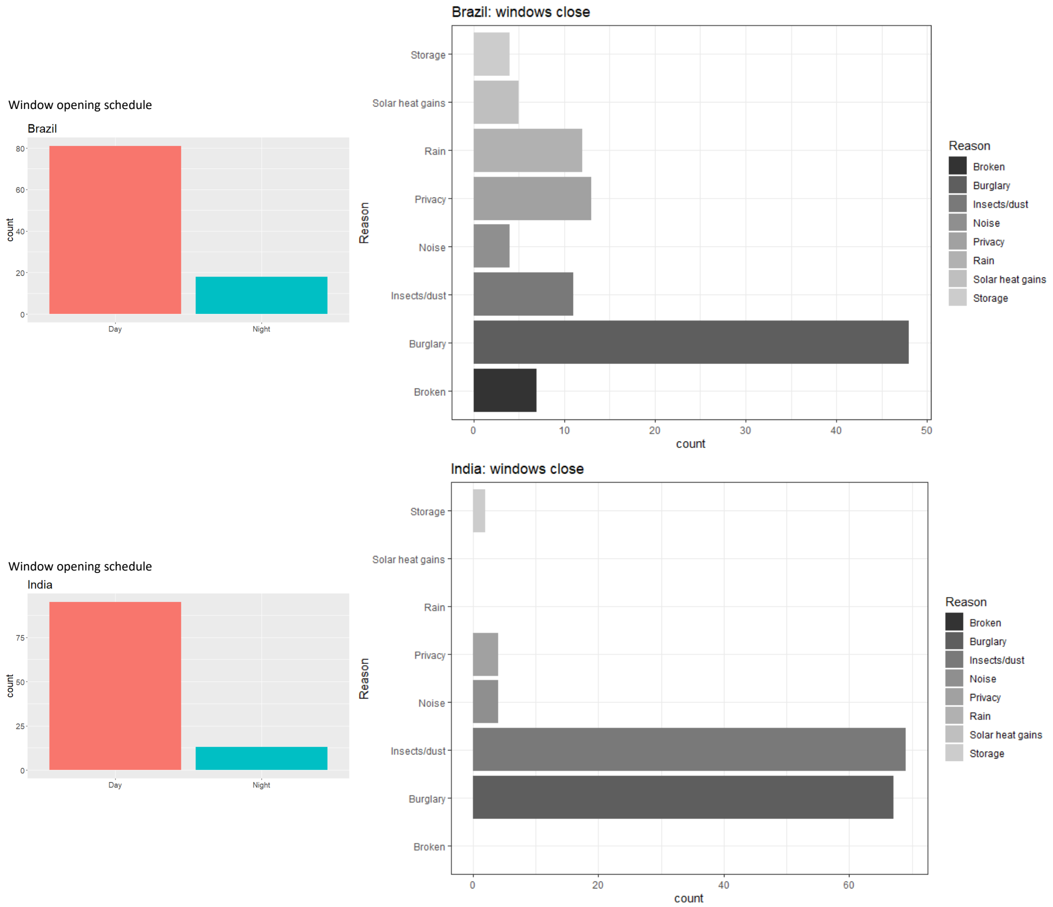

Fig 24 Windows opening and closing schedule in the study areas with the reasons for keeping windows closed at night.

5.5.2 Empirical link between cultural energy services and built environment design elements in the slum rehabilitation housing of Brazil and India

Firth's bias-reduced binary logistic regression results showed the influence of specific appliance ownership for comfort, cleanliness and convenience-based energy services. It was found that in both the study areas, the cleaning regime was manual, therefore the absence of energy-intensive cleaning devices (like a vacuum cleaner, see Fig 20). Table 11 and Table 12 shows the influence of socio-architectural variables in demand for comfort (Model 1) and convenience (Model 3) appliances in the slum rehabilitation housing (SRH) of Mumbai, India. In section 5.5.1, in Fig 20, fans were the most common comfort device (97% ownership) in the SRH, Mumbai. High ownership of fans led to a quasi-complete separation problem (Puhr *et al.*, 2017); hence, convergence failure of Model 1 with fans as the comfort devices. However, as illustrated in Table 11, rising air conditioner (AC) ownership showed a significant association with lack of privacy in the study area. It can be inferred that there is a higher likelihood of AC – ownership (O.R. = 14.939) in the SRH, Mumbai, due to discomfort due to lack of privacy. Similar results were reported by (Debnath, Bardhan and Sunikka-Blank, 2019a) as well.

The lack of privacy remains a socio-architectural design gap in the surveyed SRH of Natwar Parekh Complex (also reported in (M. Sunikka-Blank, Bardhan and Haque, 2019)). It was also mentioned in section 5.5.1., Fig 24 that one of the main reasons for keeping windows closed at night is lack of privacy. It had broader implications on energy demand for comfort as at night because household density increases as all the members stay inside. Closed windows and high occupant density (~ 0.25 person/m^2) increase the indoor temperature, and it can explain the rise in the need for energy-intensive cooling demand through AC ownership. Debnath et al., (2019) reported such a change in energy intensity causes high energy bills, which creates a poverty trap (Aklin *et al.*, 2018) for the occupants living in SRH.

Table 11 Firth's bias-reduced regression results for significant energy service demand for comfort in Mumbai, India.

Lack of socio-architectural elements	Model 1 (Dependent variable: appliance ownership; yes = 1, no = 0)		
	Air conditioners		
	β	Sig.	Exp (β)
Privacy	**2.704**	**0.047***	**14.939**
Safety	1.359	0.312	3.892
Open space/ventilated space access during night	-2.092	0.257	0.123
Walkability during day	1.066	0.499	2.903
Walkability during night	-0.110	0.954	0.895
Penalised log likelihood	-11.865		

*$p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Similar significant results were obtained for convenience related energy demand through the ownership of refrigerator and clothing irons in the Mumbai case study (see Table 12). It can be observed in Table 12 that refrigerator ownership has a higher likelihood (O.R. = 5.201) with a lack of walkability in the daytime. It can be associated with the persistent problems of lack of open and social spaces in the study area. Demand for such convenience-based energy service can be a counter-response to social distress. Such inference remains right to higher clothing iron ownership and lack of walkability at night as well (see Table 12). Comparable results were also reported (Debnath, Bardhan and Sunikka-Blank, 2019a; Kshetrimayum, Bardhan and Kubota, 2020b). These findings, thus, support our hypothesis that the lack of socio-architectural elements in the SRH influences the demand for cultural energy services.

Table 12 Firth's bias-reduced regression results for significant energy service demand for convenience in Mumbai, India

Lack of socio-architectural elements	Model 3 (Dependent variable: appliance ownership; yes = 1, no = 0)					
	Refrigerator			Clothing iron		
	β	Sig.	Exp (β)	β	Sig.	Exp (β)
Privacy	-0.895	0.358	0.408	-2.320	0.080	0.098
Safety	-0.659	0.142	0.517	0.460	0.325	1.584
Open space/ventilated space access during night	-0.857	0.381	0.424	0.515	0.600	1.673
Walkability during day	**1.649**	**0.049***	**5.201**	0.918	0.267	2.504
Walkability during night	-0.488	0.563	0.613	**-2.245**	**0.009****	**0.105**
Penalised log likelihood	-19.069			-15.998		

*$p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

In the SRH of João Pessoa, Brazil, the appliance ownership was observed twice as that of the SRH in Mumbai (see Fig 20). Therefore, regression results showed a significant influence of fan ownership in the energy service demand for comfort (see Table 13). Results showed that the daytime's lack of walkability influences a higher likelihood of multiple fan ownership (O.R. = 5.414). The Survey showed that Gadanho and Timbo Social Housing (GTSH) built environment in João Pessoa, Brazil was relatively better than SRH in Mumbai in terms of open-space and walkability planning (see section 5.4). However, it lacked appropriate socio-architectural design compatibility as per GTSH occupants (Simoes and Leder, 2018). Similarly, comfort-specific energy demand was also observed through the higher likelihood of water cooler ownership (O.R. = 18.690) due to lack of walkability at night. Thus, provisioning walkability in GTSH can aid in mitigating loss of comfort in the built environment.

Table 8 illustrates the regression results of convenience-driven energy services through higher ownership of microwave ovens, washing machines and ovens. A lower likelihood of microwave oven ownership (O.R. = 0.276) is influenced by poor safety in the GTSH. It is further explained by the negative β-coefficient associated with the 'lack of safety' socio-architectural variable (see Table 13). High burglary rates were a substantial built environment problem in GTSH, as revealed in our surveys (see Fig 24). Similar, the higher likelihood of washing machine ownership (O.R. = 1.373) is influenced by the lack of open and well-ventilated spaces (see Table 13). It indicates the shift in communal washing and drying practices to a more energy-intensive washing regime due to a lack of socio-architectural spaces. Besides, the lack of walkability and small spaces causes inconvenience. In turn, it influences higher radio ownership in GTSH as a counter-response (see Table 13).

Table 13 Firth's bias-reduced regression results for significant energy service demand for comfort in João Pessoa, Brazil

Lack of socio-architectural elements	Model 1 (Dependent variable: appliance ownership; yes = 1, no = 0)					
	Fan (more than 1)			Water cooler		
	β	Sig.	Exp (β)	β	Sig.	Exp (β)
Privacy	0.274	0.661	1.315	1.240	0.154	3.455
Safety	-0.513	0.237	0.598	-1.063	0.231	0.345
Open space/ventilated space access during night	-0.593	0.179	0.552	-1.793	0.133	0.166
Walkability during day	**1.689**	**0.046***	**5.414**	-0.888	0.491	0.411
Walkability during night	-1.284	0.199	0.276	**2.928**	**0.036***	**18.690**
Penalised log likelihood	-29.204			- 17.683		

p* < 0.05; ** *p* < 0.01; * *p* < 0.001

Table 14 Firth's bias-reduced regression results for significant energy service demand for convenience in João Pessoa, Brazil

Lack of socio-architectural elements	Model 3 (Dependent variable: appliance ownership; yes = 1, no = 0)								
	Microwave ovens			Washing Machines			Radio		
	β	Sig.	Exp (β)	β	Sig.	Exp (β)	β	Sig.	Exp (β)
Privacy	-0.763	0.292	0.466	-0.389	0.531	0.677	-1.914	0.138	0.147
Safety	**-1.284**	**0.01***	**0.276**	-0.257	0.554	0.773	-2.148	0.106	2.166
Open space/ventilated space access during night	-0.676	0.179	0.508	**0.317**	**0.047***	**1.373**	0.935	0.537	2.54
Walkability during day	1.091	0.420	2.986	0.797	0.201	2.21	**-5.324**	**0.025***	**0.004**
Walkability during night	-1.056	0.443	0.347	0.421	0.359	1.523	**1.325**	**0.031***	**3.758**
Penalised log likelihood	-19.069			-29.287			-8.709		

*$p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Therefore, the regression results presented for Mumbai (see Table 11 and Table 12) and João Pessoa (see Table 13 and Table 14) showed significant correlations between specific appliance ownership for 3Cs concerning the lack of socio-architectural variables of slum rehabilitation housing. Understanding such linkages are critical for 'good' energy policymaking (Ozawa *et al.*, 2019), as it adds a robust planning-driven component to distributive justice.

5.6 Chapter conclusion

This study investigated the energy culture in two typologically distinct slum rehabilitation housing (SRH) in India and Brazil. The energy cultures in these areas were classified through the demand for specific appliances contributing to comfort, cleanliness and convenience-driven energy services. The typologically distinct SRH represented the typical layout of such low-income settlements in the Global South's hyper-dense cities. The SRH case study in Mumbai, India, had a high-rise typology. In contrast, the Brazilian SRH case in João Pessoa had a low-rise building layout. The high-rise typology aimed to maximise occupancy and address the housing deficit (Debnath, Bardhan and Sunikka-Blank, 2019a). The low-rise typology aimed at inclusive design (Simoes and Leder, 2018). However, the SRHs understudy in Mumbai and João Pessoa had severe socio-architectural design gaps that affected the occupants' well-being. The effect of socio-architectural incompatibility on demand for comfort, cleanliness and convenience (3Cs) as cultural energy services was examined. It was assumed that provisioning 3Cs in low-income housing and appropriate built environment design variables could foster distributive energy justice.

An empirical model was developed using Firth's binary logistic regression to reduce small-sample bias. The model evaluated the ownership of specific 3C appliances concerning the lack of certain socio-architectural variables. The lack of open spaces and walkability in both the study areas may influence higher demand for comfort and conveniences specific energy services as a rebound response. Therefore, integrating socio-architectural design elements in slum rehabilitation planning can foster distributive energy justice through appropriate 3C provisioning. The key conclusions that can be drawn from this study are:

- Typology of SRH built environment can act as a critical control variable for distributive energy justice planning. It influences the demand for cultural energy services and specific appliance ownership.
- Appropriate socio-architectural design of slum rehabilitation housing can support the local social networks through access to open spaces and well-ventilated areas. These variables are crucial for occupants' demand for comfort, cleanliness and convenience (3Cs) as energy services. Higher demand for 3Cs can foster better eudemonic well-being in low-income urban population (after (Sovacool, 2011)). Thus, translating the welfare effects of 3Cs as distributive justice.
- The empirical model showed that cultural energy services were demanded as a counter-response to the lack of appropriate socio-architectural design variables in the slum rehabilitation housing (SRH) of Mumbai, India and João Pessoa, Brazil. However, the effects were different due to distinct building typologies. The SRH in Mumbai had a high-rise built form that had no provisioning of social and open spaces. Lack of privacy and safety was the main reason behind keeping windows closed for most of the day. It caused higher discomfort, leading to a rise in air conditioner ownership that increased the households' energy intensity. The SRH in Brazil had a low-rise built form with relatively better access to open spaces and walkable areas. However, it could not satisfy the socio-architectural needs of the occupants. The empirical model showed that most convenience appliances were

owned due to this socio-architectural incompatibility. For example, a higher likelihood of washing machine ownership in the study area is linked to poor access to open and ventilated spaces. Such social spaces were used for communal washing and drying regimes, which was lost during slum rehabilitation planning.

- Lack of privacy and safety were common concerns in both the SRH, which showed a higher likelihood of demand for convenience-specific energy services. In Mumbai, it translated into higher AC ownership, thus, unaffordability of energy bills. In Brazil, the lack of such socio-architectural variables translated into a higher likelihood of microwave oven ownership, an energy-intensive convenience device.

This study's policy implications address multiple disciplinary concerns of urban planning, energy sustainability, and poverty alleviation. Distributive energy justice policies for slum households must include the socio-architectural built environmental needs like open spaces, higher privacy gradient, better safety, sanitation and hygiene. It links sustainable energy provisioning in resource-constrained settings with built environment planning for ever-increasing low-income population in rapidly urbanising Global South. Thus, contributing to the contemporary discussions on 'good' energy policy (Ozawa et al., 2019). A built environment inclusive energy planning can aid in better tariff mechanism for the low-income population. Such energy access does not become a poverty trap (Mendoza, 2011). Such design-led interventions can further strengthen the policy impact of slum rehabilitation programs to UN Sustainable Development Goals, correctly SDG – 7 (clean and affordable energy) and SDG – 11 (sustainable societies and communities).

While this study established a bias-reduced empirical model using state-of-the-art small-sample regression techniques. However, the generalisability of the model remains a limitation of this study. The limitation is also due to high heterogeneity in the slum rehabilitation contexts across the Global South due to socio-cultural variations. Understanding the granular details about the socio-cultural logic of energy demand in poverty can aid in better energy provisioning in such low-income communities for fitting the welfare effects of social policies. Thus, contributing to current discussions on distributive energy justice planning. Our future work focuses on improving the preliminary empirical model's robustness and scope by integrating more slum rehabilitation building typologies from the Global South. It will create a database of energy cultures across different socio-architectural contexts of slum rehabilitation housing. It can aid planners and policymakers in evidence-driven decision making.

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CHAPTER 6 Empirical – 3

Deep-narrative analysis framework: methodological development and proof-of-concept

6.1 Chapter summary

Text-based data sources like narratives and stories have become increasingly popular as critical insight generator in energy research and social science. However, their implications in policy application usually remain superficial and fail to fully exploit state-of-the-art resources which the digital era holds for text analysis. This chapter illustrates the potential of deep-narrative analysis in energy policy research using text analysis tools from the cutting-edge computational social sciences domain, notably topic modelling. We argue that a nested application of topic modelling and grounded theory in narrative analysis promises advances in areas where manual-coding driven narrative analysis has traditionally struggled with directionality biases, scaling, systematisation and repeatability. The nested application of the topic model and the grounded theory goes beyond the frequentist approach of narrative analysis and introduces insight generation capabilities based on the probability distribution of words and topics in a text corpus. In this manner, our proposed methodology deconstructs the corpus and enables the analyst to answer research questions based on the text data structure's foundational element. We verify theoretical compatibility through a meta-analysis of a state-of-the-art bibliographic database on energy policy, narratives and computational social science. Furthermore, we establish a proof-of-concept using a narrative-based case study on energy externalities in slum rehabilitation housing in Mumbai, India. We find that the nested application contributes to the literature gap on the need for multidisciplinary methodologies that can systematically include qualitative evidence into policymaking.

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6.2 Introduction: Narrative-driven energy policy research and computational social sciences

The energy policymaking needs in today's world cannot be met alone by the existing quantification methods due to the multi-agent nature of energy justice and its associated challenges (Ozawa *et al.*, 2019). A more precise representation of these deep interdependencies is well-captured by the United Nation's 17 Sustainable Development Goals (SDGs) that provides a bird's eye view of the global policy and technology challenges. An argument often asserted by policymakers and scientists is that, despite 'sound' technology and 'rational' policies, policy implementation yields unexpected results. It is often due to the lack of multidisciplinary insights into the energy policymaking and implementation processes (Ozawa *et al.*, 2019).

The current regime of energy policymaking by scientists and technologists is guided by the promotion of preferred technologies with theoretical properties that complement the leading political forces' objectives. They justify their proposition based on quantitative models of energy and climate systems that graft directional biases in policymaking, often overlooking qualitative stakeholder deliberations' strengths. 'Good' energy policy under a technocratic directional bias, thus becomes policy focussed on 'getting the technology right' (Ozawa *et al.*, 2019). While technology can indeed be a force to achieve climate change mitigation and sustainability goals, its intended welfare effects may be restricted if a society's wants are not appropriately reflected in policy (MacKay, 2008). Non-economic drivers may be crucial in achieving the welfare effects from specific energy and climate policy, and they remain underrepresented in the current literature. So much so that even the work of the Intergovernmental Panel on Climate Change (IPCC) has been characterised as significantly directional and 'unidisciplinary' as it is based on a clear separation between the natural sciences and social sciences, and an understanding that social sciences are based on natural sciences (Vasileiadou, Heimeriks and Petersen, 2011). The problem with such technocratic directionality bias is that it leads to an inherent limitation in defininf policy goals, which become defined as 'reasonable' or 'rational' according to technical parameters.

Purely technical approaches cannot account for the multidimensional nature of the socio-cultural forces that effects policy implementation. Oversimplification of policies through quantitative and frequentist generalisation of contexts remain energy policymaking challenges. Therefore, Ozawa et al., (2019) state that the premise of 'good' energy policy is much more multi-layered, nuanced and non-obvious. Directional bias among policymakers and scientists misses this premise. A multidisciplinary perspective to modern-day energy policymaking requires a deep understanding of historical and social, political and cultural institutions that constitute the people, places and practices. It demands serious inclusion of social science and humanities thinking in energy policy, thereby leading to a much richer set of insights for 'good' energy policy in the 21st Century. However, an inherent problem with the qualitative approaches of social science and humanities for policy applications remains with its application's directionality. It can cause inferential biases that lead to reliability, validity, replicability and generalisability in qualitative research (Trotter, 2012).

A critical and relatively new object of energy and climate change research through the lens of social science and humanities is the use of narratives as a way of crystallising arguments and assumptions (Moezzi, Janda and Rotmann, 2017b). Narratives, stories and storytelling have garnered credible representation in energy and climate change research and policy (Randall, 2009; Janda and Topouzi, 2015; Lertzman, 2015; Moezzi, 2015; Rotmann, Goodchild and Mourik, 2015). However, these narratives' value depends significantly on their interpretation by researchers and practitioners, which can induce biases in the results' interpretability (Moezzi, Janda and Rotmann, 2017b). Some authors claim that such biases make narratives-driven methods ineffectual as compared to science and technology-driven quantitative methods (Bazeley, 2004; Fukuyama and Weber, 2009); though, it is worth bearing in mind that methods based on the 'hard' sciences will also have inbuilt empirical biases, for example in the choice of metrics or indicators. These methods are also likely to miss nuances in using language and lose some of the layered meanings intended by narrators. On the contrary, a human who is fully conversant with the language used can capture the contextual socio-cultural gradations by using robust qualitative methodological tools like narrative analysis using grounded theory.

The primary aim of this paper is to improve the robustness of narrative analysis in public policy research. Here, we focus exclusively on energy policy applications. In doing so, we propose a nested methodological framework based on current state-of-the-art techniques of data collection, qualitative analysis and computational social sciences. The novel nested approach presented here contributes to lessening directional biases in narrative-driven policy analysis. The innovation of this study lies in the nested treatment of two epistemologically parallel but methodologically distinct concepts (Baumer *et al.*, 2017) of topic modelling (TM) and grounded theory (GT). These parallel methods are used as complementary support to each other, which can reduce directional bias in energy policy applications.

By improving the robustness, we want to expand the applicability of text-based tools like narratives, stories and storytelling into evidence-based policymaking disciplines (Pawson, 2002). While a qualitative researcher's experience remains the most critical control variable for narrative-driven analysis, manual coding of texts is highly taxing and is limited by human cognitive abilities. At best, it allows for sensitive and insightful analysis. There is always the likelihood of some directional and researchers' bias in the complex narrative analysis (Bryant and Charmaz, 2019). We enrich the manual-coding processes of narrative analysis by employing artificial intelligence (AI) and machine-learning aided topic detection algorithm, i.e., topic modelling (TM), that can, if well-designed, lessen directionality biases. Recent studies have shown that qualitative researchers, guided by the principles of grounded theory (GT) (Glaser and Strauss, 1967; Strauss and Corbin, 1997), have incorporated a combination of manual-coding methodologies like open coding, axial coding and selective coding to improve the robustness of their analysis (Bryant and Charmaz, 2019; Williams and Moser, 2019). Our proposed methodology replaces these steps with a probabilistic step of 'word' selection using TM that statistically improves results' robustness. This step lessens directionality bias as TM deconstructs the text-corpus of the narratives into its fundamental constituent (i.e., words/terms) and aids the analyst to reconstruct the narratives through a GT driven-interpretivist approach.

The proposed deep narrative analysis framework does not intend to replace each of these distinct methods. Instead, it shows the synergistic capability of such methods that contributes to the growing literature of computational social sciences and energy policy research. The proposed nested methodology's central function is to deconstruct a text corpus collected as narratives and identify patterns among word-word, word-topic, and topic-topic probabilities in the corpus. It is intended to remove directionality biases to enable an analyst to derive more precise insights from the narratives through grounded theory for policy applications. We establish this claim by investigating its theoretical compatibility using two metrics, epistemological-fit and meta-theoretical fit. The theoretical compatibility assessment was performed through science mapping of relevant literature in the current bibliographical databases. Parallelly, a proof-of-concept was presented through a case study of energy service externalities in poverty in slum rehabilitation housing (SRH) in Mumbai, India. Primary data for the case study was collected through a gendered focus group discussion of high electricity bills in the SRH built environment.

Deconstruction of the raw-narratives into their fundamental elements (words) and then reconstructing them through an interpretivist GT application removes directionality biases. It preserves the cognitive essence of a narrative-analysis. We believe such a nested approach has never been developed or applied to humanities and social science bounded evidence-based energy policy research to the best of our knowledge. Our proposed framework contributes to the growing field of computational social sciences while expanding rigorous qualitative methods like GT-based narrative analysis. In this chapter, I presented the nested approach, its empirical extension is presented in the chapter -7.

6.3 Background

6.3.1 Narrative-analysis in energy policy research

Narratives, stories and storytelling go beyond the analytical convention of energy and climate change research. It helps approach the intersection of nature, humanity, and technology in a multidisciplinary manner, using a lens from social sciences, humanities, and practitioners 'perspectives (Janda and Topouzi, 2015). A special issue of *Energy Research & Social Science* journal, titled 'Narratives and Storytelling in Energy and Climate Change Research' (Moezzi, Janda and Rotmann, 2017a) have established the importance of narrative, stories and storytelling as critical data objects in energy and climate change research. This special issue presented 34 articles that employ stories and storytelling as avenues of gathering new data and understanding, communication, and influencing others. Narrative analysis in the same issue presented novel ways of crystallising arguments and assumptions that generated deeper policy insights (Moezzi, Janda and Rotmann, 2017b).

However, the energy and climate policy research is young, with a few narrative analysis instances in the published literature. Bushell *et al.*, (2017) proposed multiple narrative designs to promote action on climate change and the development of strategic-narratives to engage multiple stakeholders better. Hermwille, (2016) advanced the role of narratives in the crystallisation and structuring arguments in socio-technical energy policy discourse by citing examples from Fukushima and energy regimes of Japan, Germany and the United Kingdom. In doing so, the author captured the policy responses from multiple perspectives. It is one of the rare application of narratives to generate socio-technical policy responses. However, as mentioned in section 1, such application is limited by the researcher's directionality and interpretability, which can subconsciously induce biases.. Hermwille, (2016), in his concluding remark, stated that there is a need for explorative methodologies that can unveil new mechanisms of people, places and practices. Structured Dialogic Design Processes (SDDP) is another methodology that wishes to address some of the explicit normative biases of narrative-based analysis by using web-based communication platforms, thus leveraging information and communication technologies (ICT) (Laouris *et al.*, 2009). However, SDDP uses observer-dependent data and entirely depends on engaging stakeholders as "expert observers" of their embedded situation. While it remains a strength of this method, this methodology's reliability depends on the expert observers' ability to take action in their situation (Bausch, 2008). It may lead to directional biases in its generalised interpretation. A methodological advancement to a similar discourse-analysis through topic modelling was proposed by Jacobs & Tschötschel (Jacobs and Tschötschel, 2019), which provides a critical epistemological background for this study.

Methodologically there has not been much development in the use and treatment of narratives in energy and climate change research. Most developments were in the mode of data collection using narratives. For example, (Shaw and Corner, 2017) developed a narrative workshop methodology to engage the public in climate change policies. Their innovation lied in the data collection and narrative generation regimes that enabled the public to validate their values and identity. However, the results embedded directionality biases based on the interpretation of the researchers. Smith et. al., (Smith *et al.*, 2017) used the concept of 'energy utopias' to create experimental stories and generated narratives to refresh public and political conversations about energy and decarbonisation. They found that stories and narratives by themselves do not drive transformation, but they provide confidence in decision-making and public participation.

Similarly, (Howarth, 2017) found that narratives and stories could increase experiential engagement on climate change. Stories and narratives on policy could fill in the information deficit in the present techno-economic models. Our observations from these state-of-the-art articles were that the narratives and stories provided excellent multi-stakeholder engagement platforms, but they offered a piecemeal solution to the problem. The methods discussed above have their basis in grounded theory (GT), as each aims to derive a situational-theory based on the narrative-analysis. Thus, we used GT as a foundational component of the nested-model to retain the interpretive effectiveness of narrative-analysis in a computational environment.

Our proposed nested model is based on a probability distribution that provides a higher degree of freedom to zoom-in, zoom-out and zoom-through the problem. With zooming-out, possibilities and assumptions that are forgotten or taken for granted can be better recognised; zooming-in aids better understanding of the granularity hidden in the frequentist summaries of central tendencies granularities hidden in often-repeated statements. Most importantly, zoom-through in a computational model can aid in critically analysing narratives as to material reality, norms and practices that determine the energy culture. These three functions cumulatively illustrate our claim of a 'deep-narrative' analysis using unsupervised machine learning techniques.

6.3.2 Topic modelling in humanities and social science research

Computational text analysis is an emerging critical methodology social science and humanities, representing a part of the state-of-the-art in computational social sciences. It centres around probabilistic topic modelling that distributes vocabulary over probability distribution. The high probability words in each distribution can be readily interpreted as recognisable themes and are thus referred to as "topics" (Grimmer and Stewart, 2013; Jockers, 2013; Baumer *et al.*, 2017). There are many topic modelling methods, of which Latent Dirichlet Allocation (LDA) is a widely used method.

LDA is an advanced textual analysis technique grounded in computational linguistics research that calculates the statistical correlations among words in a large set of documents to identify and quantify the underlying (latent) topics in these documents. In linguistic science, (Vulić, De Smet and Moens, 2011) have used LDA to identify the translation of words among languages. (Bauer *et al.*, 2012) have used topic modelling to analyse millions of textual comments of geographical and temporal check-ins to understand behavioural pattern at a global scale. (Lui, Lau and Baldwin, 2014) have used the LDA variant to detect multilingual documents.

Similarly, topic modelling has garnered significant importance in political science and rhetoric analysis (Grimmer and Stewart, 2013). (Balasubramanyan *et al.*, 2012) have used an LDA-based topic modelling approach to investigate reactions of different political communities to the same news. Song, Kim, & Jeong, (Song, Kim and Jeong, 2014) have used topic modelling on the Twitter dataset to analyse 2012 Korean Presidential Election's socio-political landscape. In (Chen *et al.*, 2010), the authors have used an LDA model to reduce the size of auto-discovered latent opinions, words and topics in political standpoints between Republicans and Democrats in the US. German National Elections since 1990 was analysed using an extension of LDA (LogicLDA and Labeled LDA) that explored the multi-dimensionality of political documents, pushing the limits of content analysis in the social sciences (Zirn and Stuckenschmidt, 2014). A detailed explanation of topic modelling choices for political content analysis can be found (Grimmer and Stewart, 2013).

Yano, Cohen, & Smith (Yano, Cohen and Smith, 2009) have used topic modelling using a geographic LDA (LGTA, Latent Geographical Topic Analysis) to extract geographical information in online political blogs. A multi-scalar LDA model was used by Tang et al., (Tang *et al.*, 2013) to cluster very high-resolution panchromatic satellite images. More recently, LDA was used as a means of data-driven geotopic detection of urban emergencies for natural hazards, himan-made disasters and other emergencies (Wang and Taylor, 2019). Topic modelling is now being used to map consumer sentiments and understand their behavioural choices on a geographical scale to enhance business potential (Qi *et al.*, 2019; Toubia *et al.*, 2019). Critical environmental and social problems are now being identified using twitter-based geo-topics that provide rich knowledge of significant events (e.g., cultural activities, political campaigns, accidents, crisis) at an urban scale. (Yao and Wang, 2019) have used a dynamic topic modelling approach to identify urban crisis in US cities that had crucial implications in sustainable city planning and policymaking.

Although the success of LDA-based topic modelling applications in sociology, history, political science and linguistics, topic models are known to suffer from some conceptual and practical problems, like a lack of justification of Bayesian priors, divergences with statistical characteristics of original texts and the imprecision in choosing the relevant number of topics (Gerlach, Peixoto and Altmann, 2018). These causes ontological and empirical biases. Recent efforts in solving these problems refer to the cross-fertilization between multiple fields through mixed-method or multi-method interdisciplinary approaches (Gerlach, Peixoto and Altmann, 2018). (Baumer *et al.*, 2017) compared the grounded theoretic approach with topic modelling to compare interpretive social sciences (grounded theory) with statistical machine learning (topic modelling). Their results have shown that the two analyses produce similar results with field-specific drawbacks. However, their comparison suggested that the novelty of using these techniques lies in a compelling combination of such methods as a complementary entity rather than a 'replacement' of one method. In this study, we do not intend to compare all the available topic models (see (Grimmer and Stewart, 2013) for such comparative study), neither contribute to the development of such computational models. Here, we derive humanities and social scienceoriented application framework for deep-narrative analysis using the topic modelling technique.

There are a handful of studies on the application of topic modelling in energy research. For example, (Jiang, Qiang and Lin, 2016) applied topic modelling on a bibliometric dataset on hydropower research. They established 29 topics that described hydropower research's intellectual architecture and found that an interdisciplinary lens in hydropower research is needed for higher-level policy benefits. The authors also established that the topic modelling approach in energy research could provide a new outlook to evidence-based policymaking. More recently, Walker, Chandra, Zhang, & van Witteloostuijn (Walker *et al.*, 2019) have verified the critical importance of topic modelling-based approaches in deriving evidence for policy design and policymaking in public administration.

6.4 The proposed nested deep-narrative analysis framework

The proposed nested deep-narrative analysis methodology proposed is illustrated in Fig 25. The framework has three core parts that work in synergy with each other. The nested methodological arrangement efficiently extracts the mutual benefits of topic modelling (TM) and grounded theory (GT). We claim that the introduction of topic modelling in the narrative analysis will improve the robustness of the findings for policy application and reduce the inherent directionality bias. We refer to directionality bias as the consciously or sub-consciously induced biases in the interpretation of narrative-driven research that alter the objective meaning of the findings. These assumptions are coherent with the arguments of Trotter (Trotter, 2012) and Bryant & Charmaz (Bryant and Charmaz, 2019). Moreover, from an applied public policy perspective, Walker et. al., (Walker *et al.*, 2019) have argued the need for objective and robust qualitative approaches in evidence-based policymaking. They also point out that the current qualitative methods have a strong directionality quotient (referred to as 'hegemonic interpretation', pp 475, (Bryant and Charmaz, 2019)) sensitive to the interpretability-bias of the researcher, analyst or policymaker.

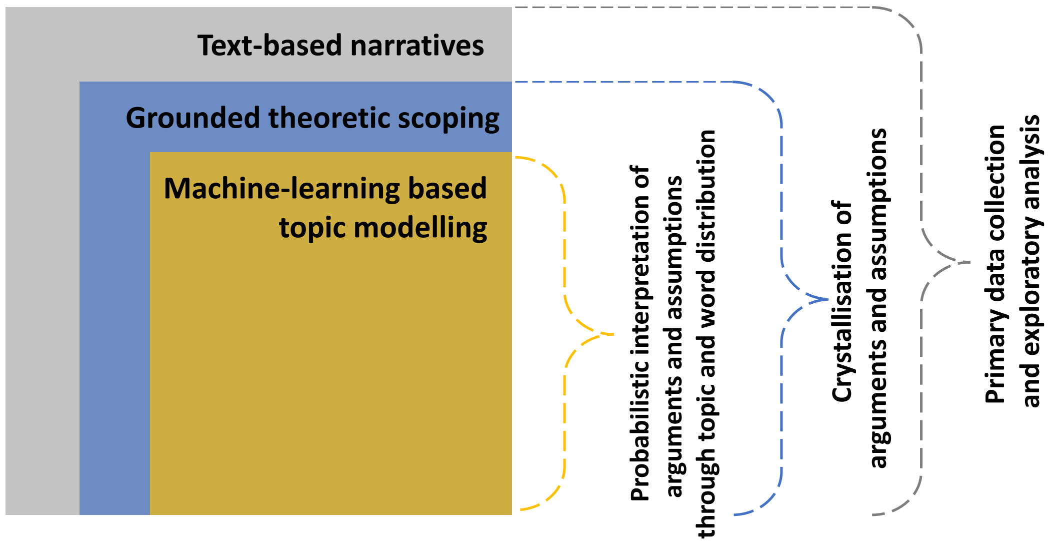


Fig 25. Proposed nested deep-narrative analysis methodological framework based on computational social science and narrative-analysis

Our proposed methodology aims to address this limitation by improving narrative analysis's objectiveness through a nested application of unsupervised machine-learning-driven TM while preserving the insight generating capability of narrative by using GT (see Fig 1). The nested approach proposed here provides a remarkable methodological polyvalence to topic modelling and the grounded theory. It is further discussed with bibliometric evidence in section 5.1 while establishing the epistemology-fit and the meta-theoretical fit. Topic Modelling (TM) represents the topic detection and clustering algorithms based on natural language processing and computational linguistics theories. The Grounded Theory (GT) represents a systematic methodology that conceptualises the latent social patterns and relationships for understanding observed social processes within a specific setting (Noble and Mitchell, 2016).

GT is a structured yet flexible methodology that is often used to discover systemic information about a little known phenomenon (Glaser and Strauss, 1967; Chun Tie, Birks and Francis, 2019). It can produce or construct an explanatory theory that uncovers the latent process inherent to the area of inquiry (Glaser and Strauss, 1967). It aims to generate a theory grounded in the data (Chun Tie, Birks and Francis, 2019), and the nested application of TM can add robustness to this process. The current epistemology associated with GT has three distinct methodological genres. The classic GT generates a conceptual theory that accounts for a relevant and problematic pattern for those involved. The constructivist GT constructs meaning about the area of inquiry. Moreover, symbolic interactionism is a sociological perspective that relies on the symbolic (subjective) meaning people attribute to social interaction processes (Chun Tie, Birks and Francis, 2019). We employ the symbolic interactionism of GT in the proposed framework (see Fig 25).

GT is also referred to as a process by which theory is generated from data analysis by the researcher who views the world through their particular lens (Chun Tie, Birks and Francis, 2019). However, its rigour depends on the quality of manual coding of the raw data and the presence of directionality biases in the narrative-collection. We overcome these limitations by the nested application of TM and GT through a deconstructivist approach of breaking down narrative corpus into its fundamental word constituents. The words are then clustered through probability distribution functions (steps of TM) used in an interpretivist manner through the lens of GT. In doing so, TM clusters high probable words from a text corpus of narratives, GT aids the analyst in crystallising arguments and insights that statistically inform evidence-based energy policymaking. However, we clarify that TM should be constructed with specific objectives in mind rather than statistical optimisation. On the other hand, GT aids in zooming-through the topics and the narratives and discover insights based on the probability distribution of the topics.

6.5 Methodology

This section illustrates the methodological framework of this study used to establish a theoretical validity and generate a proof-of-concept of the proposed deep-narrative analysis framework, as discussed in Section 6.4. The methodological framework of this study consisted of two core parts (see Fig 26). In the first part, a meta-analysis of published literature was performed to establish the proposed framework's theoretical validity. The theoretical compatibility was established by expanding two metrics; epistemological fit and meta-theoretical fit (see Fig 26). In the second part, a proof-of-concept of the proposed framework was derived using a case study. In the case study, externalities associated with demand for energy services in poverty were examined through occupants' narratives of living in slum rehabilitation housing in Mumbai, India.

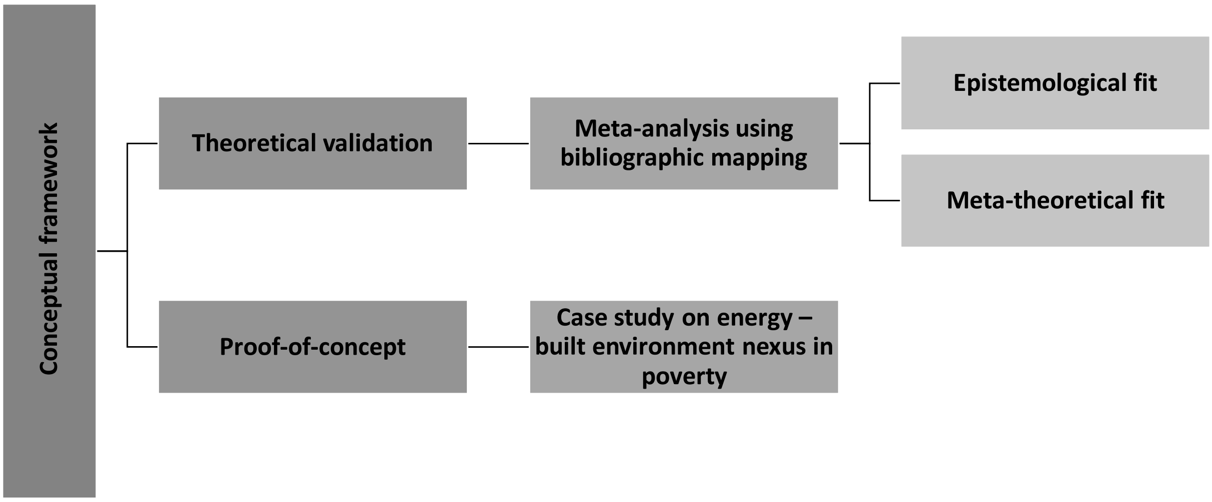


Fig 26 Methodological framework of this chapter.

6.5.1 Meta-analysis for theoretical compatibility validation

A meta-analysis for theoretical validation of the deep-narrative analysis framework was performed based on science mapping principles (Chen, Dubin and Schultz, 2014). Science mapping is used to represent the body of scientific literature in a tangible form to handle it more effectively (Chen, Dubin and Schultz, 2014). It is used to visualise the scientific landscape at different levels of granularity, i.e. the connection between keywords co-occurrences, conceptual relations between groups of articles, similarities between authors, and connections among larger scholarly organisations such as journals and institutions (Chen, Dubin and Schultz, 2014; Aria and Cuccurullo, 2017).

Using science mapping, we performed a bibliometric network analysis to identify the conceptual structure of narrative-based energy policy research and computational social science-based topic modelling in the current literature. The conceptual structure maps are used to understand the research landscape and identify the most important and most recent issues. A general science mapping workflow was adopted as per the methodological guidelines of (Aria and Cuccurullo, 2017), including bibliographic database extraction (Web of Science or Scopus), analysis using network theory and data visualisation. The network analysis results were used to generate evidence from current literature on the theoretical compatibility of nested application of topic modelling (TM) and narrative analysis using grounded theory (GT) in energy policy research, as per the proposed conceptual framework in Fig 25.

We followed two-argument lines evaluate TM and narrative analysis (using GT) for energy policy applications (see Fig 26). A meta-theoretical level fit was evaluated to examine congruency between the under-lying conceptual assumptions between TM and narrative analysis. Conceptual structure maps were derived using data reduction technique like multiple correspondence analysis (MCA) and factor analysis. The conceptual structure maps examined the research front of topic modelling and narrative analysis by using the documents' actual content to construct a similarity measure (Aria and Cuccurullo, 2017).

At an epistemological level, we argue that the methodological idea behind the nested application of topic modelling and grounded theory fits the analytical process of crystallising arguments and assumptions using narrative analysis. This epistemological fit aided in understanding how topic models generate knowledge about the texts and the words in the corpus for fulling the objectives of 'deep-narrative' analysis. A similar line of argument was used by Jacobs and Tschotschel (Jacobs and Tschötschel, 2019) for theoretical compatibility validation of their combined application of topic modelling and discourse analysis in qualitative research.

The Web of Science (WoS) bibliometric database was used as the primary data source for the science mapping. A complete bibliometric extraction was conducted that included 'title', 'abstract', 'keywords' and 'journal keywords (keyword plus)', used for the factor analysis. The WoS database showed 311 published documents between 2000 – 2019 on the topics 'energy policy' and 'narratives', referred to as 'keyword set A'. Similarly, 94 papers were found between 2000 – 2019 on the topics 'computational social sciences' and 'topic modelling', referred to as 'keyword set B' (see Fig 27). The factor analysis was performed using *FactorMineR* (Husson *et al.*, 2020) and *factoextra* (Kassambara and Mundt, 2020) libraries in R. And the data visualisations were performed using the *ggplot2* (Wickham, 2016) and *igraph* (Csardi and Nepusz, 2006a) R-libraries.

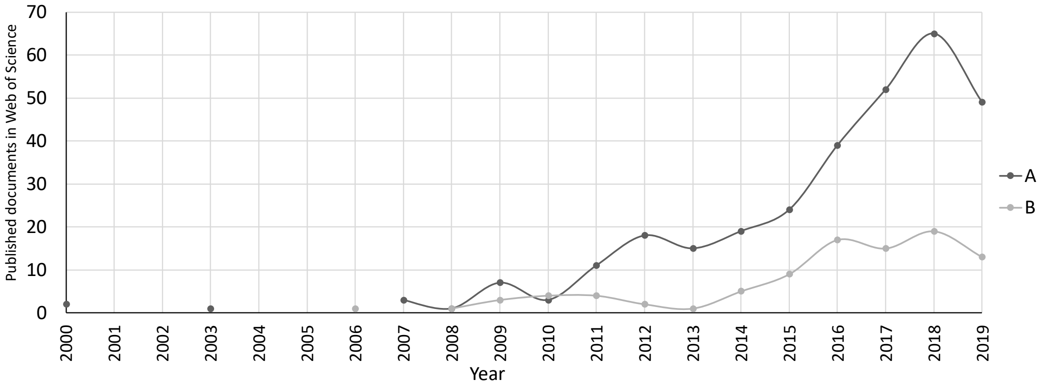


Fig 27. Published documents in Web of Science (WoS) database for the searched keyword set A: 'energy policy' & 'narratives' (n = 311); and keyword set B: 'computational social science' & 'topic modelling' (n = 94) between 2000 - 2019.

While science mapping represented the data-driven method of establishing the theoretical fit between GT and TM. A detailed rationale on the methodological polyvalence of GT and TM was also established based on the properties and complementarity of both methods.

6.5.2 Case study: Deep-narrative analysis for examining externalities associated with energy services in slum rehabilitation housing in Mumbai, India

We present a case study on the application of deep-narrative analysis on understanding energy externalities in poverty. Slum rehabilitation housing (SRH) in Mumbai, India, was chosen as the study area, where rising electricity bills are a significant concern (Debnath, Bardhan and Sunikka-Blank, 2019a, 2019b). SRH is a slum rehabilitation strategy in India where slum dwellers are rehabilitated to permanent government-sponsored housing. It is a part of the Government of India's poverty alleviation efforts (Ronita Bardhan *et al.*, 2015). The SRH understudy demographics lie in extreme low-income category with informal employment as the primary occupation (Nijman, 2015).

From an energy policy perspective, recent studies have shown that the households living in the SRH are pushed into energy poverty as occupants are unable to pay high electricity bills (Debnath, Bardhan and Sunikka-Blank, 2019a, 2019b). It was reported that the households are often billed up to 40% of their monthly income, which remain significant distress in the SRH under study (Debnath, Bardhan and Sunikka-Blank, 2019a). The reasons behind rising electricity bills in the SRH are still not clear. However, the literature showed that a shift in energy practices due to a change in their built environment could be a significant factor (Debnath, Bardhan and Sunikka-Blank, 2019b). The energy practices were shifted because slum dwellers were moved from horizontal slums to a high-rise vertical built form (the SRH) that changed their social organisation (Debnath, Bardhan and Sunikka-Blank, 2019b). The change of this social organisation is linked to the rise in energy intensity of the households. Besides, the occupants' aspiration in owning specific appliances in their 'permanent' house further illustrated an increase in energy intensity (Debnath, Bardhan and Sunikka-Blank, 2019b; M. Sunikka-Blank, Bardhan and Haque, 2019). The aspirations motivated by the change of built environment redefined occupants' demand for comfort and convenience as cultural energy services (R. Debnath *et al.*, 2020). Therefore, we hypothesised that external characteristics associated with the built environment influence more significant electricity usage in households, resulting in higher electricity bills.

To investigate this hypothesis, we conducted a focussed group discussion (FGD) with the female household members of the SRH to understand the injustices associated with the current SRH built environment that may have energy poverty implications. Female occupants were specifically chosen because it is common for women to stay at home while men work in the SRH community (M. Sunikka-Blank, Bardhan and Haque, 2019). Thus, it was assumed that they interact the most with the built environment as they spend the highest amount of time in the SRH. The female members often organise themselves in self-help groups for built environment maintenance and income-generating activities (Debnath, Bardhan and Sunikka-Blank, 2019a; M. Sunikka-Blank, Bardhan and Haque, 2019).

The FGD was conducted as per the best practice guidelines of (Gill *et al.*, 2008). Informal interviews were conducted to extract information on the energy poverty externalities in poverty in the SRH built environment (see Table 15). The FGD participants were recruited by us asking a local contact who had previously worked with us. The local contacted acted as the FGD moderator. We asked the moderator to bring along some of her friends to the FGD. This method was employed so that a familiar trust was built during the interview process. A total of 11 participants (P1 to P11) joined the interview that lasted for an hour. The participants' primary occupation was 'housewife'; however, they all were members of a self-help group called 'Mahila Milan'. Out of 11 participants, seven were middle school dropouts, while four never attended formal schooling. All participants of the FG spoke the same mother tongue, 'Hindi'. The FG moderator was proficient in bilingual translation, who transcribed the interview from Hindi – English. Verbal consent was obtained from each participant before the start of FGD.

Table 15 FGD points to explore energy-built environment nexus in slum rehabilitation housing in Mumbai, India

Energy services	Appliance ownership
	Access to information and communication technology (ICT) devices
	Devices for comfort, cleanliness and convenience
	Cooking energy (clean fuel or firewood)
Built environment services	Access to natural ventilation and its constraints
	Window opening and closing schedule
	Indoor air quality and thermal comfort perception
	Access to open spaces and playgrounds for kids
	Quality of life as compared to horizontal slums
Energy Economics	Energy bills and the possible causes of high energy bills
	Distresses concerning higher energy bills
	Availability of subsidy and appliance repair services

6.5.3 Processing the transcript of the focussed group discussion for deep narrative analysis

Based on the proposed nested framework in Section 6.4, the focussed group discussion (FGD) transcript was processed in the following stages. The first stage was preparing the textual transcript as a primary data object or corpus for topic modelling. The text transcript had a word/term count of about 9,000 words that formed the primary data corpus for topic modelling. It was a pre-processing stage where the transcript was cleaned by removing all the stop words (e.g., articles, such as "a," "an," and "the," and prepositions, such as "of," "by," and "from"), numbers, and punctuation characters and converted the text to lowercase in the corpora. This process is called lemmatisation (Manning, Raghavan and Schutze, 2009). This process also converts the word's grammatical form into the base or dictionary form (known as Lemma) (Manning, Raghavan and Schutze, 2009).

The second stage involved performing topic modelling using the Latent Dirichlet Allocation (LDA) algorithm (see Section 6.3.2 for more information on LDA applications). The transcript's lemmatised corpora were converted into a document-term-matrix (DTM) using the *tidytext* package (Robinson and Silge, 2019) in R programming language. The DTM was further calibrated as per the *tidydata* rules (see chapter 1, (Silge and Robinson, 2017)). We iteratively defined the number of topics based on our judgement and the *ldatuning* package in R (Moor, 2019). A similar approach in topic model determination was also adopted by (Li *et al.*, 2019; Walker *et al.*, 2019). Finally, we used the R-package *topicmodels* to fit the LDA model (Grün and Hornik, 2011).

The mathematical foundation for the LDA was adopted from Blei, Ng and Jordan (Blei, Ng and Jordan, 2003), see eq. (1).

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

An LDA-driven TM is an unsupervised machine learning (ML) technique with three hyperparameters ('α', 'β' and 'γ') to control document and topic similarities. Alpha (α) and beta (β) are crucial in assigning word and topic distribution over the corpus document (see eq. 1). Each sentence in the text corpus of ~9000 words was treated as a unique document using the DTM format.

A total of 311 documents were created in the DTM. It is a widely-used methodology for TM, and the cross-validation measures determine its reliability (Nikolenko, Koltcov and Koltsova, 2017; Jelodar *et al.*, 2019; Li *et al.*, 2019; Toubia *et al.*, 2019). The third hyperparameter, gamma (γ), which controls the number of topics the algorithm will detect, has to be set while implementing LDA. Gamma (γ) is crucial for TM since LDA cannot decide on the number of topics by itself (see, no γ in eq. 1). It is the most distinctive feature behind unsupervised TM versus supervised text classification techniques commonly used in qualitative data analysis tools (like NVivo, ATLAS.ti, MAXQDA, etcetera). TM's unsupervised nature reduces the directionality bias that may get embedded in supervised text classification (as discussed in Section 1). In this study, we determined the appropriate number of topics using the *ldatuning* algorithm, as mentioned above.

The third step included visualisation using the *ggplot2* package in R (Wickham, 2016). Based on the high probability words discovered through the topic models, these words are further expanded using grounded theory to support the narratives on externalities associated with the built environment - energy service nexus in slum rehabilitation housing. Thus, in this manner, we provided a proof-of-concept of deep narrative analysis using the nested application of topic modelling and narrative analysis using grounded theory.

6.5.4 Performing the nested deep-narrative analysis

The four-step process flow for the nested deep-narrative analysis is illustrated in Fig 28. The results from topic modelling (TM) was used as the starting point for the deep-narrative analysis. The discovered topic and word clusters from TM established the probabilistic (β) background for investigating the narratives (see step – 1, Fig 28). The high β values of the words in each of the topics were contextualised with the original narrative text. This contextualisation was done using a grounded-theoretic (GT) approach, such that high-β words acted as a surrogate for the 'open' and 'selective' coding process of GT-based research (Chun Tie, Birks and Francis, 2019). The contextualisation step intrinsically also linked the latent factors in the narrative data to enable an in-depth understanding of the built environment – energy nexus in poverty in the slum rehabilitation housing in Mumbai. Thus, step-2 (see Fig 28) generated our own probabilistic 'code system' based on the narrative texts.

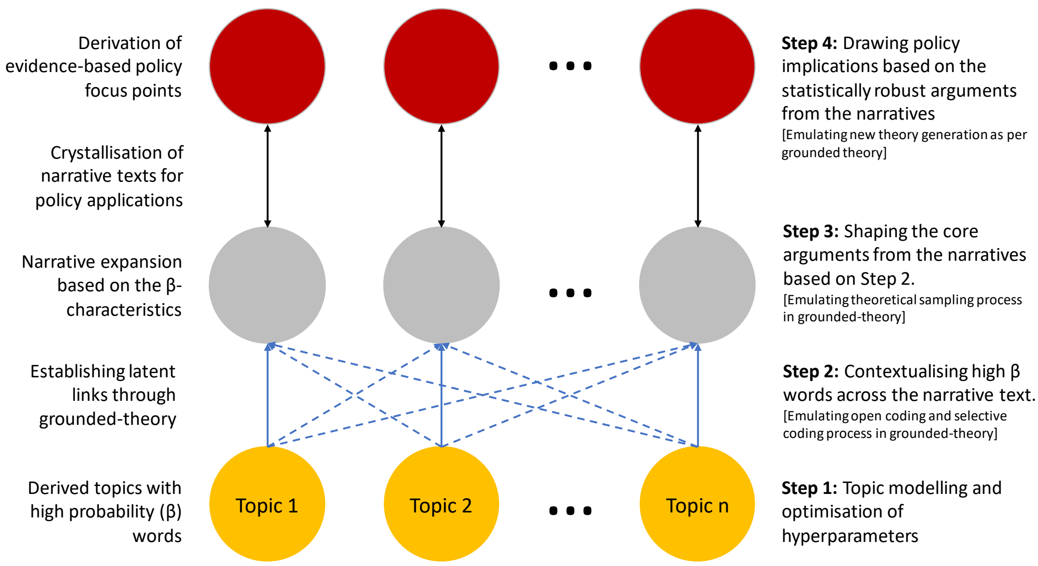


Fig 28 The deep-narrative analysis process

However, unlike qualitative data analysis, this code system has an unsupervised probabilistic background. It added statistical signification to it, but the unsupervised nature of TM also eliminated the directional biases. The code system was now used to perform 'theoretical sampling' as per GT (see step 3, Fig 28). The theoretical sampling, now supported by β-values, was used to develop the emerging theory and elaborate on the narratives' main categories (see step 4). In this study, the derived grounded-theories were used to derive grounded-policy focus points. These focus points are independent of directionality bias and have a degree of certainty due to their statistical foundation.

6.6 Results and discussion

6.6.1 Theoretical validation of the proposed deep-narrative analysis framework

The common words in the keyword set A ('energy policy' & 'narrative') and B ('computational social science' & 'topic modelling') are illustrated in Fig 29. It further shows science mapping-based experimental evidence of topic modelling policy applications through public opinion and discourse analysis (see Fig 29a). It further shows science mapping-based exploratory evidence of the policy applications of topic modelling through public opinion and discourse analysis (see Fig 29b).

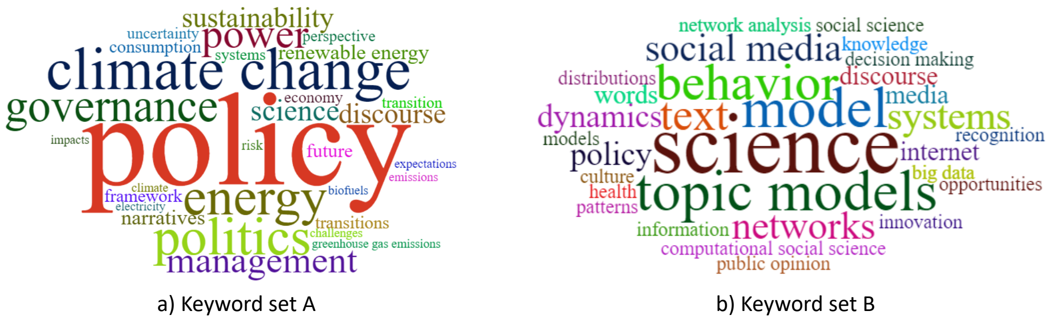


Fig 29 Word-clouds illustrating high frequency words in the WoS database for search keyword set A: energy policy and narrative (n = 311), and search keyword set B: computational social science and topic modelling (n = 94)

Meta-theoretical fit of the proposed framework

The meta-theoretical fit was used as a line of argument for evaluating the theoretical compatibility of the nested application of topic modelling (TM) and grounded theory (GT) for narrative analysis (see Fig 26). We termed this nested application as 'deep narrative analysis' (see Section 6.4 and Fig 25). The meta-theoretical fit parameter was used to examine how an analyst can subjectively and reflexively interpret the derived topic models as foundational elements for deep-narrative analysis. The analyst's task is to interpret the meaning of a topic based on how it ranks terms and how it relates to other topics. Thus, from a meta-theoretical fit assessment, our proposed nested application should retain the 'crystallising' capability of narrative analysis for arguments and assumptions in a document.

In TMs, a word's meaning are topic-specific and based on the other words that appear in the topics in which it features prominently (Jacobs and Tschötschel, 2019). This prominence of topics or words is represented through probability scores in TM. By leveraging these scores, an analyst can employ GT with a higher degree of confidence to connect the hidden dots between the words and the topics, explaining a broader process or phenomenon. These arguments demonstrate that TM and GT have robust theoretical compatibility for deep narrative analysis applications.

The nested application of these methods aligns well with the insight generation and argument crystallisation capability of narrative-analysis in policy research. TM explicitly models 'polysemy', i.e., the coexistence of multiple possible meaning for a word or phrase (DiMaggio, Nag and Blei, 2013). It traces the multiplicity of contexts of every word in the text corpus and assigns a probability value. The GT is inductive, and it aids in linking the latent connections between socio-cultural processes sensitive to policy variables (in energy research and social science context) (Bryant and Charmaz, 2019). Moreover, TM induces the quality of directness in the interpretation, which adds robustness to the GT-based narrative analysis.

In TM, the topics themselves obtain their meaning through i) the inter-relationship between words in a cluster of topics; ii) inter-cluster meaning of words between the topics; and iii) through frequent co-occurrences of other topics. Different meaning is derived by linking words to multiple topics, indicating TM's relationality feature (Jacobs and Tschötschel, 2019). Besides, GT strengthens the relationality to develop critical insight for policy applications (Bryant and Charmaz, 2019). Thus, enabling an analyst to derive quantifiable evidence from narratives analysis.

In TM, topics are interpreted as frames, themes, et cetera, but that the most appropriate interpretation depends on how the method is used by the analyst (Jacobs and Tschötschel, 2019). We expand this statement using science mapping to examine the commonality and cross-fertilisation between keyword set A and B, respectively. A higher degree of cross-fertilisation and commonality of concepts between TM and narrative-analysis (using GT) would indicate a methodological polyvalence (Jacobs and Tschötschel, 2019). The methodological polyvalence would mean that our proposed deep-narrative analysis approach can be applied to a broad scope of energy policy and social science research problems. The conceptual structure maps in Fig 30 illustrate the cross-fertilisation and commonality of the keyword set A and B, respectively.

The blue and red clusters show the cross-fertilisation of themes in current published literature in the respective keyword sets (see Fig 28). For Fig 30a, keyword set A represents the published literature's conceptual structures on energy policy and narrative analysis. It shows that the cross-fertilisation was in applying narrative analysis in energy and climate policy research by using public deliberations and opinions as to the primary data source (see Fig 30a). Similarly, for keyword set B, the red and blue clusters represent the current literature's conceptual structure on computational social science and topic modelling applications. The cross-fertilisation in keyword set B shows the use of topic modelling in 'decision-making', 'discourse behaviour', 'policy', 'text' analysis (see Fig 30b). Moreover, the blue and red clusters across Fig 30a and Fig 30b show conceptual commonalities between keyword set A and B. The cross-fertilisations of methods and the commonalities show the meta-theoretical fit of TM and GT for nested application in policy research.

We maintain a caution that using a qualitative method like narrative analysis using GT with TM should be constructed with a specific research objective in mind rather than with statistical optimisation. For example, in our proposed nested methodology (see Fig 25), we use TM with GT for deep-narrative analysis. GT aids in refining the parameters of the model interpretation to facilitate the best possible answer to those research questions. It would mean building the topic models to answer the research questions rather than adapting research questions so that they can be answered through TM. The later remains a limitation in the current application paradigm of computational social science research for public policy applications (Grimmer and Stewart, 2013; Roberts, Stewart and Tingley, 2016; Jacobs and Tschötschel, 2019).

Epistemological fit of the proposed framework

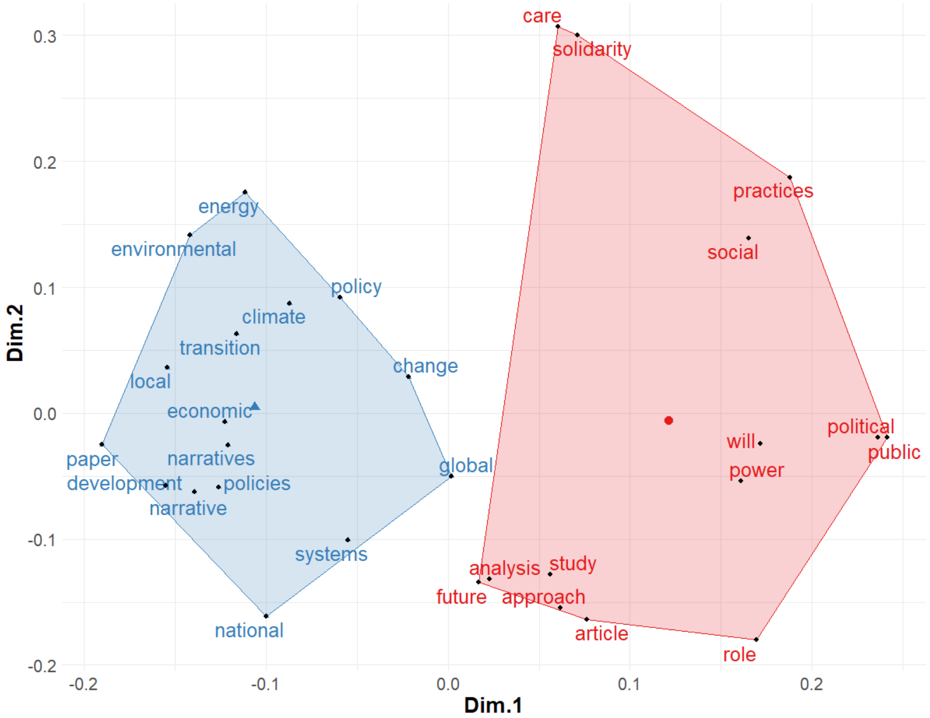
The second line of argument for theoretical validation of the proposed framework was a science mapping-based investigation of the epistemologies of Topic Modelling (TM) and narrative analysis (using GT) in energy policy research. The commonalities in the conceptual structure maps in Fig 30 illustrate a degree of coherentism (Murphy, 2020) that indicates an internal validity between TM and GT's applied concepts. However, it is impossible to establish external validity between TM and narrative analysis. They have different epistemological grounds (also pointed out by (Jacobs and Tschötschel, 2019) for TM and discourse analysis).

Epistemologically, TM is an unsupervised method and inherently inductive approach. TM purely represents the pattern of language use within the text corpus, independent its externalities. It adheres to the epistemology of the text corpus. However, GT-based narrative analysis employs a supervised application, where the analyst pre-defines categories or scales of the narratives understudy in a deductive fashion. It can induce directionality bias in interpreting the results (as discussed in section 6.3 and section 6.3.1). Our proposed nested methodology reduces this directionality bias due to TM's unsupervised and inductive nature. TM's characteristics strengthen its applicability in policy research, as illustrated by the conceptual structures in Fig 30b.

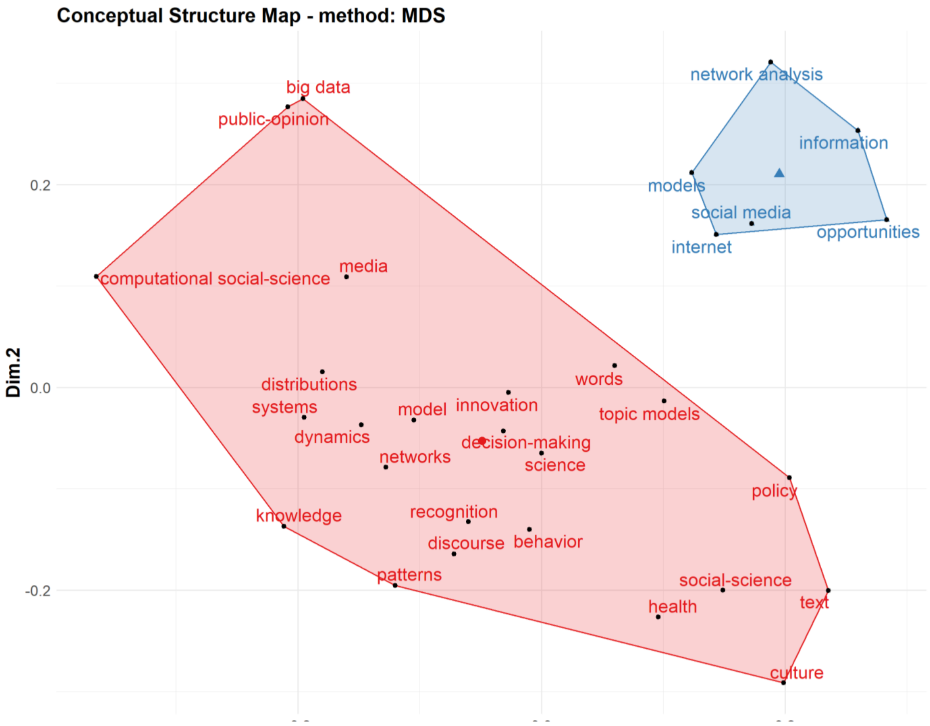
The analyst's task is to interpret and make sense of TM and generate valuable insights based on the semantic relations and crystallised arguments from the narratives. The analyst's subjective input thus continues to play a vital role and cannot be replaced by TM algorithms for 'good' policy analysis. TM enables the analyst to condense or transform a large corpus of narrative texts effectively. The analysis realises the analysis itself guided by GT (as per the nested methodology, Fig 25). The conceptual structures in Fig 30 further illustrate the parallel epistemologies that both narrative-analysis and TM represent in the scope of policy analysis. It essentially demonstrates the type of questions that can be typically investigated using our proposed methodology. For instance, the red clusters in Fig 30a and Fig 30b, respectively, thematically hints towards TM and narrative analysis's meaning-generating characteristic. Words like 'discourse', 'practice', 'behaviour', 'public opinion', 'knowledge', 'distribution' across set A and B represents the application-specific commonality of TM and narrative analysis for energy policy application. As mentioned above, these commonalities necessarily establish the internal conceptual validity of TM and narrative analysis (using GT).

The arguments we developed here concerning the theoretical compatibility of TM and GT-driven narrative analysis centres around the cross-fertilisation and the meaning-generating capability of both the methods in an energy policy research context.

The science mapping and the conceptual structure between the two methods (see Fig 30) illustrated the complementary application spaces in energy policy research. This data-driven approach established the theoretical compatibility from a policy applied perspective, thus proved the 'applied' scope of this paper. Table 16 further elaborate on the theoretical fit based on TM and GT's properties and the synergistic benefits it offers to deep-narrative analysis.



a) Conceptual structure map of themes in keyword set A: energy policy and narrative (n = 311)



b) Conceptual structure map of themes in keyword set B: computational social science and topic modelling (n = 94)

Fig 30 Conceptual structure of keyword set A and set B through science mapping to show epistemological fit

Table 16 Theoretical complementarity of using TM and GT for deep-narrative analysis

	Topic Modelling	**Grounded Theory**
Properties and epistemologies	• A quantitative approach from natural language processing; • Positivist approach; • Unsupervised process;	• A qualitative approach from interpretive social science; • Interpretivist approach; • Human reading and supervision required;
Methodological strength	• Purely data-driven; • Requires no human supervision to identify and define topics; • Rigour is established through probability distribution over a vocabulary; • Identifies critical themes from large corpus of documents ranging from thousands to millions of textual data points. • Enables generalisability through data-driven reasoning	• Generate rich, thick, descriptions; • Construct theories by interlinking latent social processes; • Provides comprehensiveness across the diverse sociological orientations by making interpretive methods more codified, legible and legitimate; • Rigour is established through confirmation of findings, either from informants or from other researchers; • Provide a common interleaving of data collection, analysis and theorization
Sources of bias	• Encoding and Empirical bias; • Algorithmic bias; • Over predictability; • Epistemic attachment to the object of research	• Directionality and interpretivist bias; • Lack of robust verifiability metrics • Significant amount of human time and energy required
Inferences from science mapping	• Energy policy application space to understand social practices, political and public opinion, innovation models, discourse and behavioural analysis, etcetera (see Fig 6); • Conceptual structure from current bibliometric dataset showed high intellectual commonalities with the narrative analysis for energy policy applications (as discussed in section 5.1)	• Widely used in narrative analysis in energy and climate policy applications; • The conceptual structure showed its application space in improving and contextualising semantic relations in text datasets, a much-needed element for drawing targeted policy implications.
Complementarity from nested application	• The nested application limits the biases and creates a complimentary scope for both positivist and interpretivist policy research; • The nested application enhances the synergistic capability of both the methods such that topic modelling removes the need for open and selective coding and theoretical sampling. Thus, reducing the sources of bias in grounded-theoretical research. While at the same time, grounded theory aids in contextualising the discovered topics and its highly probable words from the textual corpus. It the nested application process, explained in detail in section 4.3. • It brings in data-driven capabilities of machine learning while simultaneously maintaining the linguistic, contextual and interpretive insights of human reading.	

6.6.2 Case study: Energy poverty and built environment externalities in slum rehabilitation housing

The narratives collected through FGD using the questionnaire themes in Table 15 examined the role of built environment parameters in energy service demand and quality of life in poverty. The exploratory indications provided through high-frequency words in Fig 31 indicated some interconnected relationship between income, appliance ownership, electricity bills, housing standards and the built environment elements like windows and open spaces, garbage disposal (see Fig 31). Besides, the quality-of-life indicators were in the form of an effect on kids' study and play-routines and their health and well-being (see Fig 31).

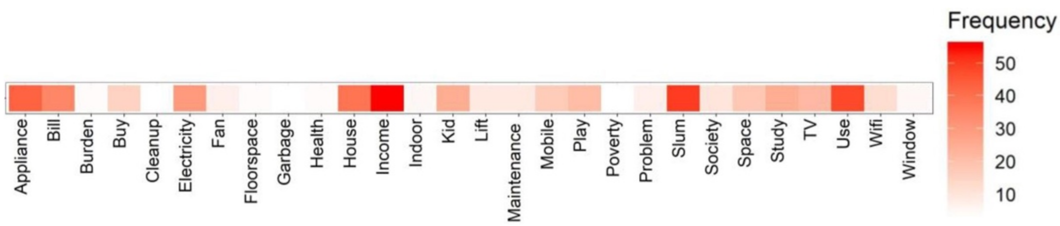


Fig 31 High frequency words from the FGD transcript (n = ~ 9000)

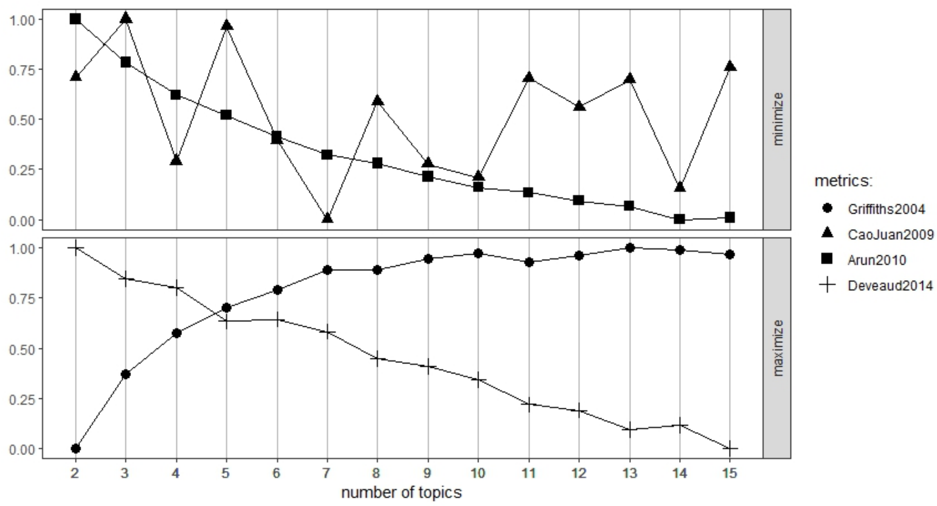


Fig 32 LDA tuning convergence for topic approximation

Seven topic clusters were found to extract the most relevant information from the FGD narratives (see Table 17), which was verified using the LDAtuning algorithm. The

CaoJuan2009 metric in the LDAtuning reached a global minimum at seven topics, whereas the Griffiths2004 metric showed a global maximum at '13' topics (see Fig 32). It was observed that specific terms began to repeat frequently beyond seven topic clusters which induced redundancies in meaning. Therefore, we decided on seven topics (see Table 17).

Table 17 Discovered topics based on the narratives on built environment – energy nexus in slum rehabilitation housing

Topic 1	**Prob(β)**	**Topic 4**	**Prob(β)**	**Topic 7**	**Prob(β)**
Bill	0.080	Appliance	0.070	Fan	0.065
Irregular	0.025	Want	0.038	Refrigerator	0.021
Month	0.022	House	0.029	Food	0.020
Electricity	0.019	Purchase	0.022	Time	0.031
High	0.018	New	0.020	Cook	0.020
Topic 2	**Prob(β)**	**Topic 5**	**Prob(β)**		
Lift	0.039	Space	0.026		
Lack	0.030	Lack	0.021		
Repair	0.030	Park	0.018		
Watch	0.035	People	0.019		
TV	0.028	Life	0.016		
Topic 3	**Prob(β)**	**Topic 6**	**Prob(β)**		
Play	0.050	Window	0.045		
Kid	0.048	Close	0.035		
Lack	0.020	House	0.028		
Space	0.020	Garbage	0.017		
Corridor	0.018	Space	0.012		

Following the proposed nested deep-narrative analysis trajectory (see Fig 24), the topics discovered in Table 17 are now expanded to reveal latent social processes that can outline externalities associated with energy usage in the slum rehabilitation housing (SRH) built environment. High probability (β) terms like the bill (β = 0.080), irregular (β = 0.025), and month (β = 0.025) have critical significance in the narratives from the SRH because irregular high electricity bills that get piled up for months is significant distress in the SRH. Occupants mentioned that sometimes they get bills after three months, almost as their monthly household income (~ 60 – 90 USD), whereas sometimes they get the same amount in a single month.

> *"… I get huge variation in monthly bills, sometimes we get Rs 1300 (~ 18 USD) and sometimes Rs 2000 (~ 26 USD) … it is usually on the higher side … The distribution company changes fast in area and so are the bills…"* (P3)

The above narrative from one of the participants (P3) revealed that a possible reason for irregular bills could be linked to the frequent change of electricity distribution companies in the study area. This narrative on irregular and high electricity bill in the SRH echoed from other participants (P6 and P7) as well,

> *"… bills were very high due to transfer from Reliance to Adani Power Company in this area. We used to get bills in the range of Rs 300-500 (~ 4 – 7 USD) but during that month the average bills were in the range of Rs. 2000-5000 (~ 26 – 67 USD) …. the bills were 15 days late as well. Many people from the society complained of getting bills as high as Rs. 10,000 (~ 133 USD …. it is more than the monthly salary of many families living here…" (P6)*
>
> *"… since the Adani Power Company took the charge of electricity distribution in this area, there are problems with the bill …. the bills are not regular and always high…" (P7)*

Thus, administrative lags due to the frequent change of distribution companies in the SRH can be regarded as a critical energy service externality that influences higher energy bills and induces distress in the households.

Topic 2 revealed another critical energy service externality in the SRH built environment related to the lack of repair and maintenance of the elevators (see Table 17). Without access to elevators, the most of the occupants' mobility got restricted that disrupted their strong social network in the community. This disruption has a substantial but latent cost on the well-being of the occupants. Similar findings on SRH built environment effects on the well-being were also reported (Vaid and Evans, 2017; Debnath, Bardhan and Sunikka-Blank, 2019a).

> *"… I am losing contact with my previous slum community members…. some of them stay on the 7th floor while some are on the 4th floor and some on the ground floor …. we do not have a common socialising space and the lifts are always broken people …. living on the top floors do not usually come down for socialising unless it is something important …" (P11)*
>
> *"… I stay on the second floor and I have knee problems …. even if my friends on the 7 floor invites me in the evening, I cannot climb five floors and I miss all the social gathering…. the lifts don't work, so I am totally stuck in my second-floor living…." (P4)*

An energy implication of the lack of mobility in the SRH built environment due to broken lifts is that physical socialising is declining. In contrast, internet socialising and TV viewing hours are increasing. Such energy practices are also related to the rise in household electricity bills (also reported in chapter - 4). Thus, topic 2 (see Table 17) crystallised the externalities associated with the lack and maintenance of lifts in the SRH built environment that indirectly influences occupants to shift to energy-intensive practices.

Similarly, Topic 3 and Topic 5 in Table 17 illustrate the critical terms on the lack of public and community spaces that have adverse impacts on occupants' health and well-being, especially kids (P5). A participant (P10) revealed that kids do not have a place to play, and they are forced to stay indoors and watch TV or play games on mobile phones. It is the energy externality associated with the lack of playground or parks in the study area. Parents do not allow kids to play on the ground floor as these zones are not safe due to alcohol and drug abuse (P3).

> *"…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 …. the occupants living next to the staircases do not let them play because of the playing noises …." (P10)*
>
> *"…. they don't have playgrounds …. they cannot play in corridors …. We never allow them to play in the ground floors, because if they go there 100% chances are that they will get addicted to either drugs or alcohol …." (P3)*
>
> *"… the general health of the kids in the neighbourhood is going down …. teachers tell us in parents-teacher meetings that allow your kids to play daily for at least 2 hours, but they don't understand that we don't have any safe space here for the kids to play …. Even doctors tell us that they are getting weaker because of lack of physical activities …." (P5)*
>
> *"… no playground and we are forced to keep our children busy with cartoons in the TV or mobile games… almost all the kids in this society has prescription glasses …." (P8)*

Topic 4 and Topic 7 discovered terms associated with the demand for energy services through appliance ownership in the SRH (see Table 17). Words like purchase ($\beta = 0.022$), new ($\beta = 0.020$) and want ($\beta = 0.038$) illustrated the aspirational and want-based element of purchasing appliance on moving into the SRH from the horizontal slum. Fulfilling these aspirations also add to the economic distress in the SRH, as more appliance use increases the energy intensity of the households (Debnath, Bardhan and Sunikka-Blank, 2019b; R. Debnath *et al.*, 2020). Moreover, occupants purchase these appliances using money borrowed from informal money lenders or friends (P3 and P11). This debt adds to the economic distress of living in the SRH.

> *"…. no, we can never afford to pay out of pocket…. we borrowed the money from a local money lender…. Some people bought appliances on monthly instalments from the stores itself …." (P3)*
>
> *"…. we just had a fan and a light bulb when we shifted here from the slums… we had to purchase all the appliances by taking loans…. Now we have borrowed money from money lenders to repay the loans …." (P12)*

Besides, appliances like refrigerators and washing machines were purchased for the greater convenience of living in the SRH (also reported in (R. Debnath *et al.*, 2020)). Few occupants saved time from using such appliances and used the extra time for income-generating activities. For example, one of the participants (P2) uses a refrigerator to store food and store flowers that she can sell in the morning market.

> *"…. most common items that are stored in the refrigerators are vegetables, water and item related to subsistence activities like flowers, garlands and home-made dairy products like curds, paneer etc …." (P2)*

Topic 6 (see Table 17) illustrated some critical aspect of the SRH design elements that significantly influence the occupants' energy use behaviour. For example, the terms window (β = 0.045) and close (β = 0.035) referred to the common practice of keeping windows closed all the time due to lack of hygiene in the built environment. Besides, occupants dump garbage between the buildings that make it a breeding ground for rats and insects (see Fig 33).

Garbage dump in between buildings | A typical slum rehabilitation house (~24 square meters) | Lack of daylight and ventilation pathways | Densely packed and high-rise slum rehabilitation buildings

Fig 33 Characteristics of the study area: Slum Rehabilitation Housing, Mumbai, India

> *"…. the design of the house is very faulty …. the builder has provided with sliding windows which always block half of the opening …. plus, we have such small rooms, the rest of the windows are blocked by our storage items…. Pests are also a big menace here…." (P8)*
>
> *" …. the problem of rats is huge here …. if we keep our windows and doors open, they would enter the house and eat up all the stored grains …. I had lost 2kg of rice last month to rats …. we seal the house completely by covering doors and windows which makes it very hot and uncomfortable…. But we do not much choice…." (P2)*
>
> *"… the rooms are small… we have lots of thieves in the complex …. and so many rats … we have to keep the door and windows closed for all the time which makes our room suffocated…." (P11)*

The energy implications of keeping the windows and doors closed for almost 24 hours is low thermal comfort and indoor air quality ranges (also reported in (Lueker *et al.*, 2019)). The rooms become stuffy, and occupants must use additional fans or air conditioners to keep the room cooler at an added economic cost. Thus, the poor design, lack of hygiene and safety of the SRH built environment are the energy externalities that indirectly affect higher electricity bills.

The deep-narrative analysis performed using the seven topic models (see Table 17) revealed the latent factors contributing to higher energy bills and their associated distress in the study area. These underlying factors were further statistically explained using the probability values of specific terms critical to the socio-cultural construct of the slum rehabilitation housing under study. Understanding and implementing such socio-cultural constructs' particular requirements can aid in better policymaking, especially in vulnerable and low-income communities. Thus, using the deep-narrative analysis, we could highlight the critical externalities of energy-built environment interaction that led to high energy bills in SRH.

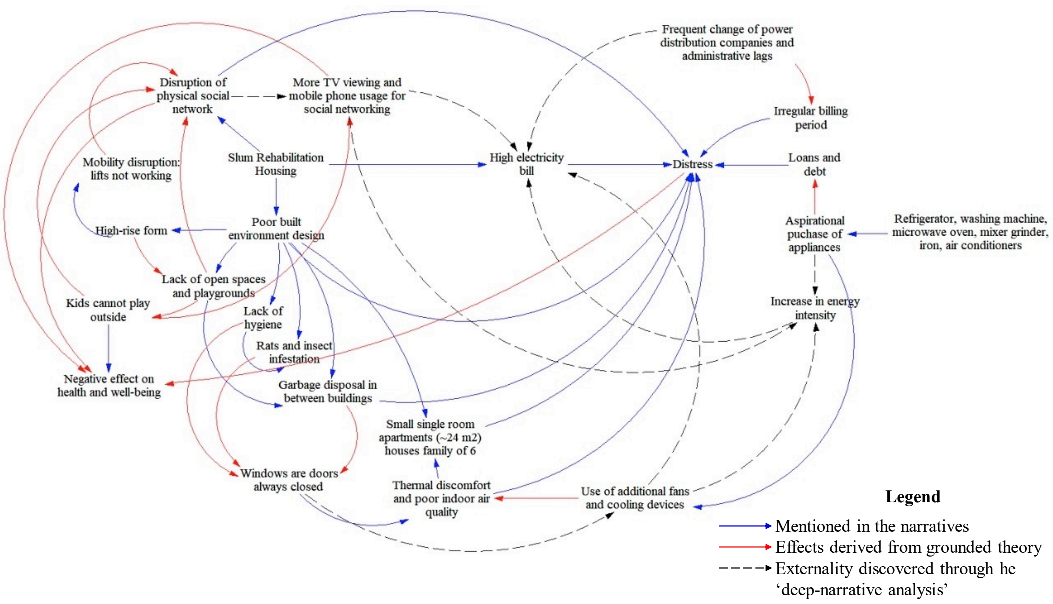


Fig 34 Energy service externality map in the slum rehabilitation housing under study

A generalised representation of derived externalities is illustrated in Fig 34. The blue and red arrows represent the narrative-based observations and effect, respectively. The dotted arrows show the latent externalities as derived through the deep-narrative analysis. It is not uncommon that such latent links could also be derived through a robust application of qualitative-only grounded theory and narrative analysis. However, as mentioned in table 16, the robustness of such use remains unverifiable. It causes a reduced degree of generalisability. From a pure qualitative textual analysis perspective, improving robustness, in this case, would mean increasing the cyclicity of open coding, selective coding and theoretical sampling process in GT until a reasonable theory is constructed. It is manually intensive and time-consuming. Moreover, the theory construction phase can induce directionality bias. Baumer et al. (Baumer *et al.*, 2017) explicitly called for the development of mixed-method approaches to address this weakness of GT (discussed in detail in section 6.3).

Our nested approach provided a probabilistic background for GT to rank words based on the relative similarities across the discovered topics. It further aided in the crystallisation of FGD texts for drawing the latent links (see dotted lines in Fig 34). Until this stage, it was an unsupervised process that eliminated the possible source of directionality biases. The probability values (β-values, see Table 17) improved our degree of confidence in connecting the latent processes in significantly less time. Furthermore, the nested application (see Fig 28) preserved the narrative texts' contextual and interpretive insights. Thus, enabling a similar elaborate analysis can be achieved through manual coding using any qualitative data analysis (QDA) tools. It highlights this chapter's methodological strength that it does not intend to replace any existing QDA methods. Instead, it brings in the mutual benefit of machine learning in qualitative research and policy analysis.

6.7 Chapter concluding remarks

This chapter presented a novel nested deep-narrative analysis approach using topic modelling and grounded theory for energy policy application. It emerged from the need for a multidisciplinary approach in energy policy research that transcends beyond the technical only feasibility of specific scientific methods to address energy and climate injustice (Ozawa *et al.*, 2019). The proposed methodology intends to contribute to the state-of-the-art literature and strengthen the use of text-driven policy analysis tools like narratives, stories and storytelling using computational social sciences. Our proposed methodology does not replace qualitative methods like grounded theory or narrative analysis, rather enhancing its insight generating capability by using Bayesian policy modelling and evidence analysis methods based on probability laws. We have argued that the combination of probabilistic models with the grounded theory for narrative-analysis may reduce directionality biases in interpreting results in energy policy research. The directionality biases are reduced because the proposed model depends solely on the word-word, word-topic and topic-topic interrelationships defined by probability distribution functions. It enables the analyst/researcher to build the topic models to answer the research questions, rather than adapting research questions so that they can be answered through topic models. It is expected to enhance the insight generation capability of topic modelling in policy research. Walker at al., (Walker *et al.*, 2019) argued that the absence of this insight generating ability in the current topic modelling methods in policy research is a structural limitation.

We examined the theoretical compatibility of both the methods in the nested approach for deep-narrative analysis using science mapping of a bibliographic database to capture the conceptual structure of narrative analysis application in energy policy research and computational social science using topic modelling. The conceptual structure map showed the cross-fertilisation and commonalities of the concepts associated with the narrative analysis and topic modelling. The theoretical compatibility showed that our proposed nested approach could aid the analysis can subjectively and reflexively interpret the derived topic models using a grounded theoretic lens. It preserves the 'crystallising' capability of narrative analysis for arguments and assumptions in a document. It enables the analyst to statistically link the critical terms/topics with the arguments' broader context. Our theoretical compatibility test showed that the cross-linking capability of topic modelling and narrativity analysis using grounded theory could be established due to the internal epistemological fit of the concepts of these two methods. However, they have different external epistemological backgrounds and cannot be used as a replacement for each other.

Furthermore, we provided a proof-of-concept of the deep-narrative analysis framework by investigating the externalities associated with energy services in slum rehabilitation housing (SRH) in Mumbai, India. The framework's application revealed latent links between energy use and the built environment in the SRH that influence high energy bill (see Fig 33). While the occupant-led focus group discussion revealed the problems and the energy culture associated with living in the SRH, the topics discovered through LDA aided in picking-up critical points in the narratives using probability values. Thus, transforming narratives toward statistical evidence for policy analysis.

In the concluding remark, we want to emphasise the limitation and implications of our methodology. Not all narrative analysis can or should be done using topic modelling techniques as it deconstructs the text corpus into its barebones. The applicability of topic models is up to the analyst's judgment on a case-by-case basis, assessing the method, the theory and the material at hand. From an ontological perspective, some problems may arise while combining topic modelling with a grounded theory is over-representating a problem that may bias the results and implications. Therefore, even in the nested application, the analyst must have a clear understanding of the context. Another bias inducing factor in our nested use is the heavy reliance on the topic models to discover critical focus points. It can further dilute the interpretivist nature of the deep-narrative analysis framework.

Some parameters that can induce biases in the interpretation of the results is the lack of interdisciplinary viewpoints. Stressing too much on one aspect of the interpretation may deem the computational part redundant. Besides, relying too much on the probability values to derive critical conclusions can also make the analysis weaker. The analyst should leverage the deep-narrative framework's nested philosophy and facilitate a balanced interpretivist approach of both topic models and the grounded theory. Ontological bias like epistemic attachment to the object of research can also misinterpret the derived topic models. Such misinterpretation may lead to over-predictability of topics, inducing encoding and empiricist bias. It can influence the understanding of the cause-and-effect relationships of the analysis. Our methodology does not solve all the challenges associated with either method. Instead, it aids in developing some of the critical questions, which systematically includes qualitative evidence into policymaking through a realist, rationalist, and relativist ontological positioning.

We limit our comment on the proposed nested model's applicability in a small – dataset, like narratives collected through focussed group discussions or personal interviews. Most topic modelling applications in the state-of-the-art literature are based on big data, whereas narrative is micro-datasets. Sensitive analysis of a big data-driven versus a micro-data driven narrative analysis and policy interpretation remains a gap in the current literature. The case study presented here showed promising results concerning our proposed model's application in narrative-like micro datasets. We further explore our proposed framework's efficacy in the identification of distributive injustices in the SRH of Brazil, India and Nigeria in chapter – 7.

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CHAPTER 7 Empirical – 4

Extraction of contextualised distributive injustice in slum rehabilitation housing using deep-narrative analysis

7.1 Chapter summary

Slum rehabilitation housing (SRH) are critical transitional spaces in urban informality that has deep-rooted implications on poverty alleviation efforts. However, current literature reports systemic injustices in SRH on access to essential services, including energy injustices. This chapter investigated distributive injustices in the SRH across three cities, Abuja, Mumbai and Rio de Janeiro, developing 'energy cultures' narratives. It employed a computational social science methodology that used textual analysis, followed by a constructivist grounded theoretic approach to inform just policy design. It is an empirical extension of chapter – 6. The analysis was performed at two scales to identify and contrast injustices in the study areas. The result at an aggregated scale showed commonalities were around the poor design of the built environment, administrative lags of the utilities and high electricity bills. Case study-specific results showed that poverty penalties were linked with the energy cultures of each SRHs. In the Mumbai case, poverty penalties were associated with the aspirational purchase of household appliances due to the move from slums to SRH. The Abuja case showed low power quality and load shedding frequently damaged appliances that increase the occupants' maintenance costs. The Rio de Janeiro SRH case had injustices embedded through the adoption of inefficient appliances received as charity from higher-income households. Fuel stacking was also observed in the SRH that illustrated cultural identities associated with cooking energy. The conclusion was drawn to support just policy design by considering the built environment's socio-cultural context, improving utility governance, and promoting a cleaner fuel mix at the household level.

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7.2 Introduction: Policy design for distributive energy justice

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. Urbanisation forces 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 (Hutt, 2016). Energy is regarded as the 'golden thread' that help poverty alleviation by connecting economic growth, social equity and environmental sustainability (Brand-Correa, Martin-Ortega and Steinberger, 2018). 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 (Brand-Correa, Martin-Ortega and Steinberger, 2018).

People use energy to derive specific energy services that contribute to their well-being, termed as human-scale energy services (Brand-Correa and Steinberger, 2017). People living in poverty are likely to be concerned with providing a range of essential energy services that can improve their well-being (Samarakoon, 2019). 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 (Sovacool, 2011). 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 always translate into improved well-being effects (Munro and Schiffer, 2019; Samarakoon, 2019). 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 (Sovacool and Dworkin, 2014; Bouzarovski and Simcock, 2017b; Bartiaux *et al.*, 2018b). 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' (Sovacool and Dworkin, 2015a). 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 the Global South using narratives as the primary data object. Here, the context of poverty in rapid urbanisation is established by investigating 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 (Nijman, 2008; Ronita Bardhan *et al.*, 2015). However, market and political-economic forces often impede the trickle-down welfare effects of these social housing (Rondinelli, 1990; Nijman, 2008). 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 (Mitlin and Sattherthwaite, 2012; Debnath, Bardhan and Sunikka-Blank, 2019a, 2019b; M. Sunikka-Blank, Bardhan and Haque, 2019). We investigated this built environment – poverty link by exploring energy cultures (after (Stephenson, 2018)) 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 (University of Cambridge, 2020). The associated injustices must be removed before it further deepens the divide and increases the poverty penalties (Mendoza, 2011).

This study's novelty 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 chapter-6 that uses machine learning and constructivist grounded theory for narrative analysis. In doing so, this chapter 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 study's primary research question 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, (Sovacool and Dworkin, 2014)). 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, 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 (*zoom-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 (*zoom-in*) investigation of the case-specific energy narratives in poverty and the demand for human-scale energy services (HUSES). The zoom-out and zoom-in approach were to discover the commonalities and contrast the injustices in the study areas.

The specific research objectives of this chapter 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), UN – SDG 3 (good health and well-being) and SDG – 11 (sustainable cities and communities) goals.

7.3 Background

7.3.1 Distributive 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 (Samarakoon, 2019) that redefines energy as a "… golden thread that connects economic growth, social equity, and environmental sustainability" (UN, 2012). 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 (Shyu, 2014; UN, 2018). 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 (Ozawa *et al.*, 2019). 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 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 (HUSES) can be provisioned for better well-being (Brand-Correa, Martin-Ortega and Steinberger, 2018; Samarakoon, 2019).

HUSES 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 (Shove, 2003a). This concept was further expanded in the theoretical proposition of urban service energy ladder (Sovacool, 2011) and energy cultures (Stephenson, 2018). 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. Its application in Medellin Columbia's local communities 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 (Samarakoon, 2019) expanded the understanding between HUSES and well-being in the Global South's energy-poor 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 energy justice issues is needed to provide energy services for poverty alleviation efficiently. However, this study did not empirically define energy service into the specificities of energy services' social and technical dynamics. 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 (Malakar, Herington and Sharma, 2019a) 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 (Malakar, Herington and Sharma, 2019b). A post-colonial conceptualisation of just energy transition in Mozambique (Castán Broto *et al.*, 2018) destabilised energy research's common assumptions. 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 (Buchholz, 2014b). In a recent review paper by (Lacey-Barnacle, Robison and Foulds, 2020) on energy justice in the developing world, the authors suggested four ways of expanding the field's current theoretical developments. It includes contextual attention to neglected regions, the inclusion of non-western philosophies, emphasising systems approaches to low-carbon transition and developing empirical frameworks to aid decision-making.

7.3.2 Policy design and modelling approaches for distributive energy justice

Public policy is often considered solution to correct injustices associated with energy transition challenges (Sovacool and Dworkin, 2015a). 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 (McCauley *et al.*, 2013; Jenkins *et al.*, 2016; Ozawa *et al.*, 2019). It is attributed to the justification of technocratic propositions of preferred 'science and technology' complementing the leading political forces' objectives (Ozawa *et al.*, 2019). It restricts climate and energy system models' scope, making them ineffective across the horizontal societal domains. Technology is 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 (MacKay, 2008; Boarnet *et al.*, 2017). 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 and Daniels, (2017) 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 spillovers, and household social class as crucial non-income variables of distributional energy justice (Grover and Daniels, 2017).

Similarly, Day, Walker and Simcock, (2016) have used the capability approach to conceptually scope the policy route to distributive energy justice in energy poverty. It was then expanded in (Walker, Simcock and Day, 2016) 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 (Walker, Simcock and Day, 2016). They argued that public deliberations on bare essentials of energy services should be considered legitimate grounding for defining minimum standards (Walker, Simcock and Day, 2016). This argument serves as a critical foundation for this study. W

We derive policy focus points through public deliberations of living in slum rehabilitation housing and the demand for human-scale energy services. A recent exploratory study by (Zhou and Noonan, 2019) 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 utility companies' racial bias and inequalities in funding clean energy programs (Zhou and Noonan, 2019). They also found that improving the government's procurement policy can improve distributive equity for energy-efficient buildings (Zhou and Noonan, 2019). 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 (Bombaerts *et al.*, 2020) titled *Energy Justice Across Borders* sheds light on energy justice in practice in the Global South. Kruger and McCauley, (2020) conduct 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 the energy system's macro-and micro-levels to deconstruct the pre-determined Western logics of justice associated with energy provisioning. They inferred that a contextual understanding of the energy mix and the energy system is essential to facilitate just energy transition in the Global South. Similar conclusions were made by (McCauley *et al.*, 2019) on a global scale. We apply a similar deconstructivist approach through topic modelling in this study. In the same book, (Govindan *et al.*, 2020) 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 is enough for associated welfare benefits for both men and women is wrong. This 'gender-blind' approach in energy policymaking needs to change (Govindan *et al.*, 2020). 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, (2020) argues that a significant barrier to distributive energy justice policy modelling is the weak understanding of local contexts and societal needs and the lack of bottom-up innovations. The author calls for gender parity in energy policies for low-income countries such that just energy provisioning materialises income generation and poverty alleviation (Tucho, 2020). A conceptual policy modelling approach for addressing energy injustices was presented by (Lee and Byrne, 2019), which was then applied to the case of South Korea's nuclear power system and Seoul's One Less Nuclear Power Initiative. In just low-carbon energy policymaking, the author argues that shedding light on underlying drivers of energy injustice embedded in the dominant modern energy paradigm is crucial for energy justice (Lee and Byrne, 2019). Debnath *et al.*, (2020) 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, Debnath, Darby, *et al.*, (2020) 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 chapter is an empirical extension of Chapter 6 to enable inclusive energy policy design in slum rehabilitation housing of rapidly urbanising Global South.

7.4 Methodology

This study's overall methodological framework adopted is illustrated in Fig 35 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 Chapter 6. The deep-narrative analysis framework's empirical expansion was performed in two scales, macro and micro-level (see Fig 35). 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 *zooming-out* of the narratives to view the broad energy cultural identities associated with the SRH. Simultaneously, 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 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.

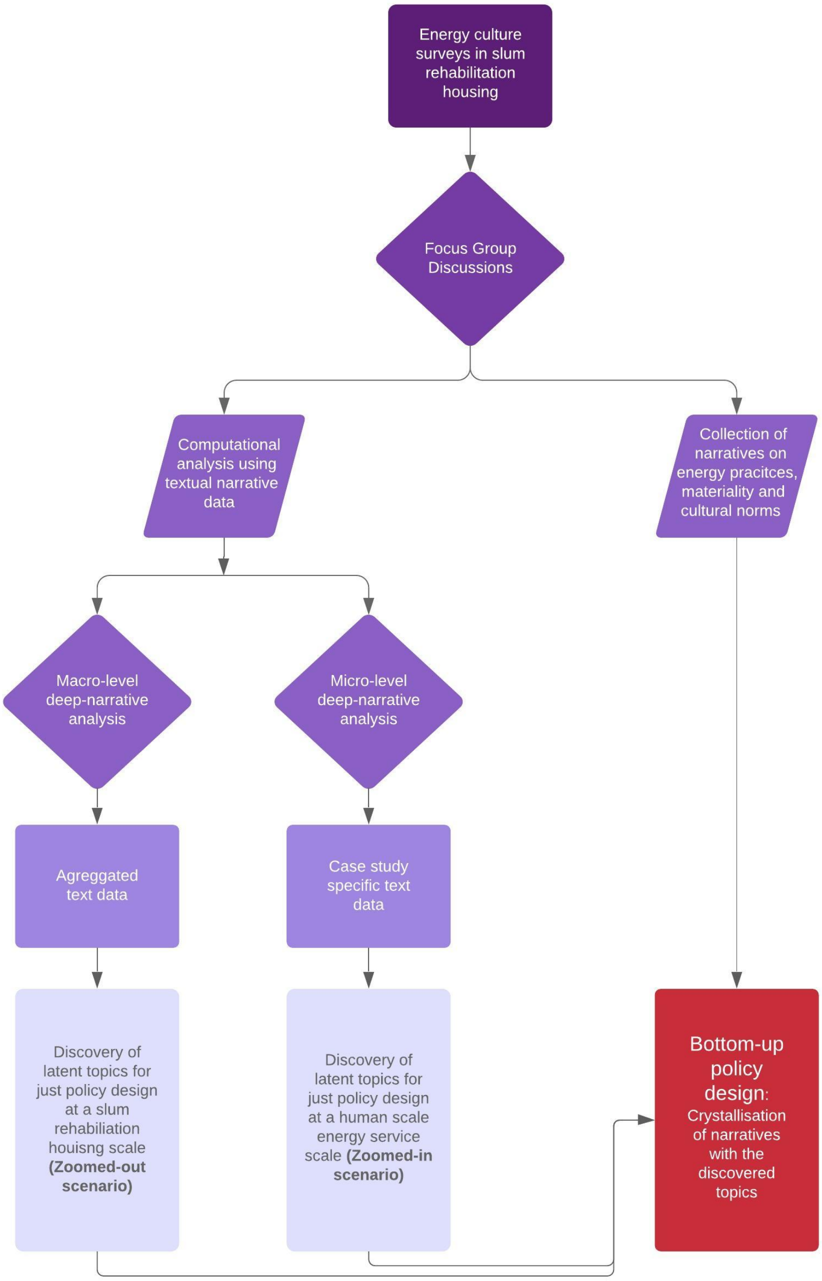


Fig 35 The methodological framework of this chapter

7.4.1 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 Rio de Janeiro, Mumbai and Abuja, respectively. FGDs were conducted as per the best practice guidelines (Powell and Single, 1996; Gill *et al.*, 2008). The interviews were conducted to extract grassroots-level information on human-scale energy service demand in poverty, using the lens of energy cultures (after (Stephenson *et al.*, 2010)). Recently, (Tesfamichael, Bastille and Leach, 2020) have used a similar approach to energy cultures investigation in Kenya. It provides valuable clues for this study to conduct the FGDs, offering a coherent explanation of 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 (Stephenson *et al.*, 2010). It provides a theoretical tool to map the cultural barriers associated with human-scale energy services (HUSES). A recent energy cultures theory application explored cultural barriers to just low-carbon transition, emphasising contextual factors associated with energy end-use, demand, and consumption (Sovacool and Griffiths, 2020b). Similarly, (Sovacool and Griffiths, 2020a) argued that insights from culture are critical in guiding energy planners and policymakers to stimulate 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 18. 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. At the same time, the male member goes out to work.

Table 18 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 meagre 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 (UN Women, 2019). 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 (Sugata, 2020). In Brazil, women remain the family's principal caregiver and have a more significant share of domestic responsibilities; this is specifically severe for informal settlements (Marín, 2017a). The 2014 total female labour force participation in Brazil was 43.8% (Marín, 2017b). In Nigeria, unemployment is higher for women, with most women employed in casual low-skilled and low-paid informal jobs. Besides, the lives of Nigerian women are heavily affected by myriads of discriminatory, traditional, and socio-cultural practices that force their underemployment even in the informal labour force (Marín, 2017b).

The gendered approach in this study was further influenced by the findings (M. Sunikka-Blank, Bardhan and Haque, 2019) 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 significantly influences gendered use of space and electricity use through specific appliance ownership (M. Sunikka-Blank, Bardhan and Haque, 2019). It further advocated that gender equality can and should be influenced by energy and housing policies.

The FGD participants were recruited by 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, to 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. The participants' primary occupation 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 (Powell and Single, 1996). 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 (Powell and Single, 1996). 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 36.

Fig 36 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 process's multilingual nature will involve uncertainties about the meaning that may induce directional biases in its interpretation (Trotter, 2012; Bryant and Charmaz, 2019). The deep-narrative analysis methodology reduces 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 Chapter 6, section 6.6). This method provided a higher degree of freedom to *zoom-in, zoom-out and zoom-through* the problem statement (Moezzi, Janda and Rotmann, 2017a; Ramit Debnath *et al.*, 2020) (see Fig 35).

The socioeconomic, energy use and built environment characteristics of the study areas are shown in Table 19. The three-case study of slum rehabilitation has distinct contexts that are critical for understanding energy cultures in poverty. For example, the slum rehabilitation in Rio de Janeiro was due to forced-displacement caused by the loss of employment in waste-recycling industries. The community members privately built the SRH without state/federal support. The SRH in Mumbai was constructed as a part of the slum upgradation policy of India's federal and state government. The federal government did the SRH in Abuja to rehabilitate rural migrants into the city (see Table 19).

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. In contrast, 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 SRH built environment illustrated the spatial characteristics of distributive energy injustices at the grassroots level. This study further investigates such injustices within the built environment and cultural scope of SRHs.

Table 19 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% (Bello, 2017)	~ 41% (World Population Review, 2020)	~ 79% (UN-SDG, no date)
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 (Ronita Bardhan *et al.*, 2015) 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

Characteristics	**Brazil**	**India**	**Nigeria**
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	 	 	 

7.4.2 Performing the deep-narrative analysis on the FGD data

The methodology for deep-narrative analysis was adapted from Chapter 6, section 6.4. It involved four key steps that employ topic modelling to develop a statistical foundation for grounded theory-based narrative analysis. This study emulated these four steps as step 1 detailed 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 in grounded theory (Chun Tie, Birks and Francis, 2019; Ramit Debnath *et al.*, 2020). The advantage of using topic modelling was reducing biases during this process through unsupervised machine learning (see section 6.6.1, Chapter 6) for a detailed reference to the biases involved in computational textual analysis). The best practices on textual analysis for energy research and social sciences were adopted from (Müller-Hansen, Callaghan and Minx, 2020).

Step 3 involved crystallisation of the core arguments from the narratives that began reconstructing 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 35). 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 to 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.

7.4.3 Topic modelling using Latent Dirichlet Allocation (LDA) algorithm

The LDA computation was done by a publicly accessible toolkit called tidytext; computational tools are written in the R programming language (Silge and Robinson, 2019).

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 37. 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 of (Silge and Robinson, 2017)). 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 7.4.1). Each sentence was treated as a unique document in the DTM, which resulted in 504 sets of unique documents (***M***) that had ***w*** (words) and ***z*** (topics) as per LDA model specification (see Fig 38), after the best practice guidelines of (Blei, Ng and Jordan, 2003).

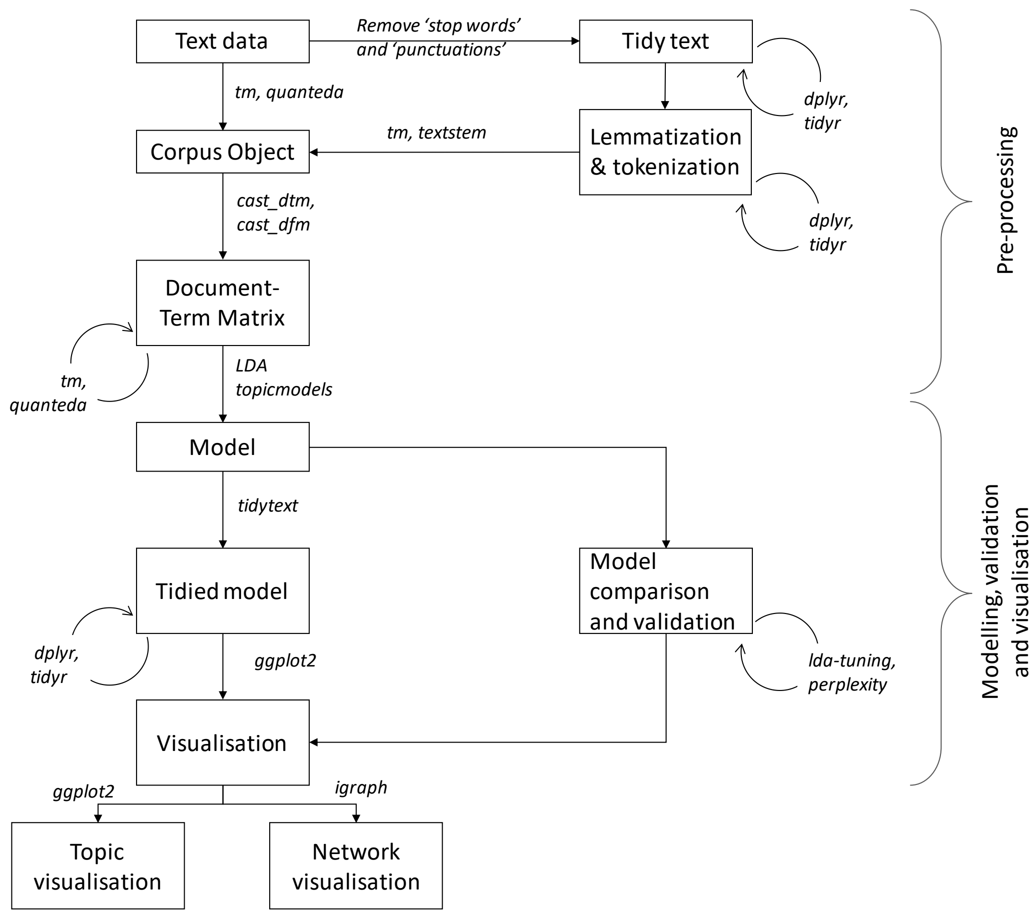


Fig 37 Analytical steps adopted in the LDA-based topic modelling of the narrative text data

[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]

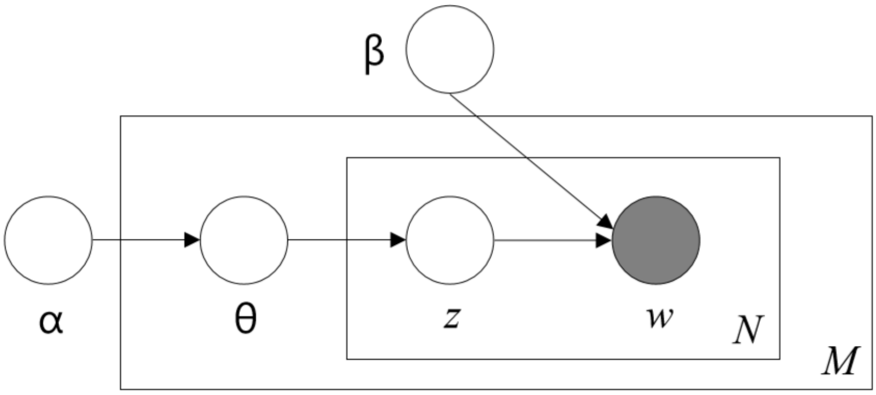


Fig 38 Graphical model representation of LDA. The boxes are "plates" representing replicates. The outer plate represents documents (M), while the inner plate represents the repeated choice of topics (z) and words (w) within a document (N). 'Θ' is the topic distribution for document i. 'α', 'β' are the hyperparameters of Dirichlet distribution (Source: (Blei, Ng and Jordan, 2003))

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

The mathematical foundation for LDA is illustrated in eq (1), after (Blei, Ng and Jordan, 2003). The hyperparameter α and β modulate the word and topic distribution over the corpus documents as mentioned above. 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 the narrative analysis (Baumer *et al.*, 2017; Nikolenko, Koltcov and Koltsova, 2017; Ramit Debnath *et al.*, 2020), 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*. The lemmatisation process involved removing the inflectional ending of words and converting the grammatical form into the base or dictionary form (known as *Lemma*) (Manning, Raghavan and Schutze, 2009). 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 the variational expectation-maximization (VEM) algorithm in the tidytext package (Robinson and Silge, 2019). Using this DTM, visualisation of the extracted topic and semantic network maps were created using ggplot (Wickham, 2016) and igraph (Csardi and Nepusz, 2006b) packages (see Fig 37).

Cross-validation of the derived topic models was done through perplexity scores (Hankerson, Harris and Peter D Johnson, 2003) and using the ldatuning algorithm in R (Moor, 2019). 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 (Grün and Hornik, 2011). 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 the 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 (Walker *et al.*, 2019; Debnath and Bardhan, 2020).

7.4.4 Grounded theoretic reconstruction for policy design focal points

Another core process of the deep-narrative analysis framework illustrated in chapter 6, section 6.4, is reconstructing the latent process from the narrative texts and topic models for policy applications. This step involved generating 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 39. Here, we refer to policy design to reconstruct the contextualised narrative using grounded theory to inform specific policy focus points in the study areas.

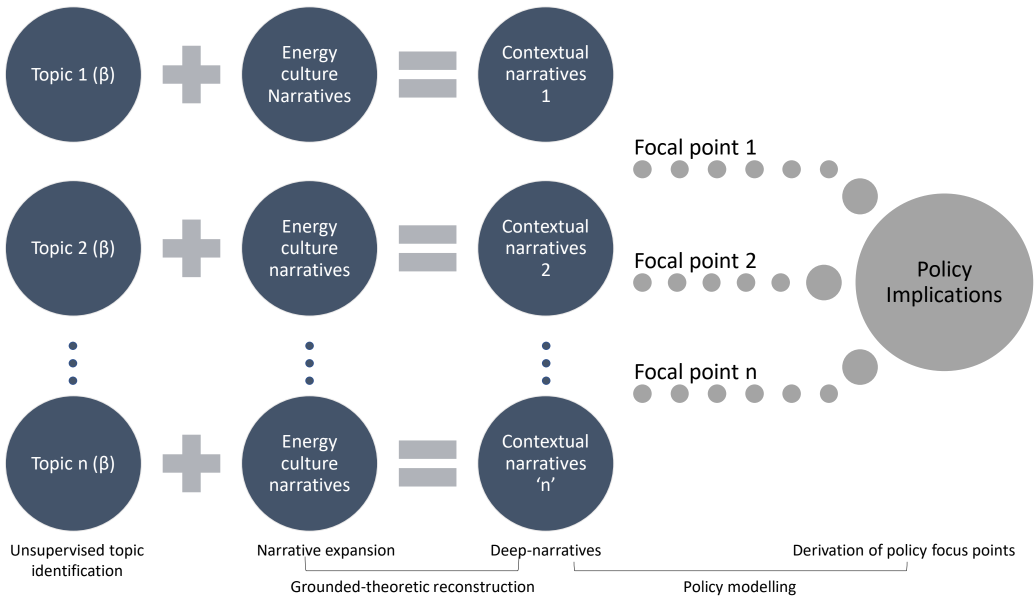


Fig 39 Derivation of policy design focus points from topic clusters using grounded-theoretic reconstruction

The grounded-theoretic reconstruction used in Fig 39 is influenced by the constructivist theoretical lens of Charmaz (Apramian *et al.*, 2017). We adopted Charmazian grounded theory (GT) to offer a broader scope of interpretivism (Bryant and Charmaz, 2019). A comparison of Charmazian GT with other approaches can be found (Apramian *et al.*, 2017). 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 (Richards and Farrokhnia, 2016). Here, we employed the deep-narrative analysis framework from Chapter 6 (see Fig 25) that demands an inductive and multi-layered approach to narrative interpretation for contextualised policy design. This approach acknowledges the post-modernist turn in the humanities and social sciences to computational social sciences (Wasserman, Clair and Wilson, 2009; Clarke, Friese and Washburn, 2017). It is especially relevant to our analytical context of distributive energy justice as this study uses culture-based identification of injustices associated with SRH under study (see Table 19).

7.5 Results

7.5.1 Energy cultures in the slum rehabilitation housing

The energy cultures in the slum rehabilitation housing (SRH) in the three cities under study have heterogeneity concerning energy practices, norms and material culture that relate strongly with built environment's typology. 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 the 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 housing planning and execution. 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 Table 20.

Aspirations play a critical role in defining the norms of the SRH communities under study. It can be seen from Table 20 that owning certain appliances are a 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.

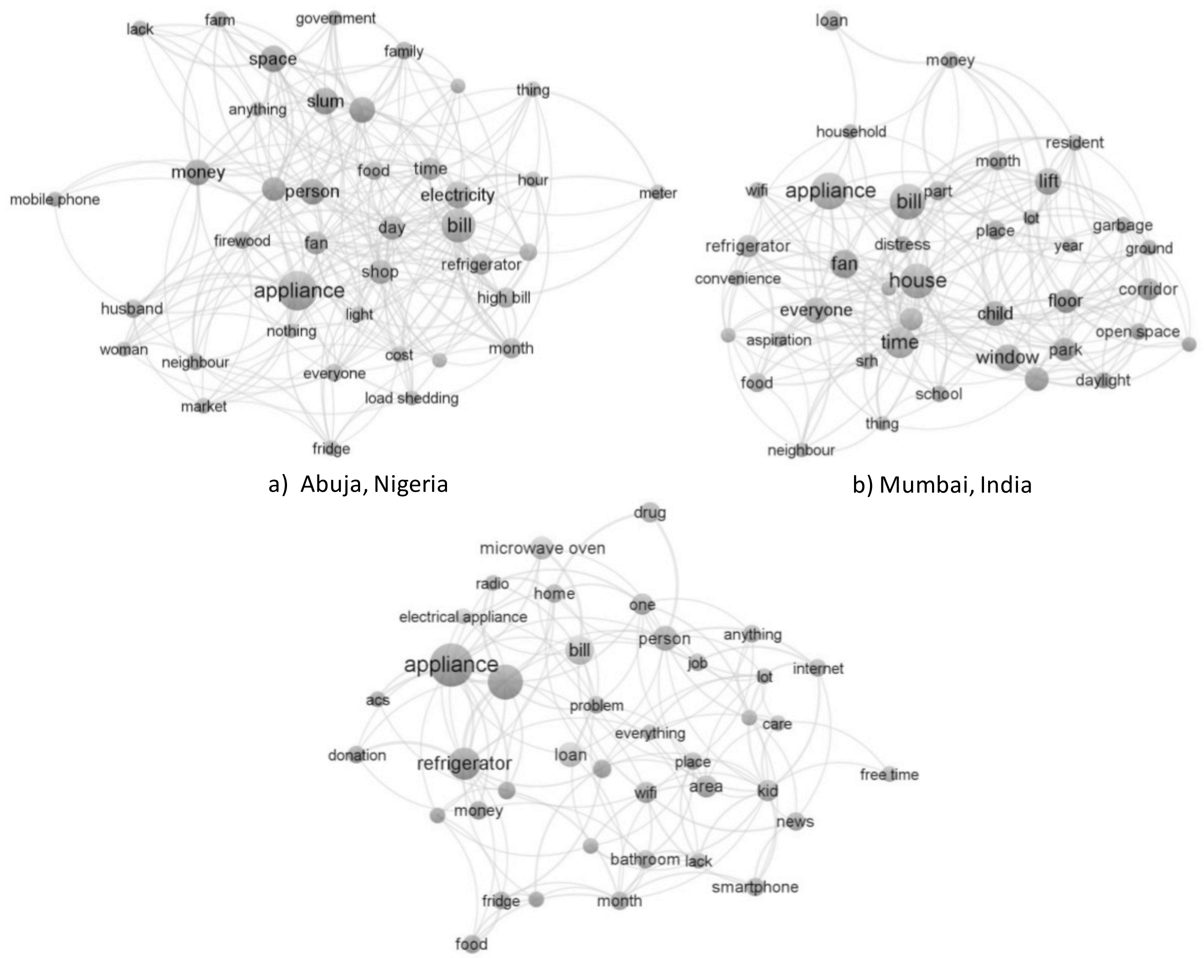
The built environmental characteristics also shape these energy aspirations. For example, Mumbai's lack of open spaces and the cramped vertical structure of the SRH forces occupants to spend more time indoors, resulting in higher energy intensity. It created a shift in energy practices, as shown in chapter-4, that is influencing the socio-cultural energy service demands (see chapter -5). Similarly, in Abuja, the strong rural-community settings of the SRH had established a shared energy cultural identity that 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 increased distress and energy demand (see Table 20).

Table 20 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.	- 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.	- Poor power quality and reliability is a significant issue. Heavy use of power stabilizers that damages appliances. - Lack of responsiveness from utility companies concerning

Energy cultures	Rio de Janeiro, Brazil	Mumbai, India	Abuja, Nigeria
	- 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.	- 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 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.	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.

The heavy influence of the SRH built environment factors in the occupants' energy cultures narratives in the three cities can also be observed from the semantic network of high co-occurring terms in Fig 40. The built environment effect on the energy cultures is distinct for Abuja, Mumbai and Rio de Janeiro, where the circle's size shows 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 they had ramifications in the short operational life of appliances. It added to occupants' energy burden as the repair shops were far from the SRH. The time – cost associated with it was significant, an example of distributive injustices' spatial characteristics at the grassroots level.



a) Abuja, Nigeria

b) Mumbai, India

c) Rio de Janeiro, Brazil

Fig 40 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 40. For example, in Abuja, 'lack' and 'space' denoting lack of space in the SRH dwelling units (see Fig 40a). 'Garbage', 'corridor' and 'open spaces' illustrate the lack of open spaces and open garbage dump between SRH buildings in Mumbai (see Fig 40b). Lack of 'bathroom' implicating poor sanitation and hygiene conditions in the SRH of Rio de Janeiro (see Fig 40c). These built environment design factors have an indirect implication on the energy cultures and high energy 'bills' in the study areas discovered through the deep-narrative analysis.

7.5.2 Zooming – out: topic discovery in aggregated narratives

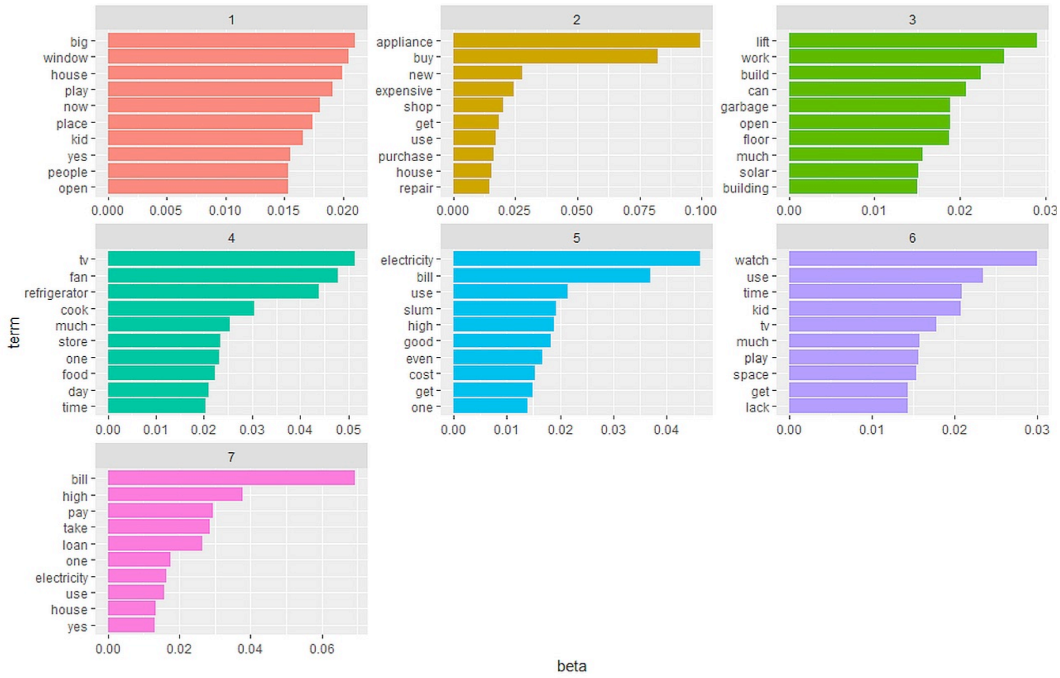


Fig 41 Topic discovered by LDA from the energy cultures narratives in the slum rehabilitation housing of Abuja, Mumbai and Rio de Janeiro. [Note: 'beta' represents per-topic-per-word probability]

Seven topics were discovered through topic modelling using LDA (see Appendix-I 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 energy cultures' commonalities in the low-income built environment. The discovered topics generate critical inference for identifying distributive injustices at the grassroots level.

Topic 1 and topic 6 appear to be related to the SRH built environment's socio-spatial dynamics (see Fig 41). 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 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 in Fig 40. For example, an occupant from Mumbai said that her child ran away from home as he could not access any playgrounds as compared to living in horizontal slums (R10 Mumbai).

> *"… 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 to her home because of such built environment conditions. In Abuja, the room's small size and lack of space for storing firewood for cooking were abundant in the narratives (also shown in Fig 40).

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 20 (also observed in (Debnath, Bardhan and Sunikka-Blank, 2019a, 2019b; R. Debnath *et al.*, 2020)). Energy cultures associated with thermal comfort and appropriate ventilation can be referred to 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 (Bardhan, Debnath, Jana, *et al.*, 2018a).

Availing internet services through Wi-Fi informs on the changing energy cultures and the kind of energy services 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 20). 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 (Sovacool, 2011)).

Topic 2, topic 4 and topic 5 revealed information on the energy cultures and appliance uptake in the SRH (see Fig 41). Change of household practices due to slum rehabilitation was associated with higher energy intensity through higher appliance uptake in Mumbai *(Debnath, Bardhan and Sunikka-Blank, 2019b)*. The energy cultures associated with appliance uptake in the SRH were highly intertwined with the socio-cultural energy services derived in poverty (see Table 20). 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 the cooling-only device in this SRH. In Rio de Janeiro, refrigerators were used as 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 40a).

The occupants also revealed that in Abuja, instead of refrigerators, people buy deep freezers to 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, 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 characteristic of a Brazilian energy culture that can also produce repair and second-hand retail shops in Rio de Janeiro (Scartezini, 2013). However, it raises the question of the energy efficiency of such pre-owned and passed-on appliances for people living in poverty. 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 41).

High electricity bills were the most common complaint in the Indian and the Nigerian case (see Table 20 and Fig 40). 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 they get very high bills despite frequent load-shedding, almost 90 - 150% of their monthly households' income. Surprisingly, they were yet to have electricity meters. Therefore, thw administrative lag of the DISCOMs at the low-income end-use side is a critical distributive justice issue in the SRH.

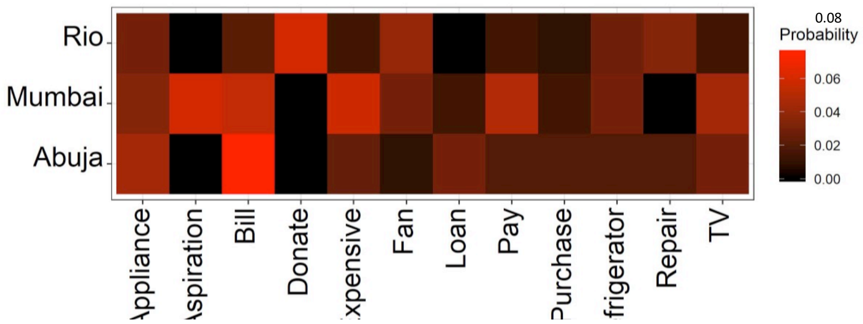
High probability (β) of words like 'loan', 'bills', 'electricity' and 'house' in topic 7 (see Fig 42) further emphasised the poverty penalty of living in SRH due to injustices caused by poor governance and high tariff rates of the utilities. Additionally, in the three case studies, occupants revealed they had to travel far to repair or purchase appliances that added to the poverty penalty of living in the SRH built environment. Moreover, no trusted pre-owned appliance shop in the Indian and Nigerian case and no culture of handling-down used appliances (like in the Brazilian case). It further illustrated that occupants had to pay the full price and travel and daily wage costs to purchase a brand-new (expensive) appliance. It showed the nexus of the poverty penalty and human-scale energy services in such a built environment. Just energy policy should address this nexus to reduce the 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. 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 illustrates where community-led microdonations schemes are being used to fund communal energy services like streetlights and lift-operations in the buildings (see Fig 41). Section 7.5.3 zoom-in through these topics to extract crystallised narratives of energy injustices in the study areas.

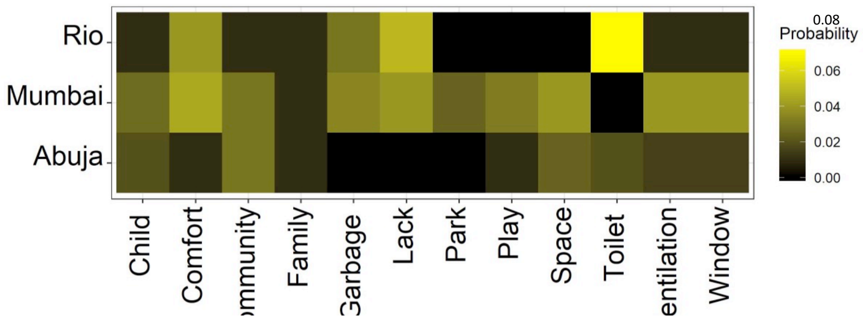
7.5.3 Zooming – in: deep-narratives of distributive injustices from the study areas

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 42). These clusters represent the energy injustices in the respective slum rehabilitation housing (SRH). Fig 42a illustrates the injustices associated with energy service demand through appliance ownerships. The highest probability words in this cluster are associated with the word 'bill' and 'expensive', representing 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 (see *R3 and R4, Mumbai, India*),

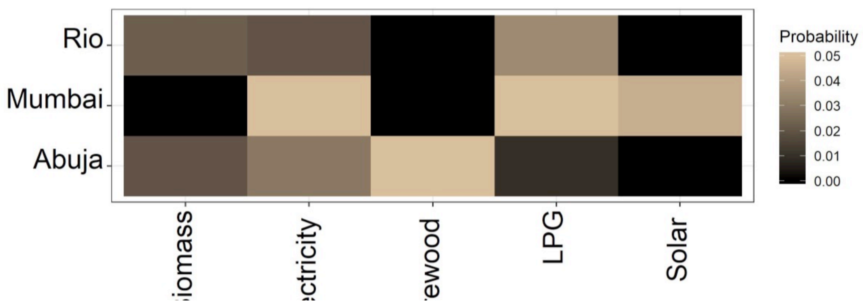
> *"… there is always huge variation in the bills, sometimes we get Rs. 1300 (~19 USD) and sometimes Rs. 2000 (~28 USD). But it is usually on the higher side and extremely irregular…I got my latest bill after three months…"* (R3, Mumbai, India)
>
> *"… many people complained to the distribution company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



a. Cluster A: Appliance ownership factors



b. Cluster B: Built environment factors



c. Cluster C: Fuel stacking

Fig 42 Zooming -in the high probability words in the energy cultural narratives from the slum rehabilitation housing in Abuja, Mumbai and Rio de Janiero (Rio)

In the case of Abuja SRH, injustices are in high and irregular electricity bills (see *R1 and R5, Abuja, Nigeria*). The low quality of power and frequent load-shedding also adds to this distress (see *R1, Abuja Nigeria*), as it shortens the appliances' operational life. The poverty-penalty associated with repairing and replacing the damaged appliances are very high (see *R2, Abuja, Nigeria*). Occupants must travel to the city centre to avail repair and maintenance services at the cost of daily wages (see *R1, Abuja Nigeria*). 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 (see *R1 and R2, Mumbai, India*) and Abuja (see Fig 42a and *R4, Abuja Nigeria*) and 'donations' for Rio de Janeiro (see *R1, Rio de Janeiro, Brazil*). 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 chapter – 5). It defines the 'norm' specific element of energy cultures of these places. In contrast, the poverty-penalty associated with such aspirational buying adds to the households' energy distress (also discussed in chapter – 4, *see R1, Mumbai, India and R5, Abuja, Nigeria*). In the Rio de Janeiro case, the aspirations were of buying was in parallel with that of receiving appliances as 'donations' (see Fig 42a and *R1, Rio de Janeiro, Brazil*). However, this donation-based model passes on energy inefficient or older appliances with higher operational and maintenance costs (also mentioned in section 7.5.2). It adds to the poverty-penalty in 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 7.5.2, households in Mumbai and Abuja try to derive economic utility from a refrigerator by storing flowers (see *R3, Mumbai, India)* to renting racks in the refrigerators for cold storage (see *R4, Abuja, Nigeria)*. However, in Rio de Janeiro, the refrigerator had a more excellent utility as a storage cabinet (see *R8, Rio de Janeiro, Brazil)*.

> *"…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 42b shows the high probability word clusters associated with built environment design and energy cultures in the study areas. Section 7.5.1 and 7.5.2, respectively, define how poor design elements in the SRH are affecting energy decision-making in the households and influencing the energy cultures (see Fig 40; and *R2 and R11, Mumbai, India; R3 and R4, Rio de Janeiro, Brazil; R2, Abuja, Nigeria*). 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 study areas (see Fig 42c). It has critical implications for distributive energy justice at the grassroots level. It translates to climbing the urban energy ladder to improved household welfare in poverty (also implied in (Sovacool, 2011)). For example, in Abuja, cooking fuel primarily remains firewood-based. which has a significant health burden (see *R1, Abuja, Nigeria*). In contrast, the primary source of energy for households is grid-based electricity that remains unreliable and expensive. The occupants want alternate sources of energy that are affordable and accessible (see *R4, Abuja, Nigeria*). 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 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 (see *R3, Mumbai, India*).

> *"… 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)

7.6 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 the 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 40 and Table 20. Utilising this connection is critical in policy design for the UN SDG – 7 (clean and affordable energy), UN SDG – 3(good health and well-being) 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 communities. Section 7.5.2 established the commonalities linking the 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 41). 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, a lack of repair infrastructure and household appliances mechanisms result in lost wages. The occupants must travel far to get appliances frequently repaired due to low power quality and recurrent load shedding in the SRH (see section 7.5.2).

Similarly, in Mumbai, the lack of open spaces in the vertical slum-like structures of the SRH affects 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 dwelling units' poor design (see section 7.5.2).

The seven discovered topics (see Fig 41) 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 and 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 41). Solar rooftop PVs installed through micro-donations from the communities in Mumbai SRH for delivering communal energy services was another example of such a 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. Topic 4 (see Fig 41) further showed the need to provide affordable repair and maintenance shops and trustworthy outlets of used appliances. It will reduce the poverty penalties associated with repairing appliances and promote affordable appliance uptake. Appliance uptake is critical to improving household welfare in low-income (Sovacool, 2011; R. Debnath *et al.*, 2020).

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 negatively affected the households. These factors pushed the households to energy poverty and increased the poverty penalties of living in the SRH (see section 7.5.1 and section 7.5.2). Just policy design must create a robust feedback mechanism to report the occupants' grievances 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. They should be leveraged for better energy governance (see Fig 41), thus supplementing the implications of topic 5. Moreover, topic 7 showed that banking institutions and finance mechanism's role is critical in enabling occupants to climb up the urban energy ladder that is significant to distributive energy justice in poverty (see section 7.5.2).

The zoomed-in view aided in to explore the depth of energy injustices from the narratives (see section 7.5.3). Three topical clusters of high probability words were extracted that illustrated the granular differences in energy cultures in the study areas (see Fig 42). These clusters are crucial in fine-tuning the just policy design variables as they contextualised the spatiality of distributive energy justice. For example, in Mumbai, energy culture is highly influenced by the transitional 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 Chapter 4. This aspirational sentiment is embedded in the energy cultures of the SRH that often motivate 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 7.5.3).

A similar observation was made in Abuja. The occupants are pushed into a poverty trap through frequent damage of appliances due to low power quality (see Fig 41, also discussed in section 7.5.2). In Rio de Janeiro, the norm of donation of older appliances to low-income households created a poverty trap associated with the appliances' energy inefficiency. The occupants often need to pay out-of-pocket to avail repair services 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 42). 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 (M. Sunikka-Blank, Bardhan and Haque, 2019). This built environment design and energy justice link are generalisable for the upcoming wave of low-income housing in the Global South due to rapid urbanisation forces.

Cluster C in Fig 42 showed the energy cultures of fuel stacking in the SRH that indicate that energy justice policies must improve 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 (Bardhan, Debnath, Jana, *et al.*, 2018a; Lueker *et al.*, 2019). 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 7.5.3), which must be financially supported and replicated by government agencies to enabling cleaner fuel switching.

Section 7.5.2 and section 7.5.3 also presented the collective knowledge on the distributive energy injustices in the study areas embedded in the built environment design and energy cultures. The use of deep-narrative analysis also illustrates collective intelligence's power in understanding the length and breadth of distributive injustices in resource-constrained communities. For example, we found that a critical contextual understanding of energy injustices in the Mumbai case study was the disappearance of slum-social networks due to poor built environment design that, in turn, affect energy cultures and the demand for HUSES. In the Rio de Janeiro case, the donation of energy inefficient appliances to low-income households also reveals a critical context-specific injustice unique to this study area. Similarly, in Abuja, the distributive energy injustices were deeply embedded in the spatial distribution of SRH communities. Occupants must frequently repair or buy appliances that are often damaged due to low power quality and load shedding. It adds to the poverty burden of living in these areas.

Collective intelligence-driven methods like the deep-narrative analysis contribute to the current methodological gap of extracting contextualised understanding of energy injustices (see section 7.3.1 and section 7.3.2). Novel crowdsourced datasets like narratives and experiences can bridge the knowledge gap in bottom-up just energy policy design. However, further research is needed on the scalability of such methods.

7.7 Chapter 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 energy cultures' theoretical lens in slum rehabilitation housing (SRH). The SRHs are a transitional 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 presented in Chapter 6, which 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 UN SDG – 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 from this chapter 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 these communities' cultural identities associated with availing specific energy services are transferred across the transitional built environment. It will mean exploring newer definitions and contextual distributive energy justice theories, 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. This study's findings showed that 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 the household level in low-income settlements like the SRH must be accelerated to avoid fuel stacking behaviour. Results showed that in Abuja SRH, the household's energy mix 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 appliances. Therefore, the fuel mix is not clean, and it is 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. In the Mumbai SRH, 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 influences 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.

This chapter's findings represent 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; this study's bounded scope is a limitation. A theoretical limitation was posed by the static definitions of distributive energy justice 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 to identify the changing cultural identities with human-scale energy services in poverty. It can inform researchers to design solutions to improve household welfare through infrastructural, administrative and technical means.

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CHAPTER 8 Concluding remarks

Thesis conclusion, implications, limitation and future work

This thesis investigated distributive energy injustices in poverty using case studies of slum rehabilitation housing (SRH) in Brazil, India, and Nigeria. The critical purpose was to explore and identify primary links between built environment design variables and human-scale energy service (HUSES) demand in low-income and transitional communities to inform just energy policy design. These links are critical in reducing affordability asymmetries associated with the accessibility of HUSES in poverty to improve the well-being and sustainable development of low-income communities. In doing so, a conceptual framework was forwarded to evaluate the spatio-temporality of HUSES in slum rehabilitation communities. That is, the location-based (spatiality) and time-based (temporality) effects were explored to evaluate the associated energy injustices using a mixed-method computational approach.

The mixed-method approach combined the empirical and narrative-based analysis of distributive injustices on accessibility, usability and affordability of modern form of energy using field-based observations, data and understanding in the SRH. The central methodological contribution was in developing a novel deep-narrative analysis framework that enabled zooming-in and zooming-out of a large corpus of narratives using natural language processing and machine learning techniques to reveal statistically significant and contextually relevant 'words/terms' for policy design application (see Chapter 6 and Chapter 7). This methodology of using machine-learning-based topic modelling and constructivist grounded theory to extract latent themes from the narratives of energy injustices in the SRH of India, Brazil and Nigeria combining can be considered as an advancement to the growing body of literature in computational social sciences (as described in Chapter – 6). While the deep-narrative analysis identified spatial aspects of distributive injustices, the temporalities associated with SRH and its effect on distributive injustices were evaluated through the changes in household energy practices before and after moving to SRH (see Chapter 4 for the case study in Mumbai SRH). These changes were quantified and empirically correlated with the study areas' built environment design variables using structural equation modelling (SEM). Additionally, causal relationships between built environment design elements and demand for comfort, cleanliness and convenience as socio-cultural energy services were investigated using a comparative case study of India and Brazil (see Chapter – 5).

This thesis was built on the research gap in the present energy justice literature that demanded context-driven policymaking in the Global South's marginal communities. Contextualisation of household energy demand across the spatial and temporal scales in the SRH of India, Brazil, and Nigeria helped derive granular insights into the socio-technical and socio-cultural processes that drive the demand for specific energy services in poverty. The systematic placement of built environment design variables at the centre of distributive justice's discourse in low-income community informs the broader implications of this thesis. Moreover, the deep-narrative analysis framework offered a methodological toolkit for extracting rich and context-specific insights from the grassroots level using narratives and stories of distributive injustices. For example, it was found that in the Mumbai SRH, a significant injustice was caused by the administrative lags of electric utility companies that irregularly billed occupants, which was usually more than their monthly household income. This thesis's contextualised investigation revealed that administrative lags were caused due to frequent change of utility companies in the SRH.

In Abuja, injustices were deeply embedded into poor power quality, frequent load shedding and high monthly electricity bills. The poor power quality and load shedding damaged the household appliances that create a poverty trap as the owners must travel to the city to get it repaired or buy a new device at an additional cost of travel and lost wages. It revealed distributive injustices linked with the spatial placement of the SRH and energy provisioning in the built environment unique to this context. Similarly, in Rio de Janeiro, distributive injustices were embedded through inefficient appliances donated to the people living in low-income communities. While passing down used appliances to low-income households is acclaimed as a welfare program, but contextualised understanding shows the formation of a poverty trap through inefficiency burden.

This thesis showed the unintended consequence of slum rehabilitation and affordable housing policies in the Global South that profoundly maximise occupancy to fill the housing deficit. Contextualised understanding of distributive injustices in the study areas also revealed that open spaces and walkable streets are critical built environment variables that modulate occupants' demand and practices for specific energy services through appliance ownership. Besides, lack of built environment elements like daylight, indoor air quality, and cross-ventilation also indirectly influenced appliance ownership in the SRH households. For example, in Chapter – 4, a causal model was developed linking shift in household practices, built environment factors and appliance ownership criteria for occupants who moved to an SRH in Mumbai in the past six months. Results showed that two non-income factors were critical in influencing higher appliance ownership. First was poor built environment quality and lack of open and community spaces. The second was an aspirational driver of owning specific appliances as they now moved into a permanent housing structure.

Similarly, in Chapter – 5, a spatial comparison was made between an SRH in India and Brazil. It was found that the built form was critical in modulating energy service demand. The Indian built form was multi-storeyed vertical structures with eight floors with no open spaces or walkable areas. In comparison, the Brazilian built environment was characterised by one-storeyed housing units with adequate open spaces and walkability. The Brazilian households had higher appliance ownership demand as they demanded higher energy for comfort and convenience than the Indian households.

The above examples show that even in similar socio-economic conditions, the contexts vary due to the distinct typology of the built environment. This thesis further demonstrates the need for new empirical data to capture the contextualised distinctions of energy demand in such communities. Here, Chapter – 3 illustrated the systematic approach towards identifying temporal and spatial contexts of distributive injustices in the study areas using structured (e.g., household energy use survey data) and unstructured datasets (e.g., narratives of energy cultures).

Concluding remarks are presented in two sections. Section 8.1 presents a detailed summary of key findings and their policy implications. Section 8.2 illustrates this thesis's new theoretical contribution, and section 8.3 presents the novel practical and methodological contribution of this doctoral research. The limitation and future work are presented in section 8.4 and section 8.5, respectively.

8.1 Summary and key findings

The primary aim was to understand the unintended consequences of a developmental policy such as SRH, which promises to close the looming housing deficit in the developing world. While the SRH policy on its own is much needed, but also opens up several unanswered questions on distributive justice, which this thesis intended to respond to through a series of questions. This section provides a summary of the critical findings and the policy implications.

1. How does the transition from slums (informal settlements) to a low-income built environment (SRH) affects the demand for energy service?

The transition from horizontal slums to a low-income built environment like the SRH influences energy demand through changes in household practices. In Chapter – 4, a causal relationship between changing household practices, appliance ownership and built environment variables were established using structural equation modelling (SEM) on a 1224 household survey dataset in an SRH in Mumbai. It shaped the socio-technical discourse of this thesis, as per the analytical framework presented in Chapter 3.

Chapter – 4 investigated the temporalities of domestic energy demand in transitioning built environment. Results showed that appliance ownership rise after shifting to SRH is significantly substantial for refrigerators and washing machines. Almost 72% of the refrigerators and 75% of the washing machines were bought after moving into the rehabilitation house (see Fig 15). Television ownership almost doubled (49%) on moving to SRH, and similar numbers are recorded for an increase in clothing iron ownership (47%).

The ownership of air conditioning units (AC) rose by 100% (see Fig 15), even though AC units represented only 4.90% of total appliance ownership in the study area. Almost 99% of the households had ceiling fans as the primary cooling device. However, there was a 35.45% increase in its ownership upon shifting to the SRH (see Fig 15). Such an increase in cooling device ownership indicated increased discomfort in the built environment that was statistically established in the SEM model.

Temporal changes in household practices were illustrated in Fig 16, which showed an almost 50% reduction in cooking, washing, and cleaning time. There was no time allocated for subsistence activity in the SRH, usually more than 2 hours in the horizontal slums. On the contrary, the time spent using ICT devices and watching TV increased by almost 50% (see Fig 16). These change in the temporal pattern was found to be associated with the built environment design of the SRH, as life became more private, and household practices reoriented around it. The washing time reduced due to the shifting of practices to washing machines, the cooking time went down as they had to cook for only the family members, and not as a communal meal. Indoor and private cooking also influenced the higher adoption of refrigerators in the households as they could store a larger quantity of cooked meal for days. It was absent in the horizontal slums because the community preferred readily cooked meals, which limited the requirement of a refrigerator. Lack of space in the horizontal slums was also contributed to the low refrigerator ownership.

The SEM results showed that that change of built environment from horizontal slums to vertical SRH apartments positively influenced household practices (0.16), while it significantly accentuated on specific appliance characteristics (0.20, $p < 0.01$) to be central in purchase decision making (see Fig 17). The appliance characteristics had a significant positive influence on the changing household practices in the SRH (0.47, $p < 0.01$) (see Fig 17). It was found that household practices in the horizontal slums revolved around the outdoor spaces where activities like cooking, cleaning and washing clothes used to be performed communally. The current design of the SRH restricts such as social spaces, which was shifting these activities indoors, that in turn, was increasing the energy intensity of the activities that are translated into higher electricity bills for these low-income households.

Model results also showed that there was a significant increase in indoor household activities upon moving into the SRH that significantly influenced the household practices (0.10, $p < 0.01$), which strongly influenced higher appliance ownership (0.27, $p < 0.05$) (see Fig 17). It was also found that poor built environment conditions due to the inappropriate design of the SRH negatively affected thermal comfort (0.52, $p < 0.01$) and indoor air quality (0.25, $p < 0.01$) level. The built environment design and appliance uptake in SRH had a significant negative factor loading (0.22, $p < 0.01$). A generalisable relationship was established by evaluating the direct and indirect effects on the appliance purchase after shifting. The total estimated effect of each factor is presented in Table 6. Appliance characteristics (0.158) and household practice (0.265) had a stronger total effect on appliance ownership after shifting to the SRH. The built environment had a stronger indirect effect (0.75) on the increased appliance ownership after shifting.

Chapter – 4 demonstrated that non-income factors around energy practices influence appliance ownership, and therefore electricity consumption. It was found that appliance ownership increases when household practices shift indoors due. It illustrated the temporalities in energy demand due to the built environment transition from horizontal slums to vertical SRH units. Another critical effect observed was that poor indoor air quality, hygiene, and thermal comfort acted as a compensatory trigger for higher appliance purchase. Sub-standard design of social housing like the slum rehabilitation housing poses health hazards to the occupants, but the empirical findings indicated the possibility of energy burden on the occupants through higher electricity bills.

While Chapter – 4 established an empirical relationship of the temporal effects of slum rehabilitation on household practices and energy demand in SRH of Mumbai, India. Chapter – 5 further expanded it spatially across SRH in Joao Pessoa, Brazil. Here, the effects of the built environment were investigated by factoring in the influence of building typologies on domestic energy demand. However, building on the limitations of the practice-based approach across spatial scales, the energy demand was envisaged as the need for socio-cultural energy services for comfort, cleanliness, and convenience (3Cs) (as discussed in section 3.2.2).

Chapter – 5 empirically showed that lack of built environment parameters like privacy and window opening in the SRH of Mumbai, India influences higher energy-intensive cooling device ownership with an odds-ratio (O.R) = 14.939 at $p < 0.05$ (see Table 11). It was found that occupants do not open the windows of the SRH units due to privacy issues. Closed windows and high occupant density (~0.25 person/m2) increase the indoor temperature, leading to a rise in the need for energy-intensive cooling demand through AC ownership. Table 12 further illustrated that lack of walkability influenced counter-responsive behaviour towards higher the likelihood of convenience device ownership like clothing iron (O.R. = 0.105, $p < 0.01$) and refrigerator (O.R. = 5.201, $p < 0.05$) in the Mumbai SRH.

It was also found that In the SRH of João Pessoa, Brazil, the appliance ownership was observed to be twice that of the SRH in Mumbai (see Fig 20). Regression results showed a significant influence of fan (O.R. = 5.414, $p < 0.05$) and water cooler (O.R. = 18.690, p <

0.05) ownership in the energy service demand for comfort (see Table 13). It was found that the built environment design of the Brazilian SRH was relatively better than that of the Mumbai case. However, it lacked appropriate socio-architectural design compatibility, i.e., lack of social context-specific design of the SRH built environment (see Table 8). Occupants revealed a lack of safety and well-ventilated spaces as significant distress. This socio-architectural incompatibility was found influence higher demand for convenience-led energy services through appliance ownership like microwave ovens (O.R. = 0.276, $p < 0.05$), washing machined (O.R. = 1.373, $p < 0.05$) and radio (O.R. = 3.754, $p < 0.05$) (see Table 14).

Chapter – 5 showed that energy demand in transitioning built environment is critically influenced by the typology of the slum rehabilitation housing and its socio-architectural design compatibilities like privacy, safety, walkability and open spaces. It further showed that for contextualising energy justice in SRH, it is critical to weigh the appropriateness of built environment design, influencing the demand for socio-cultural energy services (comfort, cleanliness and convenience). The lack of these elements translates into distributive injustices.

2. What are the distributive energy injustices in low-income built environment (SRH)?

This question was addressed in Chapter – 6 and Chapter – 7 through an in-depth investigation of distributive energy injustices in the SRH communities at a spatial scale, i.e., using case studies across India, Brazil and Nigeria. The injustices were identified using occupant-led narratives of energy cultures in the study areas. Energy cultures theory was used to derive multifaceted context around energy practices, social norms and built environment factors of the SRHs (the conceptual details are discussed in Chapter – 3 and section 3.2.2).

The distributive injustices were evaluated across two levels. Macro-level presented a combined view of injustices across three study areas, while the micro-level presented granular details about the social-technical and socio-cultural processes associated with specific energy service demand in the SRH. The deep-narrative analysis (DNA) methodology was developed to enable objective scalability in narrative analysis (see Chapter – 6 for detail). DNA helped in zooming-in and zooming-out of the narratives of energy injustices.

At the macro-level, it was found that administrative lags of utility companies were causing distress amongst the SRH occupants. For example, both in Abuja and Mumbai, the occupants received electricity bills in a lumped and irregular manner. It often led to bills higher than most households' monthly income, creating energy poverty traps. Zooming-in to Mumbai's case, it was found that such administrative lags were caused due to frequent shuffling of utility companies as they find SRH less profitable. Similarly, zooming-in Abuja's case, found that poor power quality and frequent load shedding may cause administrative delays.

The regular load shedding and poor power quality in Abuja frequently damaged the household appliances. Occupants must travel to the city centre to either repair these appliances or purchase new ones at a heavy financial burden. They revealed that a return trip to the city centre usually accounts for an entire day of lost wages. It creates a poverty trap associated with the poor power quality and spatial inaccessibility of the SRH units from the city centre. Similarly, in the Mumbai case, occupants revealed that they take loans from informal money lenders to pay electricity bills that create additional poverty traps (see Chapter – 7). Besides, the narratives from Mumbai SRH also revealed that despite higher electricity bills, they have to keep their lights and fans on throughout the day as their housing units do not get adequate daylight or ventilation. Thus, it revealed distributive injustices caused by poor built environment design.

On the contrary, the SRH in Rio de Janeiro did not have formal electricity provisioning, and occupants usually access electricity from the nearby electricity pools using frugal methods like hooking. Such distributive injustices were created as this was an informal SRH created due to employment-related displacement (see Chapter – 7 and Table 19).

Results showed two distinct characteristics in distributive injustices in accessing energy services in these communities. The socio-technical characteristics represented a lack of physical energy infrastructure and poor built environment planning, as mentioned above. The socio-cultural system showed specific cultural characteristics that shaped the demand for specific energy services. For example, the SRH occupants in Mumbai had a dichotomous urban-rural characteristic that shaped their energy practices as communal activities (also shown in Chapter – 4). They needed open and communal spaces to maintain their social network, which modulated their energy service demand. On rehabilitating to the SRH, this social network was broken that shifted their practices indoors, thus, increasing the energy intensity (as discussed above). This change in practice demanded energy for watching TV and ICT devices, operating washing machines and individualistic cooking. It resulted in higher electricity bills (shown in Chapter – 4) and revealed through narrative analysis (see Fig 34).

The SRH occupants in Abuja had a strong rural characteristic that shaped their needs for socio-cultural energy services. For example, households shared appliances like refrigerator and derived economic utility by renting their shelves in the summer months. It was a distinct socio-cultural process that shaped convenience-based energy demand (see Chapter – 7). However, distributive challenges occur when shared appliances are damaged frequently due to poor power quality. Repairing becomes a significant financial burden. Similarly, distributive injustices were embedded in fuel stacking behaviour as these households primarily used firewood for cooking while the rest of the appliances were operated on electricity. The prevalent use of firewood was due to rural-centric energy cultures, and it is inexpensive compared to LPG stoves (see section 7.5.3 and Fig 42).

The distributive injustices in Rio de Janeiro's case were embedded in its informality as the SRH was built privately by occupants. It did not have access to amenities like toilet, sanitation or electricity connections. Occupants usually received used appliances in donations from higher-income households, but this process had a distinct distributive injustice. This donation scheme fundamentally handed down inefficient appliances that embedded higher costs (see section 7.5).

Besides, poor built environment design and planning was found to cause distributive injustices by restricting occupants of open spaces, walkable streets, daylight, ventilation, privacy and safety in the study areas, as discussed in the previous question.

3. What is meant by contextualised just energy policy for people living in SRH?

Contextualisation of the distributive justice in the SRH was done by investigating the temporal and spatial dimension of energy demand in such a built environment (see Fig 10 and Fig 11). The temporalities were derived through a practice theory-based lens that accounted for the change in time spent in specific household activities and its associated influence on appliance ownership and household energy demand (see Chapter – 4).

The spatial dimensions were evaluated using narratives of energy cultures. Chapter – 7 showed that contextualisation of distributive energy justice in poverty must emerge from built environment design appropriateness. This approach to policy design may ensure that these communities' cultural identities associated with availing human scale energy services (HUSES) are transferred across the transitional built environment (like SRH).

This study also showed that distributive justice at the household level in poverty occurs from the energy system's distribution side. Findings showed the need of enhancing the existing administrative mechanisms around the utility governance of electricity in low-income communities under study. Narrative analysis revealed administrative lags, irregularity of billing cycle and low power quality in the SRHs are directly linked to more significant poverty penalties of living there (see Chapter – 7). The administrative lags are translated into injustices in low-income communities, and they must be addressed systematically in inclusive policy design.

Another critical contextualisation factor derived in this study was the need for an appropriate fuel switching mechanism in low-income communities. Cleaner fuel switching at the household level in the SRH must be accelerated to avoid fuel stacking behaviour. Chapter – 7 showed that in Abuja SRH, the household's energy mix consisted of firewood for cooking and electricity for household appliances. Similarly, in Mumbai SRH, the energy mix consisted of kerosene and LPG for cooking and electricity for powering appliances. 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. In the Mumbai SRH, the occupants collected micro-donations to install rooftop solar PV systems to power public goods like lifts and streetlights. It demonstrated that with solar energy solutions getting cheap and accessible, it influences the energy culture towards self-reliance. Castán Broto, V et. al, (2018) refers to it as energy as emancipatory project or energy sovereignty in post-colonialism. Just energy policy in this context must support such micro-scale transition in the household fuel mix.

4. How to extract context-specific information on energy injustices from the occupants living in SRH? How to quantitatively analyse narratives for just policy design?

This research question was addressed by developing an original narrative analysis methodology using natural language processing (NLP) and constructivist grounded theory. This new method was called deep-narrative analysis (DNA), and its analytical details are presented in Chapter – 6. This methodology presented a nested approach to extract context-specific information on energy injustices using grounded narratives of the occupants living in the SRH. The narratives were collected through participatory surveys like focus group discussions (FGD).

The DNA enabled quantitative analysis of narratives for just policy design introduces insight generation capabilities based on the probability distribution of words and topics in a text corpus. In this manner, the proposed methodology deconstructs the corpus and enables the analyst to answer research questions based on the foundational element of the text data structure. As mentioned earlier, DNA is based on the foundation of a probability distribution that provides a higher degree of freedom to zoom-in, zoom-out and zoom-through the problem. With zooming-out, possibilities and assumptions that are forgotten or taken for granted can be better recognised; zooming-in aids better understanding of the granularity hidden in the frequentist summaries of central tendencies, granularities hidden in often-repeated statements. Most importantly, zoom-through in a computational model can critically analyse narratives as to material reality, norms and practices that determine the energy cultures.

The DNA is based on a four-step process flow. The NLP-based topic modelling (TM) results were used as the starting point for the deep-narrative analysis. The discovered topic and word clusters from TM established the probabilistic (β) background for investigating the narratives (see step – 1, Fig. 28). The high β values of the words in each topic were contextualised with the original narrative text. This contextualisation was done using a grounded-theoretic (GT) approach, such that high-β words acted as a surrogate for the 'open' and 'selective' coding process of GT-based research. The contextualisation step intrinsically also linked the latent factors in the narrative data to enable an in-depth understanding of the built environment – energy nexus in poverty in the slum rehabilitation housing in Mumbai. Thus, step-2 (see Fig. 28) generated our own probabilistic 'code system' based on the narrative texts.

However, unlike qualitative data analysis, this code system has an unsupervised probabilistic background. It added statistical signification to it, but the unsupervised nature of TM also eliminated the directional biases. The code system was now used to perform 'theoretical sampling' as per GT (see step 3, Fig. 28). The theoretical sampling, now supported by β-values, was used to develop the emerging theory and elaborate on the narratives' main categories (see step 4). In this thesis, the derived grounded theories were used to derive grounded-policy focus points. These focus points are independent of directionality bias and have a degree of certainty due to their statistical foundation. Thus, adding a quantitative basis to narrative analysis.

DNA does not replace qualitative methods like grounded theory or narrative analysis, rather enhancing its insight generating capability by using Bayesian policy modelling and evidence analysis methods based on probability laws. The combination of probabilistic models with the grounded theory for narrative analysis may reduce directionality biases in interpreting results in energy policy research. The directionality biases are reduced because the proposed model depends solely on the word-word, word-topic and topic-topic interrelationships defined by probability distribution functions. It enables the analyst/researcher to build the topic models to answer the research questions, rather than adapting research questions to be answered through topic models.

8.2 New contribution: Contextualising distributive energy justice theory from bottom-up

The conceptual framework presented in chapter 3 specified the temporal and spatial scope of this thesis's energy injustice investigation. The temporal dimension of distributive injustices in this study was defined by the before and after human-scale energy service (HUSES) demand among the slum households of Mumbai. It was observed that energy intensity increases on slum rehabilitation due to change in the built environment, influencing household practices and norms. For example, in the Mumbai SRH case, a lack of social spaces was shifting household activities like cooking and washing indoors, which was usually performed as a collective activity in horizontal slums. This indoor practice shift was found to increase the energy intensity of the activities through specific appliance ownership, translating to higher electricity bills (discussed in Chapter -4).

The energy injustices observed in this temporal investigation implied the need for revision in regulatory and structural frameworks of the energy-housing nexus in poverty. While any slum rehabilitation policy's practical goal is to fulfil the housing deficit and improve the quality of life of its occupants, the actual translation of these policies into practice is led by market forces. For example, in Mumbai SRH, the houses were built with the sole objective of maximising occupancy that can address the government's national policy of 'Housing for All'. This intrinsic motivation led to a market-driven SRH planning mechanism, where the developers build the SRH and get the slumland to construct luxury apartments for the pricey real-estate market. This mechanism renders the SRH unit an industrial design project with apartments stacked like shoeboxes in hyper-dense conditions. The ultimate effect is creating another vertical slum that inherits distributive injustices in the energy, water and sanitation sectors.

A key conclusion of this thesis from Chapter – 4 was the accountability of built environment design appropriateness that can foster energy conservation by enabling practices associated with the socio-cultural identity of the occupants. Provisioning of open and social spaces in the SRH fabric can create hybrid modes of performing household activities to balance the rising energy intensity. From a distributive energy justice theory perspective, such actions represent contextualised interventions connecting housing, built environment and energy dimensions of HUSES in the low-income built environment. Such examples of contextualised policy design are scarce in the present energy justice literature (see section 2.1), and this thesis contributed significantly to this gap.

Similarly, the horizontal investigation of distributive injustice revealed the need for a contextual understanding of the process of slum rehabilitation across the spatial scale. For example, the slum rehabilitation context was distinct in the Indian, Brazilian and Nigerian cases. In Mumbai, the SRH is under the government's 'Housing for All' policy, which mandated rehabilitating slum dwellers to vertical hyperdense apartment units. Similar, government-led slum rehabilitation was in the Joao Pessoa, Brazil social housing case. In contrast, the Rio de Janerio's SRH case was due to the unemployment-led displacement of occupants. In Abuja's SRH case, the rehabilitation was characterised by rural to urban migration. Therefore, a contextualised policy design must include such distinct levels of informality to address distributive injustices across spatial scales.

This thesis contributes significantly to the non-western understanding of distributive energy justices scarce in the existing energy justice literature (see Chapter 2). The deep-narrative analysis (DNA) framework provided new a methodology to integrate grounded narratives to just policy design by systematically analysing narratives using a statistical background. Concurrently, this methodology helps remove directionality biases and reduces the manual coding burden in a large narrative corpus. This method extracted latent information on the energy cultures of living in poverty that shaped energy practices, social norms, and material realities in the SRH built environment. Such grounded information is essential in the current discourse of just policy design and the need for a context-specific approach.

Socio-cultural datasets are complicated as they are highly context-specific, small-sized, and subjective to research bias. It makes it challenging to generalise socio-cultural findings for policy analysis. The DNA framework presented in this thesis was designed to handle such datasets embedded in text-based narratives. The use of machine intelligence-based tools like natural language processing, text-based clustering and unsupervised machine learning in handling such complex datasets further illustrated the applicability of social data science in addressing technical limitations of contextualising energy justice poverty. For example, we could empirically zoom-in and zoom-out of occupants' narratives of energy injustices in the study areas using this tool (see Chapter – 7). This zooming-in and zooming-out function are beneficial for contextualising distributive justice problems as it enables the analyst to explore the length and breadth of a socio-cultural context.

Lastly, the built environment's role in just energy policy design was found to be very critical. It remains less explored in the current literature (see section 2.4). This thesis established this link using empirical models using both socio-economic and narrative-based datasets. For example, chapter – 4 employed a structural equation modelling (SEM) approach to derive causal links between built environment design, appliance ownership choice-sets and shifting household energy practices. It was found that a built environment transition influences household practices to purchase more appliances that inadvertently increase the energy intensity of the households. Chapter – 5 presented an empirical model using Firth's binary logistic regression to link built environment design variables with the demand for socio-cultural energy services (comfort, cleanliness, and convenience) through specific appliance ownership across spatial scales. It demonstrated that a lack of appropriate built environment design of the SRH could trigger higher appliance demand for convenience as a counter-responsive mechanism. Such objective transformation of socio-cultural contexts into empirical models are rare in the literature and critical for contextualising distributive justice.

The empirical approach in Chapter – 6 and Chapter – 7 followed the DNA to handle the text-based datasets. These methods extracted rich narratives of energy cultures that revealed the built environment's characteristics for distributive energy injustices in the study areas. Thus, enabling contextualisation of the injustices across the dimensions of fuel stacking, appliance ownership and architectural design elements.

8.3 Policy implications

This thesis contributes to the current discussion on contextualised policy design for low-carbon and just energy transition concerning the built environment and demand-side interventions. Chapter – 4 showed the importance of temporal data and appliance-specific information for accurate demand-side modelling and forecasting of rapidly urbanising cities where most low-income building stocks are yet to be built. Chapter – 5 further demonstrated the need for the systematic inclusion of socio-cultural indicators into household energy models as it can fine-tune HUSES estimations. For example, Mumbai SRH's regression model showed that the increase in demand for energy-intensive cooling devices was due to heightened discomfort caused by lack of open spaces and window opening in the built environment. Similarly, the Brazilian SRH case's regression model showed a lack of walkable spaces caused an increase in energy service demand for convenience.

This research also revealed an under-studied area of utility governance in low-income communities. Case studies from Brazil, India and Nigeria revealed that lack of administrative accountability of utilities and distribution companies in the SRH contributed significantly to the distributive injustices (see Chapter – 7). It was common in Mumbai and Abuja's case that occupants had irregular billing periods that led to lumped electricity billing cycles. They usually receive aggregated bills after three to four months, which is almost twice their monthly income. Even a single month's bills would usually cost around 40 - 60% of their monthly household income. Thus, pushing the households to energy poverty. Occupants' narratives revealed that in Mumbai, the distribution company frequently changes that shuffles the tariff and billing mechanisms leading to irregularity and lumped billing. There is no feedback mechanism for the occupants to amend it, and if they complain, nothing changes.

Critical policy implications drawn from studying the energy cultures in the SRH were associated with the rehabilitation contexts (see Chapter -7). For example, in Abuja, the SRH occupants had a rural identity due to recent rural-urban migration that shaped their social norms towards energy-use behaviour. Fuel stacking was widespread, with firewood being the standard cooking fuel even when electricity and liquefied petroleum gas (LPG) were available. On the contrary, in Mumbai, the households' fuel mix consisted of primarily clean and modern energy sources (electricity and LPG) as the SRH had a stronger urban identity. It was similar to the Brazilian cases, even though these energy sources did not have formal provisioning. Such granular information on non-income drivers of HUSES demand is critical for designing just policies in poverty. A just policy, in this case, should ensure that such asymmetries to accessibility and affordability to modern and clean fuel are reduced.

The knowledge generated through this thesis has practical applications towards two different policy instruments. The first is towards the appropriation of building codes and compliances for low-income neighbourhood design. The built environment design effects on distributive energy justice are critical for future sustainability planning of rapid low-income urbanisation in the present decade. It is profound in the Global South. Such design contextualisation is critical to ensure long-term distributional outcomes of the built environment on overall energy sustainability and the occupants' quality of life, as discussed above.

The second policy instrument is towards streamlining the regulatory framework to alleviate energy poverty and reduce low-income communities' energy burden. It is an absolute necessity for hyper-dense cities like Mumbai and Rio de Janeiro (and many more from the Global South) as they face the climate change effects through frequent and extended heatwave events. Soon, such events will multiply, implicating higher cooling demand. Poor built environment design can increase the indoor overheating phenomenon in the SRH. Occupants will face severe health consequences or be compelled to purchase energy-intensive cooling devices (like ACs). Both of these will cause economic strain at the household level and energy stress at the neighbourhood level. With a flawed distribution system, such energy demand stress can further deteriorate power quality and increase load shedding events. Regulatory reforms and market incentives must address such externalities to address distributive injustices.

This thesis also developed a novel narrative analysis methodology for extracting latent information from the text and public deliberations (like narratives and stories) using a nested application of natural language processing and constructivist grounded theory (see Chapter – 6). This methodology has critical practical applications in the policymaking space as it enables policymakers and analysts to collectively use large scale text-based datasets from narratives to inform decision-making. This methodology represents 'collective intelligence', which creates an enhanced capacity for technology-driven decision-making towards a common welfare goal. Collective intelligence (CI) emerges when these contributions are combined to become more than the sum of their parts for purposes ranging from learning and innovation to decision-making.

CI can enable governments to better understand facts and experiences through citizen opinions and deliberations. These data can be mobile phone location data, grounded voices, social media data and other forms of online data to better understand social problems. Such approach further enables authorities/governments to engage more deeply with citizens to collect their ideas and involve them in decision-making. Digital tools can also enable citizens to propose and debate ideas for the physical infrastructure of their communities.

The policy actors who will benefit from such CI-based tools can be scaled across municipal, state and national levels. The findings of this study are specifically scoped to help municipal and state-level actors responsible for planning and decision-making associated with the slum rehabilitation process. As a strategic approach, CI can enable better representation of grounded voices and, therefore, greater contextualisation of the problems associated with energy access and just transition at the local scale. More importantly, this thesis showed the importance of leveraging the high penetration of ICT devices in the low-income communities using CI-based toolkits to capture the deep narratives of distributive injustices of living in SRH-like housing structures. For example, in all the study areas smartphones were the most common device which forms a central part of occupants' daily lives. It was observed to be device of coping with the loss of physical social networks in Mumbai, whereas in Abuja and Rio de Janeiro it was mostly related with an entertainment and news reading device. The women in all the cases were specially attached to their smartphones because it helped them socialise, watch favourite daily TV series or movie and even purchase products through home delivery services like Amazon. Although this thesis did not explicitly study the influence of ICT devices in the SRH occupants, but its influence on daily lives of the occupants show that it can be leveraged as a CI-tool for gaining better insight into the grounded realities. Such an approach also encourages the use of local and contextualised knowledge in policymaking in highly heterogeneous societies. The International Energy Agency (IEA) precisely translated this aspect of this research in their policy guidelines on the role of digitalisation in cities of the Global South (see here).

There is broad scope for incorporating such CI-based toolkit at national policymaking discourse, significantly because India, Brazil and Nigeria are rapidly expanding their affordable housing building stocks under federal affordable housing policies like the 'Pradhan Mantri Aawas Yojana' (India), the 'Minha Casa, Minha Vida' Programme (Brazil) and the 'National Social Housing Programme' (Nigeria). Grounded narratives of distributive injustices in such programs can act as a much-needed feedback mechanism for fine-tuning such federal programmes of poverty alleviation. As demonstrated in this study, the use of digital tools like natural language processing and machine learning can actively crystallise meaningful information from large datasets like the people-centric narratives of living in SRH. Such tools can be leveraged to derive contextualised metrics and indicators from informing national building codes and energy tariff programs specific to low-income communities. For example, this thesis showed that the lack of appropriate built environment design considerations (like community open spaces) across the study areas contribute to the vicious cycle of energy poverty. Therefore, it identified built environment design as a distributive energy justice action point. A just policy action, in this case, would be to improve the national building codes and guidelines to incorporate social spaces in such affordable housing programs. Similarly, improving the accountability of distribution companies towards such vulnerable consumers can be an essential step towards bottom-up just energy transition.

8.4 Limitations of this dissertation

This research is limited by its scope as a non-income driver of energy services demand in poverty. This thesis makes a generalised assumption that people living in slum rehabilitation housing (SRH) are poor and mainly participate in the informal economy. However, appliance purchasing is a significant economic decision, and the income factor must be considered when scaling or generalising the findings to a macro-policy level.

Assumptions and boundaries were set during empirical modelling of core sociological concepts from practice theory and energy cultures theory. It aided in novel empirical analysis and methodological development. For example, in Chapter – 4, energy practice theory was converted into empirical modelling using questionnaire surveys and structural equation modelling with 'time' as the key indicator of 'change/shifts in household practices'. Such hard-coding of energy practices as a temporal variable shaped our interpretation of the practices. However, efforts to convert practice theory into empirical models for decision-making remains an active research topic with limited scholarship; and this thesis contributed significantly to this research gap.

In Chapter – 5, the empirical interpretation of the socio-cultural energy services as comfort, convenience, and cleanliness (3Cs) was based on the assumption that specific appliances contributed to these 3Cs (after a hypothetical urban energy ladder by Sovacool (2011)). It provided a new intersectional understanding of appliance usage and the social norms shaping the human scale energy service (HUSES) demand. The social norms were assumed to be shaped by the socio-architectural characteristics of the built environment. Such assumptions can be refined by a more extensive and diverse sample size in a transitioning world, and context-specific urban planning variables will improve the empirical models' generalisability.

The theory of energy cultures was converted into an empirical methodology in Chapter – 7 using participatory survey questions. This approach can be improved through real-time monitoring or micro-surveys beyond this thesis's scope due to time and resource limitations.

Fieldwork and the data collection across multiple study areas were significant challenges, especially in communities like SRH. Lack of safety remains a constant concern that needed local contact support. Moreover, language barriers were a substantial factor that needed a translation for normalising the transcript into a common language, English. Such translations often embed translators' cognitive biases inherited as legacy biases in the textual analysis in Chapter – 6 and Chapter – 7. These biases cannot be reduced but can be handled through custom natural language processing (NLP) of the local languages/dialects. Building such NLP models is a state-of-the-art problem in computer science engineering and are highly resource intensive.

8.5 Future work

The future work of this dissertation can be steered in two directions. First is developing empirical approaches that can connect with economic theory with distributive energy justice-driven public policy design. This study was built on the existing definition of distributive justice and welfare based on Amartya Sen and Martha Nussbaum's Capability Approach. However, as mentioned in section 8.4, the scope was limited by investigating non-income drivers of energy demand, assuming that everyone living in SRH is in extreme poverty. It will require evaluation of panel and temporal effects of living in the SRH that can inform the economic impacts of living in such communities. In this manner, the built environment design effects on economic utility can appropriately be understood, and better policy instruments can be designed.

For public policy applications, the connections have to be made with financial, state, and civil-society institutions that can design contextualised just occupants' policies. It will also ensure that a just policy will improve the occupants' financial well-being and improve the overall quality of life through affordable housing programs. It is vital in the current paradigm of low-income urbanisation in the Global South as urban centres' prosperity attracts rural and low-income migrants, usually expanding the slums.

A just slum rehabilitation/redevelopment policy must address every step of the supply chain and ensure the housing–energy nexus is appropriated. From an energy modelling and energy efficiency perspective, contextualised understanding of social processes is critical to building accurate forecasting models. Slum rehabilitation has embedded contexts that must be utilised, and novel crowdsourced and collective intelligence-based approaches can better understand these people-centric processes. This research contributed to such collective intelligence tools by developing the deep-narrative analysis methodology.

The second direction of future work is refining and strengthening the deep-narrative analysis framework as a generalisable toolkit. It can be either a web-based or software product and easily implementable. A requirement of the deep-narrative analysis framework is the text corpus. Using a web-based interface can aid in crowdsourcing narratives of living in low-income communities across spatial boundaries.

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Appendix – 1

A.1 Survey questionnaire for Chapter – 4

Occupant Survey Form

I. Demographics

1. Total no. of members in the family ________

2. Gender, age and education level of each member (including children)

ID	Gender	Age	Education

Respondent ID: ___________

3. How much is the total family monthly income?
   - ☐ Below 5,000 INR
   - ☐ 5,000-10,000 INR
   - ☐ 10,000-25,000 INR
   - ☐ 25,000-50,000 INR
   - ☐ Above 50,000 INR

II. Measured Energy Use

4. Monthly Electricity bill (in INR) ______________

5. Photograph of the electricity bill
   - ☐ Yes
   - ☐ No

(If yes, photograph of electricity bill to be taken) please emphasize on the photograph of the bill .

III. Appliances

6. Which of the following appliances do you have at your home?
   - ☐ TV
   - ☐ Computer
   - ☐ Laptop/Tablet
   - ☐ Refrigerator
   - ☐ Microwave
   - ☐ Washing Machine
   - ☐ Geyser
   - ☐ Kettle
   - ☐ Toaster
   - ☐ Iron
   - ☐ Vacuum Cleaner
   - ☐ Cooking Stove (If respondents are not mentioning about the cookstove reconfirm or ask for alternate cooking mechanism)
   - ☐ Room Heater
   - ☐ AC
   - ☐ Fan
   - ☐ Water Coolers

7. Which of these appliances have you bought after shifting into this house? (Link to Ques 6)
   - ☐ TV
   - ☐ Computer
   - ☐ Laptop/Tablet
   - ☐ Refrigerator
   - ☐ Microwave
   - ☐ Washing Machine
   - ☐ Geyser
   - ☐ Kettle
   - ☐ Toaster
   - ☐ Iron
   - ☐ Vacuum Cleaner
   - ☐ Cooking Stove
   - ☐ Room Heater
   - ☐ AC
   - ☐ Fan
   - ☐ Water Coolers
   - ☐ None

8. Which member usually decides to buy these appliances?
   - ☐ Female
   - ☐ Male

9. What are the criteria for choosing these appliances?
   - ☐ Product Cost
   - ☐ Energy Efficiency
   - ☐ Brand
   - ☐ Size
   - ☐ Quality
   - ☐ Cost Savings
   - ☐ Easy interface
   - ☐ Advertisement
   - ☐ Partner's choice/Other family member's choice
   - ☐ "Neighbours had it"
   - ☐ If others, please specify__________

IV. Household Practices

A. Occupancy patterns (Females)

Only females are to be surveyed for this entire survey and incase no female member is present, move to the next household

10. How many hours do you spend at home on weekdays?
    - ☐ Less than 12 hours
    - ☐ 12-18 hours
    - ☐ More than 18 hours

11. How many hours do you spend at home on weekends?
    - ☐ Less than 12 hours
    - ☐ 12-18 hours
    - ☐ More than 18 hours

12. How many hours do you spend on the following activities?

Activity	Do not perform this activity	Less than 1 hour	1-2 hours	More than 2 hours
Cooking & Eating				
Cleaning				
Washing Clothes				
Watching TV/Computer				
Subsistence Activity (Work from Home)				
Playing with children				

Break Q13 into two parts.

13. Did you perform any of the below mentioned activities in outdoors before shifting?
    - ☐ Cooking & Eating
    - ☐ Cleaning
    - ☐ Washing Clothes
    - ☐ Watching TV/Computer
    - ☐ Subsistence Activity
    - ☐ Playing with children

13 A. Do you perform any of the below mentioned activities in outdoors after shifting?
- ☐ Cooking & Eating
- ☐ Cleaning
- ☐ Washing Clothes
- ☐ Watching TV/Computer
- ☐ Subsistence Activity
- ☐ Playing with children

14. How much time does the other members of the family spend at home on weekdays?

ID (same as question 2)	Less than 12 hours	12-18 hours	More than 18 hours

15. In which of the following activities does your partner/other family members participate?
- ☐ Cooking
- ☐ Cleaning
- ☐ Washing Clothes
- ☐ Taking care of children
- ☐ None of the above activity

16. Where did the children (below 14 years) spend most of their playing time before shifting?
- ☐ Inside the house
- ☐ Outdoors-playground etc.
- ☐ If others, specify

16.A Where do the children (below 14 years) spend most of their playing time after shifting?
- ☐ Inside the house
- ☐ Outdoors playground etc.
- ☐ Common spaces within the housing complex such as staircases, corridor etc.
- ☐ If others, specify

B. Cooking

17. Which of the following appliances do you use in daily cooking?
- ☐ Microwave
- ☐ Geyser
- ☐ Kettle
- ☐ Toaster
- ☐ Cooking Stove
- ☐ Portable Induction Cooktop

18. Do you open windows when you cook inside the unit?
- ☐ Yes
- ☐ No

19. At what setting do you keep your refrigerator on (on a scale of 1 to 5)?
- ☐ 1 (Low Cool)
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5 (High Cool)

C. Cleanliness

20. How do you do the laundry?
- ☐ Hand washed
- ☐ Machine washed
- ☐ Outsourced

21. What equipment do you use to clean the house?
- ☐ Hand held vacuum cleaner
- ☐ Upright vacuum cleaner
- ☐ Others____________
- ☐ None

D. Entertainment

22. Which of the following gadgets are used by the family members?

Gadgets	Male members (Y/N/Do not have it)	Female Members (Y/N/Do not have it)	Children (Y/N/Do not have it)
TV			
Laptops			
Cellphones			
Tablet			

23. For how long does the TV remain switched on daily?
- ☐ Runs constantly in background
- ☐ On demand
  - less than 2 hours
  - 2-6 hours
  - 6-10 hours
  - More than 10 hours

24. For how long does the laptop/tablet remain switched on daily?
- ☐ Runs constantly in background
- ☐ On demand
  - less than 2 hours
  - 2-6 hours
  - 6-10 hours
  - More than 10 hours

25. Do you use the standby button while using these gadgets?
- ☐ Yes
- ☐ No
- ☐ Not Applicable

V. Comfort

A. General Perceptions

26. How thermally comfortable do you find your current home to be?

1	2	3	4	5	6	7
Very cold	Cold	Slightly cold	Neutral	Slightly hot	Hot	Very hot

27. How do you generally feel when you are at current home?
- ☐ Hot
- ☐ Warm
- ☐ Neutral
- ☐ Cool
- ☐ Cold (Hindi translation to be corrected)

28. Compared to your previous house, how would you rate your current house in terms of thermal comfort in summers?
- ☐ More thermally comfortable
- ☐ Less thermally comfortable
- ☐ Same

29. Which of the following actions do you take to maintain comfortable indoor spaces?
- ☐ Opening/closing of windows
- ☐ Drawing Curtains
- ☐ Opening/closing of doors
- ☐ Adjusting clothing level
- ☐ Use of Plants
- ☐ Roof wetting
- ☐ If others, specify

B. Space Cooling

30. Which of the following equipment do you have for cooling?
- ☐ AC
- ☐ Ceiling Fan
- ☐ Table Fan
- ☐ Exhaust Fan
- ☐ Water cooler
- ☐ Others_____________

31. When do you use the following cooling equipment?
- ☐ At night
- ☐ When guests are at home

- ☐ When males are at home
- ☐ When children are at home
- ☐ Always when I am at home and feel too hot

32. For how much duration do you use these cooling equipment?

Equipment	Less than 2 hours	2-6 hours	6-10 hours	More than 10 hours
AC				
Ceiling Fan				
Table Fan				
Exhaust Fan				
Water Cooler				
Others				

33. In which months do you generally switch off the cooling?(Multi answer)

- ☐ January
- ☐ February
- ☐ March
- ☐ April
- ☐ May
- ☐ June
- ☐ July
- ☐ August
- ☐ Sept
- ☐ October
- ☐ November
- ☐ December
- ☐ Never

34. If you use AC, at what temperature range (in degree Celsius) do you generally keep it?

- ☐ Below 18
- ☐ 18-20
- ☐ 20-22
- ☐ 22-24
- ☐ 24-26
- ☐ Above 26

35. Who dictates the temperature setting and/or takes adaptive measures to ensure comfort?

- ☐ Male
- ☐ Female

C. Ventilation

36. Which of the following complaints do you have regarding the indoor air quality?

- ☐ Dusty
- ☐ Stuffy Air
- ☐ Moldy Odours
- ☐ Smoky
- ☐ Pungent Smell (of some chemicals)
- ☐ None

37. On a scale of 1 to 5, how would you rate the indoor air quality?

- ☐ 1 (Very poor)
- ☐ 2
- ☐ 3 (Neutral)
- ☐ 4
- ☐ 5 (very good)

38. Do you keep your windows open during day time?

- ☐ Yes
- ☐ No

39. Do you keep your windows open at night?

- ☐ Yes
- ☐ No

40. If yes, who takes the decision to open the windows?
- ☐ Male
- ☐ Female

41. When do you generally open the windows?

- ☐ During cooking
- ☐ Early Morning
- ☐ Evening
- ☐ Bedtime
- ☐ Never

42. If closed, the main reason for keeping windows closed?

- ☐ Lack of Privacy
- ☐ Risk of Burglary
- ☐ Entry of Insects/Dust
- ☐ Used as storage
- ☐ Others, ________

43. In the past six months, have you or any of the family member experienced the following symptoms? (Multiple options can be chosen)
- ☐ Frequent cough
- ☐ Multiple Cold
- ☐ Wheezing (except colds)
- ☐ Nasal congestion
- ☐ Sinus infections
- ☐ Sore throat
- ☐ Shortness of breath
- ☐ Hoarse voice
- ☐ Migraines
- ☐ Headaches
- ☐ Burning or irritated eyes
- ☐ Sneezing attacks
- ☐ Other (please specify) _________
- ☐ None

44. Which of the following medications are you currently taking on daily or weekly basis?
- ☐ Pain relievers (aspirin, Tylenol, etc.)
- ☐ Antidepressants
- ☐ Decongestant
- ☐ Antihistamines
- ☐ Other (please specify) _________

VI. Change in Practices

45. How have your household practices changed since you shifted? Tick the relevant practices from the following:

- ☐ Watching more TV
- ☐ Less socializing with neighbours
- ☐ More socializing with neighbours
- ☐ Spending more time indoors
- ☐ Children spending more time outdoors
- ☐ Children spending more time indoors
- ☐ Less opening of windows
- ☐ Others_________

46. How would you rate your present disposable income as compared to before shifting?
- ☐ Less
- ☐ More
- ☐ Same as before

47. If more, how do you as a family spend it on?
- ☐ Buying Appliances
- ☐ Savings
- ☐ Going out
- ☐ Spending on children and their education
- ☐ Sending money to relatives
- ☐ Supporting extended family

☐ Your partner/other family member decides
☐ Others_________

VII. Future Aspirations

48. Which of the following appliances are you planning to buy in near future?

48A. In order of Priority? (Ranking)

☐ AC	①	②	③	④	⑤	⑥
☐ Cooling Fan	①	②	③	④	⑤	⑥
☐ Washing Machine	①	②	③	④	⑤	⑥
☐ Mobile phone	①	②	③	④	⑤	⑥
☐ Vacuum Cleaner	①	②	③	④	⑤	⑥
☐ Refrigerator	①	②	③	④	⑤	⑥
☐ Laptop/Tablet	①	②	③	④	⑤	⑥
☐ Others ________						

49. Which of the following appliances would your partner/other family member like to buy as a priority?

49A. In order of Priority? (Ranking)

☐ AC	①	②	③	④	⑤	⑥
☐ Cooling Fan	①	②	③	④	⑤	⑥
☐ Washing Machine	①	②	③	④	⑤	⑥
☐ Mobile phone	①	②	③	④	⑤	⑥
☐ Vacuum Cleaner	①	②	③	④	⑤	⑥
☐ Refrigerator	①	②	③	④	⑤	⑥
☐ Laptop/Tablet	①	②	③	④	⑤	⑥
☐ Others ________						

VIII. Attitudes and Consciousness

A. Energy Bills

50. Deleted

51. Do you know different slabs for electricity pricing?
☐ Yes
☐ No

52. Who physically pays the electricity bill?
☐ Male
☐ Female

53. Have you ever checked your meter reading?
☐ Yes
☐ No

53A. Are you aware of the energy efficiency ratings of appliances?
☐ Yes
☐ No

B. Environment

54. How do you rate yourself as an energy user?
☐ Efficient
☐ Moderate
☐ Conscious

55. Do you try to save energy?
☐ Yes
☐ No

56. If yes, tick the relevant measures taken by you.
☐ Switching off lights, fan, AC etc. when leaving a room
☐ Buying energy efficient appliances
☐ Trying not to buy unnecessary things
☐ Others________

57. If your electricity was free, would you have taken energy saving measures?
☐ Yes
☐ No

58. Are you concerned about the environment and climate change?
☐ Yes
☐ No
☐ Unaware

59. If yes, tick the relevant reason.
☐ Worried about children
☐ Was brought up in such a way
☐ Others________

60. Do you engage in any of the following related to green lifestyle?
☐ Recycling of waste
☐ Riding a bicycle
☐ Using Public transport
☐ Switching off lights, when not required
☐ Segregation of waste

61. If you have a personal vehicle, would you travel in
☐ Personal vehicle
☐ Public Transport
☐ Walking

IX. General Satisfaction with Design

62. On a scale of 1 to 5, how you rate your housing unit in terms of meeting you need?
☐ 1 (Very much dissatisfied)
☐ 2
☐ 3 (Neutral) (Hindi translation to be corrected)
☐ 4
☐ 5 (very much Satisfied)

☐ What are the major problems you are facing in your current home
☐ Insufficient cooking space
☐ Lack of privacy
☐ Lack of personal outdoor space
☐ Thermally uncomfortable
☐ Poor indoor air quality
☐ Lack of daylight
☐ Lack of safety
☐ Lack of community feeling with neighbours or social isolation
☐ Poor aesthetics
☐ Too noisy
☐ Others___________

X. Health & Well-being

63. How often do you feel you are making progress towards accomplishing your household activities and family goals? (0 = never, 10 = always)

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

64. In general, how would you say your health is? (0 = terrible, 10 = excellent)

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

65. To what extent are your household chores purposeful and meaningful? (0 = not at all, 10 = completely)

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

66. How satisfied are you with your current physical health? (0 = not at all, 10 = completely)

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

67. At home while doing household chores, how often do you feel positive? (0 = never, 10 = always)

1 2 3 4 5 6 7 8 9 10

68. Compared to others of your same age and sex, how is your health? (0 = terrible, 10 = excellent)

1 2 3 4 5 6 7 8 9 10

69. To what extent do you feel appreciated by your family memebers? (0 = not at all, 10 = completely)

1 2 3 4 5 6 7 8 9 10

70. Taking all things together, how happy would you say you are with your household chores? (0 = not at all, 10 = completely)

1 2 3 4 5 6 7 8 9 10

71. At home, how often do you become absorbed in what you are doing? (0 = never, 10 = always)

1 2 3 4 5 6 7 8 9 10

72. To what extent do you receive help and support from family members when you need it? (0 = not at all, 10 = completely)

1 2 3 4 5 6 7 8 9 10

73. At home, how often do you feel angry? (0 = never, 10 = always)

1 2 3 4 5 6 7 8 9 10

74. To what extent do you generally feel that you have a sense of direction in your household chores? (0 = not at all, 10 = completely)

1 2 3 4 5 6 7 8 9 10

75. At home how often do you feel joyful? (0 = never, 10 = always)

1 2 3 4 5 6 7 8 9 10

76. In general, to what extent do you feel that your household chores are valuable and worthwhile? (0 = not at all, 10 = completely)

1 2 3 4 5 6 7 8 9 10

77. How often are you able to handle your household-related responsibilities? (0 = never, 10 = always)

1 2 3 4 5 6 7 8 9 10

78. How satisfied are you with your family relationships? (0 = not at all, 10 = completely)

1 2 3 4 5 6 7 8 9 10

79. At home, how often do you feel anxious? (0 = never, 10 = always)

1 2 3 4 5 6 7 8 9 10

80. To what extent do you feel excited and interested in your household chores? (0 = not at all, 10 = completely)

1 2 3 4 5 6 7 8 9 10

81. At home, how often do you feel sad? (0 = never, 10 = always)

1 2 3 4 5 6 7 8 9 10

82. At home, to what extent do you feel contented? (0 = not at all, 10 = completely)

1 2 3 4 5 6 7 8 9 10

83. How often do you achieve the important household related goals you have set for yourself? (0 = never, 10 = always)

1 2 3 4 5 6 7 8 9 10

84. How lonely do you feel at home? (0 = not at all, 10 = completely)

1 2 3 4 5 6 7 8 9 10

85. At home, how often do you lose track of time while doing something you enjoy? (0 = never, 10 = always)

1 2 3 4 5 6 7 8 9 10

A.2 Supplementary data for Chapter – 4

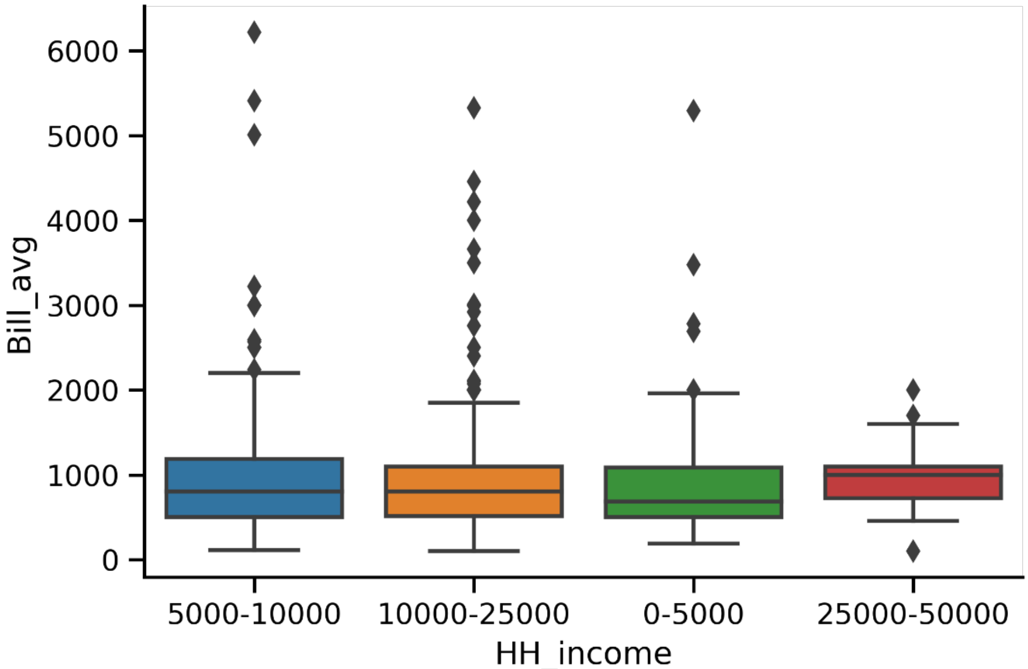

Figure A. Household monthly income (in INR) versus the average monthly electricity bills (in INR) (n = 1224)

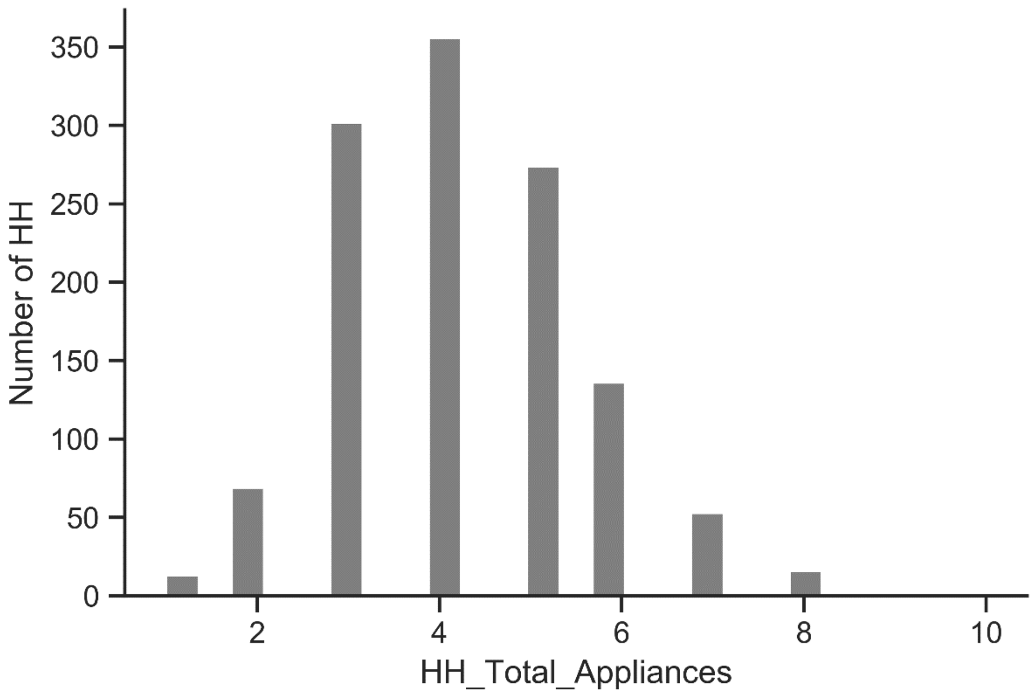

Figure B. Histogram of total number of household appliances with respect to number of households in the survey area (n = 1224)

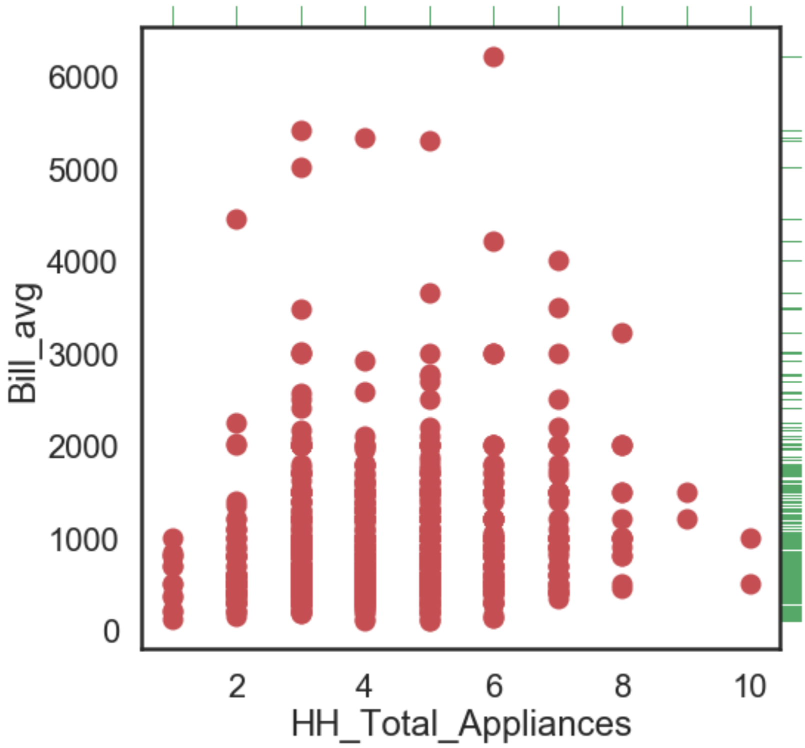

Figure C. A jointplot representing total household appliance ownership with the average monthly electricity bills (in INR) in the study area (n = 1224)

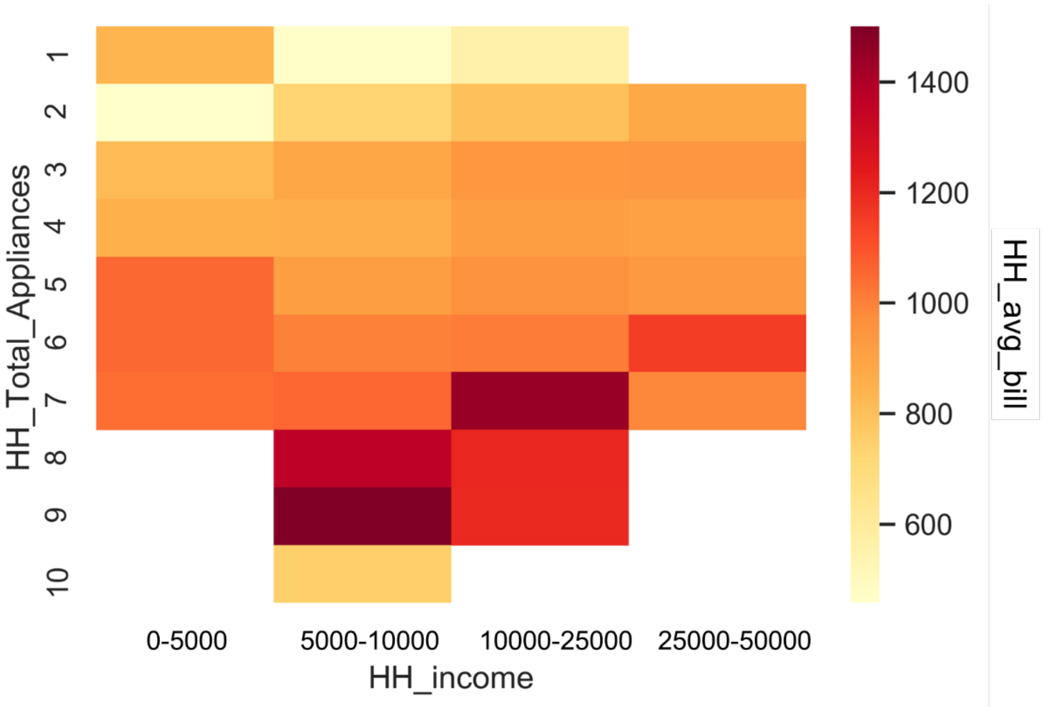

Figure D. A heatmap representing the relationship between appliance ownership, monthly household income (in INR) and monthly household electricity bills (in INR). (n = 1224)

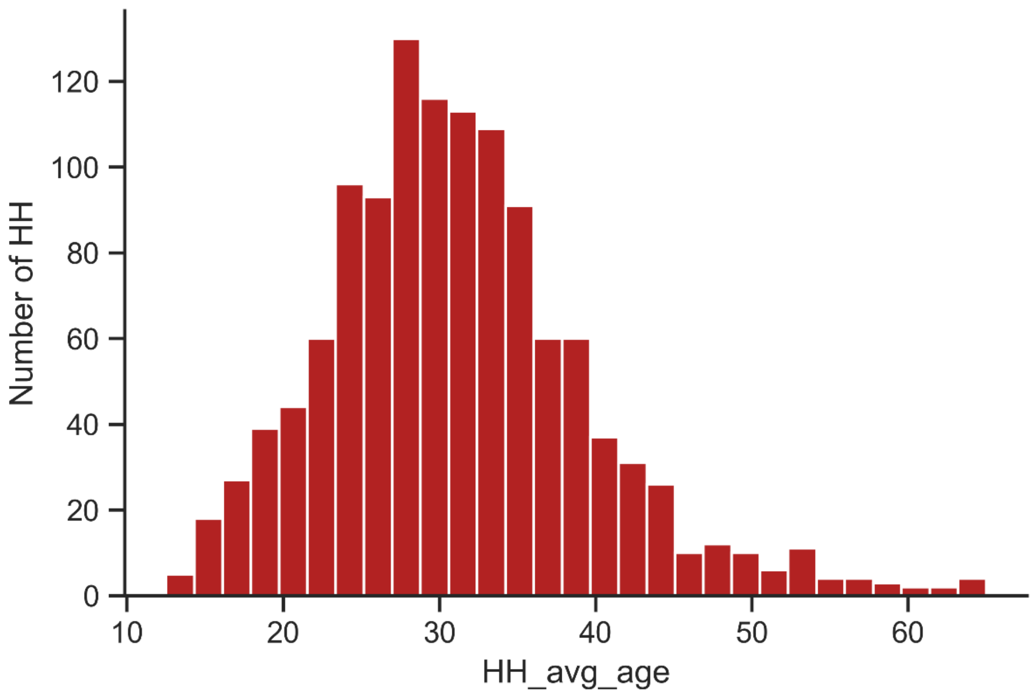

Figure E. Average age of household (n = 1224)

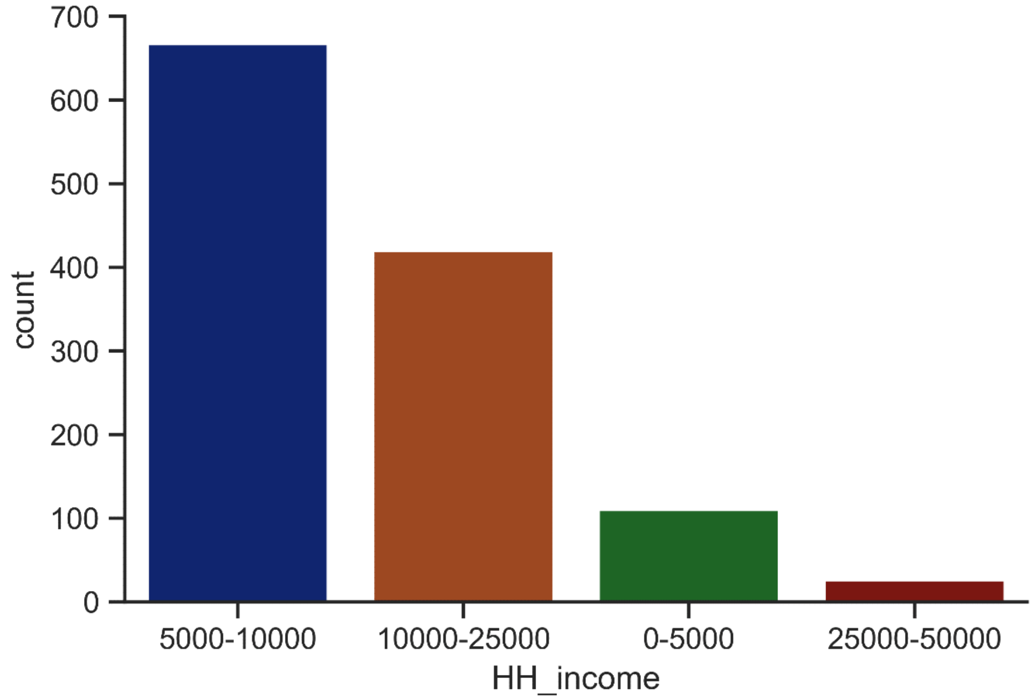

Figure F. Monthly income distribution (in INR) of the surveyed households (n = 1224)

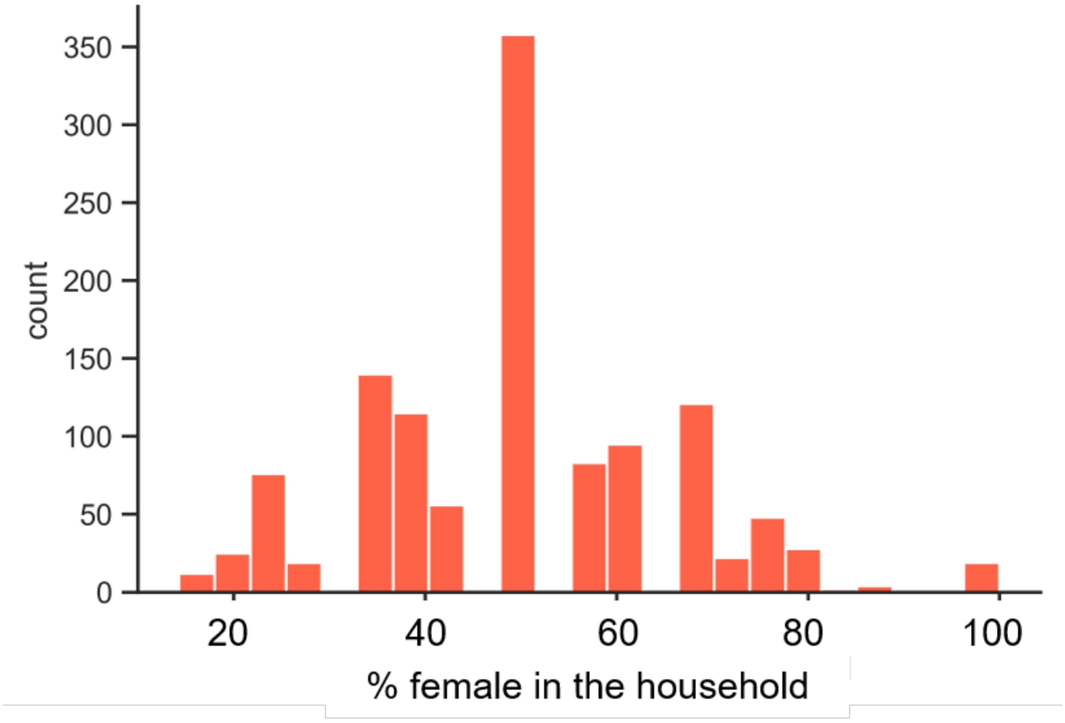

Figure G. Percentage of female in the surveyed households (n = 1224)

Other related conference presentations, invited talks, panel discussions, policy reports and media coverages with the author as the sole contributor are appended below:

Conferences

Debnath, R. (2021) Identifying distributive injustices using deep-narrative analysis. Artificial Intelligence in UK – 2021, The Alan Turing Institute, London ***(* selected as one of top 10 AI UK research poster)***

Debnath, R. (2020): *Deep-narrative analysis for policy support.* Artificial Intelligence in UK – 2020, The Alan Turing Institute, London https://www.turing.ac.uk/events/ai-uk-2020-digital-poster-exhibition ***(* selected as one of top 13 AI UK research poster)***

Debnath, R. (2020): *Energy Justice in Poverty: Policy modelling using computational social sciences*, Global Young Scientists Summit (GYSS) 2020, Singapore https://gatesopenresearch.org/posters/4-12 (****Recognised as a Young Scientist by the National Science Foundation Singapore)***

Debnath, R. (2019): *Invisible drivers of energy-use in poverty: Investigation in the slum rehabilitation of Mumbai,* Gates Day of Research 2019, Jesus College, University of Cambridge. https://gatesopenresearch.org/posters/3-1457 ***(*Awarded the best poster)***

Debnath, R. (2019): *Energy justice in poverty*. ASEAN Emerging Research Conference, Cambridge ***(*Awarded the best oral presentation)***

Debnath, R. (2019): *In search of energy sustainability in the Global South*. SymposiumMX 2019, University of Cambridge

Debnath, R. (2019): *How does slum rehabilitation influence energy-use in poverty?* Churchill College Conference on Everything (CoE) 2019, University of Cambridge. https://gatesopenresearch.org/posters/3-1422

Invited talks and panel discussion

Debnath, R., (2021): *Contextualising energy justice in poverty: Towards data-driven narrative analysis*, MIT Media Lab, **Massachusetts Institute of Technology**, Boston, USA.

Debnath, R (2021): *Panel on climate change vulnerabilities on health, energy and gender interactions,* **Cambridge Science Festival**, Cambridge, UK

Debnath, R., (2021): *Zooming – in and Zooming – out of energy narratives in poverty for just policy design using natural language processing*, **International Energy Agency**, Paris, France.

Debnath, R. (2020): *Systems modelling through deep-narrative analysis in energy poverty*, **UNDP – Accelerators Lab,** New York, USA.

Debnath, R. (2019): *Policy modelling for energy justice in poverty in Global South*, Brownbag Seminar, Environmental Change Institute (ECI), **University of Oxford**, UK

Debnath, R., (2019) *Energy Justice in Poverty: Modelling the invisible drivers in slum rehabilitation*, Michaelmas Gates Internal Symposium, November 2019, GSCR, University Centre. Cambridge.

Debnath, R. (2019) *Invisible drivers of energy demand in poverty*. Energy Policy Research Group (EPRG) Team Workshop, July -2019, Clare College, **University of Cambridge**

Debnath, R., (2019) *Low and Middle-Income Countries: remodelling appropriate resources for use in constrained settings*: Panel Discussion, Global Scholars Symposium-2019, **Rhodes House**, University of Oxford (https://gss2019.weebly.com/speakers.html)

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Contribution to policy reports

IEA (2021), Empowering Cities for a Net Zero Future, **International Energy Agency**, Paris https://www.iea.org/reports/empowering-cities-for-a-net-zero-future

IEA (2021), Renewables Integration in India, **International Energy Agency**, Paris https://www.iea.org/reports/renewables-integration-in-india

Debnath, R., Sagar, A., & Babu, S. (2021). COP 26 Futures We Want - India Country Profile. **Cambridge Open Engage**. https://doi.org/10.33774/coe-2021-ns37b

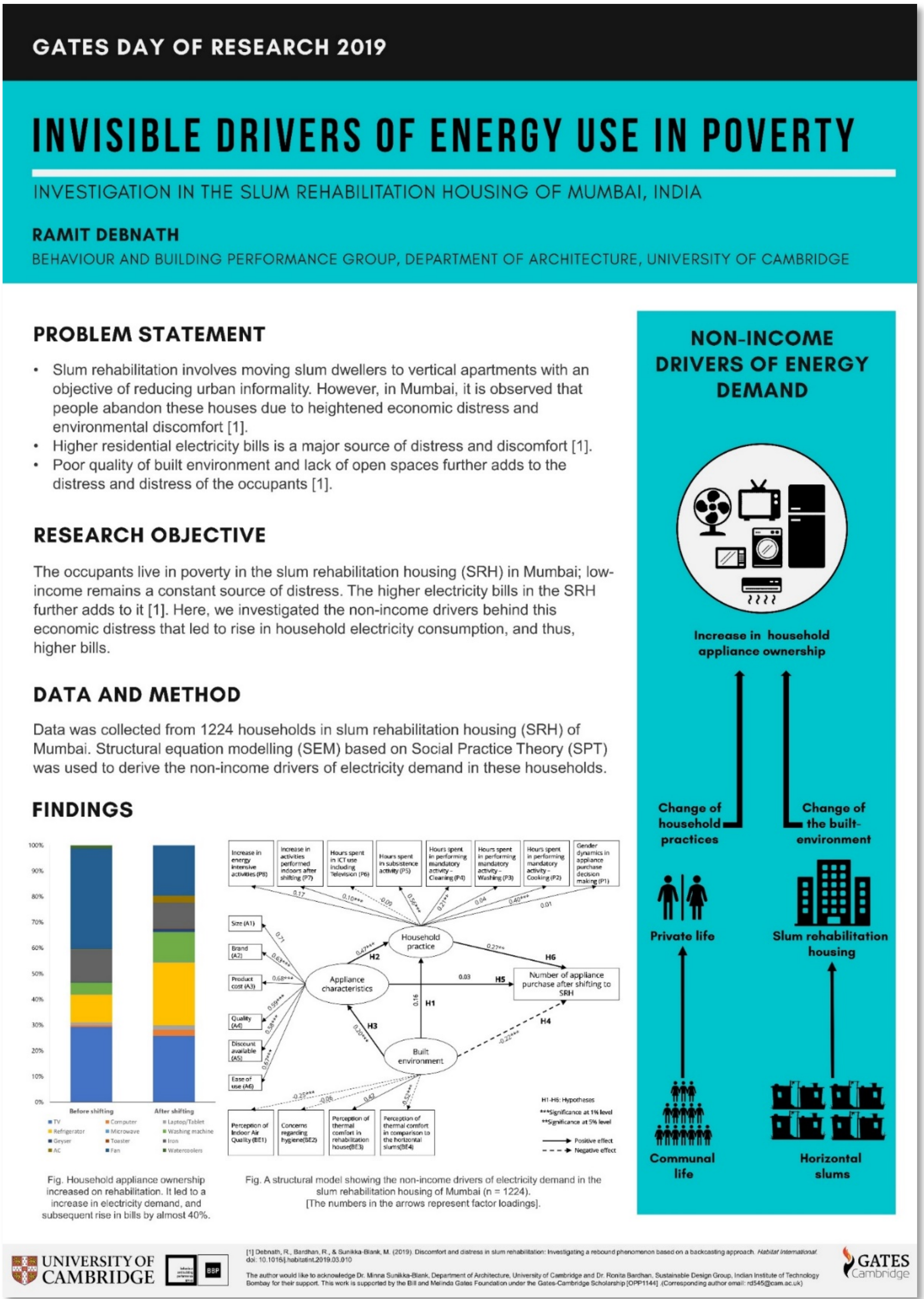
Related media coverage of this research

The Hindustan Times: Rising electricity bills of Mumbai slums threaten India's energy security, reveals Cambridge study

Quartz India: India's lockdown has left millions holed up inside shanties without fans as summer peaks

Scroll.in: In India, urban design must evolve to allow social distancing in slums

The Hindustan Times: 7 Indians selected for Gates Cambridge Scholarship



Won **the Best Poster award** at the Gates Day of Research 2019 conference, Jesus College, University of Cambridge

A.1 Survey questionnaire for Chapter – 5

Occupant Survey Form

HH ID: ___________
Location: __________

A. Built environment characteristics

1. What is the building typology of the slum rehabilitation units?

☐ Low-rise (Number of floors ______)

☐ High-rise (Number of floors ______)

2. Floor area of one unit: __________ m^2

3. Where are the slum rehabilitation houses located?

☐ Away from slum location

☐ On the same site

4. What are the problems faced in the built environment? (socio-architectural investigation)

☐ Lack of privacy

☐ Lack of safety

☐ Lack of open and social spaces

☐ Lack of sidewalks and walkable areas

☐ High burglary rates

☐ Poor sanitation and hygiene

☐ Lack of provisioning of garbage disposal

☐ Lack of toilets

5. What is the thermal comfort perception in the current home as compared to the slums?

1 Very cold — 2 Cold — 3 Slightly cold — 4 Neutral — 5 Slightly hot — 6 Hot — 7 Very hot

☐ Don't know

☐ Depending on the time of the day

Occupant Survey Form

HH ID: ___________
Location: __________

B. Demographics characteristics

6. Total number of members in the family____________________

7. Primary occupation of the head of household (HoH) ____________

8. Education level of the HoH ______________

9. How much is the total family monthly income?

☐ Below USD 50

☐ USD 50 - 80

☐ USD 80 - 110

☐ USD 110 – 140

☐ USD 140 - 170

☐ USD 170 - 200

☐ Above USD 200

C. Energy service demand

10. Monthly electricity bill of the households (in USD) ________________

11. Monthly household energy consumption as per the bill (kWh) ________

12. Do you receive any subsidy on the electricity bills?

☐ Yes

☐ No

Occupant Survey Form

HH ID: ___________
Location: __________

13. What do you use energy for?

☐ Cooking

☐ Cooling

☐ Heating

☐ Lighting

☐ Entertainment

☐ Leisure

14. What is your primary cooking fuel?

☐ LPG cylinder

☐ Kerosene

☐ Firewood

☐ Electricity

☐ Solar

15. Which of the following appliances do you have at your home?

☐ TV

☐ Computer

☐ Laptop/tablet

☐ Refrigerator

☐ Microwave oven

☐ Washing machine

☐ Geyser

☐ Kettle

☐ Toaster

☐ Clothing iron

☐ Vacuum cleaner

☐ Cookstove (electric or non-electric)

☐ Room heater

Occupant Survey Form

HH ID: ___________
Location: __________

☐ Air conditioners (AC)

☐ Ceiling Fan

☐ Table fan

☐ Water cooler

☐ Coffee machine

☐ Blender

☐ Juicer

☐ Food mixer

☐ Radio

☐ DVD player

☐ Video game consoles

16. What is your primary cooling device?

☐ Fan

☐ AC

☐ None

D. Practices and norms

17. How many hours do you spend at home on weekdays?

☐ Less than 12 hours

☐ 12 – 18 hours

☐ More than 18 hours

18. How many hours do you spend at home on weekends?

☐ Less than 12 hours

☐ 12 – 18 hours

☐ More than 18 hours

Occupant Survey Form

HH ID: ____________
Location: ___________

19. How do you improve your thermal comfort?

□ Adjusting clothing levels

□ Drawing curtains

□ Drink cold water / beverage

□ Go out to street in the day

□ Go out to street at night/ evening

□ Open/close doors

□ Open/close windows

□ Roof wetting

□ Sleep in a better environment (day)

□ Sleep in a better environment (evening/night)

□ Stay in most ventilated space (day)

□ Stay in most ventilated space (evening/night)

□ Take a bath

□ Use of indoor plants

□ Using fan

20. If fan is your primary cooling device, for how long do you use fan daily?

□ Less than 2 hours

□ 2 – 6 hours

□ 6 – 10 hours

□ More than 10 hours

□ Do not use fans

21. If natural ventilation is your primary cooling strategy, when do you keep your windows open?

□ Day

□ Night

□ Both times

Occupant Survey Form

HH ID: ____________
Location: ___________

22. With windows closed the room becomes very hot. Why do you keep your windows closed?

□ Broken windows

□ Risk of burglary

□ Lots of insect and dusts

□ High noise levels

□ For privacy

□ To prevent rainwater getting in

□ Solar heat gains

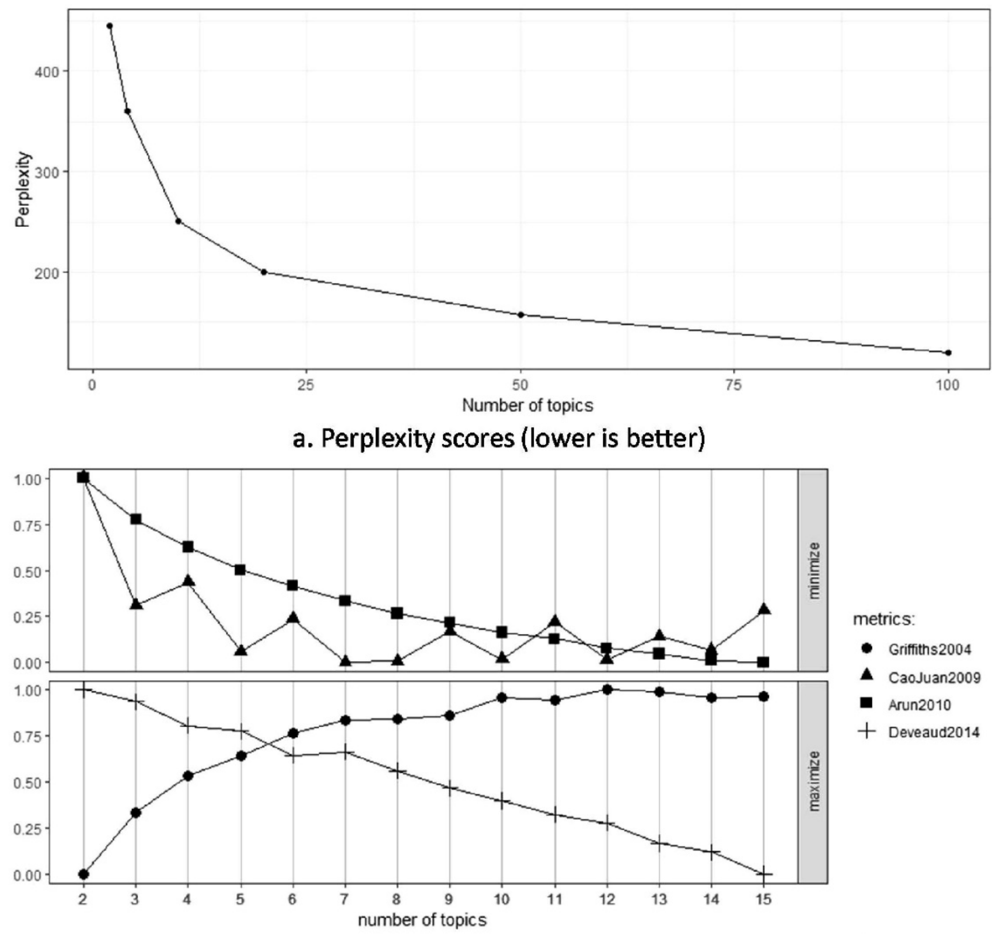
□ Using widow space as a storage

Appendix – 2

Model validation for chapter – 7

Topic identification and model validation for Section 7.5

The model validation results are illustrated in Fig. A2 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. A2b). The perplexity measure showed a sharply localised bent around 7 topics in Fig. A2a. Using the elbow rule in interpreting perplexity score, 7 topic clusters were decided as an appropriate number for this study. Cross-validating with Fig. A2b, it showed agreement with CaoJuan2009 metric.



a. Perplexity scores (lower is better)

b. Optimal number of topic determination using LDAtuning algorithm

Figure **A2**. Cross validation for topic determination in the topic modelling.