Vincent J. Loon - 4712943

Determining Energy-Efficient Appliance Adoption Drivers in Indian Households

A Mixed Methods Analysis

Image by PNG Box: pngbox.in

Determining Energy-Efficient Appliance Adoption Drivers in Indian Households

A Mixed Methods Analysis

By

Vincent J. Loon

in partial fulfilment of the requirements for the degree of

Master of Science
in Complex Systems Engineering and Management

at the Delft University of Technology,
to be defended publicly on Thursday, November 23, 2023, at 1:00 PM.

First Supervisor:	Dr. Nihit Goyal	TU Delft
Second Supervisor:	Dr. Özge Okur	TU Delft
Committee Chair:	Dr. Lisa Scholten	TU Delft

This thesis is confidential and cannot be made public until November 23, 2023.

TU Delft

Acknowledgements

With great pleasure, I hereby present my master thesis, the final chapter of my time as a student at Technology, Policy and Management. With this project, I conclude my program in Complex Systems Engineering and Management. The past years have been filled with incredible learning experiences fuelled by the opportunities the program provides. For me, the master's student path has been slightly unconventional. While most students initiated the program with the immersive 'CoSEM boot camp', for me this introduction followed starting with the (online) master courses. The flexibility and support of the CoSEM teachers and my fellow students quickly offset these initial challenges in the subsequent years. What will stick with me most, are the memories created during my international exchanges. Travelling to South Korea for a semester at Seoul National University and interning in India at both The Energy & Resources Institute and the Embassy of The Netherlands have been opportunities of a lifetime.

I feel lucky and blessed that I have gotten the chance to spend my student time in such a renowned teaching environment as the TU Delft. The program fit me like a glove. Projects discussed real-world problems and taught me to have a technological view of societal problems, and vice versa. Both the bachelor's and master's programs of TPM are the perfect places for people with technical talent but an interest reaching way beyond that. Before embarking on my thesis journey, I knew I wanted to do an international project in the energy domain. The people around me have helped me tremendously in the progression from that to a proper research project.

I would like to express my gratitude to my graduation committee. My first supervisor Dr. Nihit Goyal, has helped me make my thesis months an exceptionally thrilling experience. Allowing me to explore opportunities in India and at the same time nudging me in the right direction for my research has been immensely helpful. His constant support, flexibility and advice have been instrumental in pushing me to think deeper than I did before. I would like to thank my second supervisor Dr. Özge Okur and my chair Dr. Lisa Scholten for helping me shape my thesis project, providing very useful feedback and being extraordinarily flexible. Furthermore, the support of the TU Delft throughout my thesis cannot be forgotten. I am very grateful for the financial support through the TU Delft – India Collaboration Grant.

In India, I would like to extend my heartfelt appreciation to my supervisor at TERI, Dr. Sanjukta Subudhi. The warm welcome she gave me in Delhi and the effort she put into connecting me with the right people in the organization have been most helpful for my research. Furthermore, my dear friend and colleague Sambit Ghatak, who took me under his wing, showed me around Delhi and helped me appreciate and understand this beautiful country. I am also very grateful to Priya Joshi, from The Embassy of The Netherlands in India. Both her encouragement to continue my efforts to come to India and the energy she put into making my time there as useful and interesting as possible have had a tremendous influence. I would also like to thank Ambassador Marisa Gerards and Counsellor Joost Geijer for allowing me to work and learn at the embassy, getting a glimpse of what the life of a diplomat is all about.

Over the years, I have been able to rely on the unwavering support of my family. I would like to express my profound gratitude to my parents, Eric Jan and Judith for their help, advice and love. Furthermore, I would like to thank my brother Oscar for all the discussions on my data and modelling challenges. My love and gratitude go out to my girlfriend Sophie, whose unconditional love and support encouraged me to expand my horizons and go to India.

A final thank you to all my friends in Delft. My time as a student here has been shaped by the people I met and the incredible adventures we shared.

Vincent J. Loon
Delft, November 2023

Executive Summary

At a time when India experiences rapidly rising living standards, while facing increasing sustainability challenges, decoupling economic growth from the increase in energy consumption is a critical challenge. Energy efficiency solutions in the residential sector have an important role, as these can significantly curb energy consumption. To steer future adoption towards energy-efficient appliances, it is imperative to understand the drivers and barriers behind consumer choices.

The objective of this study is to understand the drivers and barriers behind the adoption of energy-efficient appliances in Indian households. These insights can be used to accelerate the adoption of these appliances and help India transition to a greener and more sustainable future. This study leverages an explanatory mixed methods approach in which a quantitative logistic regression model is followed by a qualitative analysis consisting of semi-structured expert interviews. This methodology is suitable for this research as it performs a robust empirical analysis of data through a regression. At the same time, the methodology allows deepening the understanding of observed patterns and contextualizes findings through expert insights. This synergy combines quantitative rigour with qualitative depth, providing a holistic understanding of factors influencing energy-efficient appliance adoption.

The initial phase consisted of a critical literature review, showing a limited academic focus on understanding the drivers behind energy-efficient appliance adoption in the Indian household sector. Variables relevant to adoption patterns were developed in this section, based on an overview of the academic research. In addition, the policy environment was conceptualized to create an overview of the policy domain and understand the effect of various Indian policies on energy-efficient consumer choices. This overview aided the understanding of the breadth and impact of policy measures. The quantitative element of the mixed methods approach is a logistic regression model in R, leveraging the IRES survey and the AEEE energy-efficiency index datasets. To corroborate and contextualize the quantitative findings, a qualitative phase was developed, consisting of 10 semi-structured expert interviews in India with policymakers, researchers, industry leaders, and lobby organizations. Insights from the qualitative phase were systematically extracted using a thematic analysis. Lastly, an integration step was taken to combine the findings from both research phases and offer a comprehensive and nuanced understanding of drivers and barriers behind the adoption of energy-efficient lighting and fans.

This quantitative analysis revealed key drivers behind the adoption of LED lighting and energy-efficient ceiling fans such as a clear relationship between household income and the adoption of energy-efficient appliances, with higher income levels correlating strongly with increased adoption likelihood. Awareness, particularly regarding star labeling and environmental benefits, along with higher education levels and living conditions, such as grid connections and climate zones also positively influences energy-efficient appliance adoption. Urbanization significantly impacts the adoption of energy-efficient ceiling fans, while its effect on LED lighting adoption, though present, is not statistically significant. State-level policy impacts appear more nuanced, highlighting the need for further qualitative exploration to understand underlying regional influences. In the thematic analysis following from the expert-interviews, patterns around evolving themes were developed, revealing the dynamics behind the observed relationships between variables. Economic factors, such as household income, perceived value of energy efficiency, the impact of subsidies and differing product life cycles, are central. Socio-cultural dynamics emphasizes the full spectrum of awareness: from basic knowledge to understanding of both personal and societal benefits, with language barriers potentially affecting regional awareness. Policy-wise, the expert panel deemed awareness campaigns, demand aggregation, and financial incentives crucial elements, though currently challenged by fragmented implementation and insufficient monitoring. Environmentally, an urban-rural accessibility gap and climatic influences on usage patterns emphasized the need for context-specific information in adoption strategies.

The integrated analysis of this study highlights key drivers in the adoption of energy-efficient appliances in Indian households. Economic capability, particularly household income, emerges as a crucial factor, proving the importance of affordability, as evidenced by the success of the subsidized LED lighting program UJALA. Beyond just cost, variations in perceived appliance value, influenced by usage patterns and anticipated savings play a role. Consumer awareness of cost savings, durability, and environmental impact is another pivotal driver. The qualitative findings add depth, revealing that understanding of personal benefits further shapes consumer choices. Geographic contexts, including climate zone differences and urban-rural divisions, also impacts adoption patterns. The essentiality of grid connections for adoption and the higher urban access to energy-efficient ceiling fans show these geographic influences. While the quantitative data suggest a nuanced impact of state-level policies, the qualitative insights point to complexities in policy implementation and varied governance models, affecting adoption incentives.

Both quantitative and qualitative findings show the interplay of factors such as economic, awareness, geographic, and policy. These factors are all driving adoption levels of energy-efficient appliances. For policymakers, the path forward could involve integration of robust awareness campaigns with targeted financial interventions to accelerate adoption. Such strategies can drive Indian households towards a more sustainable future. The growth in appliance adoption in India will significantly impact the energy transition and therefore making the right choices now is key.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AC	Air Conditioning
AEEE	Alliance for Energy Efficient Economy
AP	Andhra Pradesh
AS	Assam
BEE	Bureau of Energy Efficiency
BR	Bihar
CEEW	Council on Energy, Environment and Water
CH	Chhattisgarh
DL	Delhi
EE	Energy-Efficient
GJ	Gujarat
HP	Himachal Pradesh
HR	Haryana
IRES	India Residential Energy Survey
JH	Jharkhand
KA	Karnataka
KL	Kerala
kWh	Kilowatt-hour
LED	Light Emitting Diode
MH	Maharashtra
MP	Madhya Pradesh
OR	Odds Ratio
OR	Odisha
PB	Punjab
RJ	Rajasthan
SDA	State Designated Agency
TERI	The Energy & Resources Institute
TN	Tamil Nadu
TS	Telangana
UJALA	Unnat Jyoti by Affordable LED for All
UK	Uttarakhand
UP	Uttar Pradesh
UT	Union Territory
WB	West Bengal

1. Introduction

1.1. Context and Problem Definition

Energy is a vital component in the economic advancement of nations (Stavytskyy, Kharlamova et al. 2018, Le and Nguyen 2019). The duty of policymakers to support both industrial sectors and citizens by supplying them with affordable and consistent energy flows is imperative. Especially in net-importing countries such as India (with a higher usage than its own production), the question of how to supply energy in such a way that it meets the demand is highly relevant in safeguarding their economies (TERI 2021). Unfortunately, the constant search towards more energy to fulfil the demand has led economies to deplete the planet by overconsuming fossil fuels. The devastating effects of overconsumption of energy on our climate is by now crystal clear, and this has led to an increasing pressure to change the way energy is produced, transported and consumed (Brown and Huntington 2008). All countries around the world have announced and enforced measures to combat climate change and reduce the environmental impact of our societies to aim for an ecosystem where we can stay within planetary boundaries. For this task, it is necessary to utilize the energy we have as efficiently as possible.

Decarbonizing the energy sector requires a combination of demand- and supply-side interventions. Supply-side interventions such as increasing the share of renewable energy production and clean energy generation are essential. At the same time, demand-side interventions such as providing incentives to accelerate the adoption of energy-efficient products and services for all utilities across the economy are equally important. The adoption of demand-side actions such as behavioural changes and sustainable choices of consumers could reduce the annual global emissions by over 2 gigatonnes in 2030. This is about one-fifth of the emissions reductions needed by 2030 according to the Paris Agreement. (IEA 2023).

In this context, energy efficiency emerges as a critical solution. Energy efficiency is the ratio between energy conversion inputs and useful outputs. To increase energy efficiency is analogous to eliminating energy waste in the conversion process. In 2017, global greenhouse gas emissions were reduced by 12% in comparison to the baseline scenario due to the implementation of energy efficiency measures and it is expected that 40% of the emission reduction needed to be implemented by 2040 will be through the adoption of energy efficiency measures (IEA 2019).

India is one of the largest and fastest-growing economies in the world. Since the beginning of May 2023, the country has the largest population on the globe, surpassing China (UN, 2023). India has a population of 1.4 billion, divided over around 300 million households. It is also the world's third largest primary energy consumer, with further energy consumption increase expected (IEA 2020). In 2035, its energy consumption is expected to have overtaken China and the USA as the largest consuming nation (Singh, Mantha et al. 2018). Although India currently has a lower per capita consumption than other large consumers, its growth in economy and increasingly urbanizing population present an increasing consumption trend with the expected per capita electricity consumption to triple before 2040 (NITI Aayog 2017). In the period between 2020 and 2050, the primary energy demand in India is predicted to double. The growth is even stronger for energy usage in the household sector. This sector currently consumes a fourth of the total electricity generated in India and is projected to rise eight-fold by the year 2050 (Thapar 2020). Its contribution to the energy consumption in India is 30% and with its expanding and urbanizing population, this share is expected to grow even further in the coming years. The residential sector has thus been identified as having a high potential for electricity conservation, as the existing stock of appliances and residential buildings used have been developed without technical standards (Singh, Mantha et al. 2018). Household electrification has been a strong driver of electricity demand growth in India as well. (IEA 2020). These trends show the importance of curbing the increasing consumption of energy in the residential sector in India.

Specifically, appliances in the residential sector play a pivotal role in shaping the sector's energy usage. Increased appliance usage is something to strive for as an emerging economy, as it is often linked to enhanced socioeconomic outcomes and economic growth, offering significant benefits to society (Richmond, Agrawal et al. 2020). While transitioning to a sustainable society, it is essential to continue improvements of living standards for the poorer part of the nation, as the energy access of the marginalized communities in India is currently much poorer than the rest (Pelz, Chindarkar et al. 2021). However, it also leads to higher energy demands. Incorporating energy-efficient solutions can be critical in curbing the overall energy consumption and decoupling energy consumption and economic growth (Thapar 2020). Appliance usage is still in relatively early stages in India compared to other large emitters, but sees strong growth (IEA 2020). Currently, electrical household appliance penetration in India is between 15% - 30%, depending on the appliance, and expecting to reach levels of ~90%, similar to much of the developed world (TERI 2021). Appliance integration is already becoming the standard for newly developed projects, and it is easier to implement sustainable choices before consumer behaviours have been set in their way (Khosla and Janda 2018). Once appliances are in use, they will consume energy, so focusing on optimizing the choice of models and their efficiency rating is paramount.

The expected surge in appliance use could add 300-500 terawatt-hours to India's annual electricity demand—nearly a third of the total generated in 2019—with choices favouring lower efficiency appliances potentially doubling this figure (TERI 2021). This exemplifies the importance of understanding the dynamics of energy-efficient appliance adoption in the residential sector in India.

A critical component in India's transition towards a renewable energy system with a lower carbon footprint is the development and implementation of energy efficiency policies. Energy efficiency policies aim to reduce energy consumption and optimize energy use. India has set a target for the reduction of emission intensities of 33-35% in 2030 in comparison to 2005 levels (NITI Aayog 2017). Energy efficiency policy is still an underleveraged element of energy transition strategies, with the global energy sector prioritizing policies focused on energy security, pricing, absolute reductions in carbon emissions, and facilitating energy access (Jain, 2015). Despite the underrepresentation of demand-side management in research and policy discussions, energy efficiency is an equally important aspect of a successful energy transition (Goyal 2021, Knayer and Kryvinska 2022). This is particularly true for the residential sector, where energy efficiency policies could potentially lead to very high sustainability gains. By adopting energy-efficient appliances and buildings, the growing consumption share of the residential sector could be substantially limited (Parikh and Parikh 2016). In India, a variety of measures have been developed by the Bureau of Energy Efficiency (BEE) to improve energy efficiency in the residential sector such as setting standards, labelling, and developing demand-side management policies. However, not all energy efficiency policies are equally effective, and in India large differences in effectiveness occur across states and social groups (Yu, Tan et al. 2017). These differences across states can be seen in the Energy Efficiency Index (Bureau of Energy Efficiency, 2022). Limited insights have been generated in the literature on state-level differences, even though the state is often the jurisdiction to adopt and implement energy efficiency policies (Yu, Tan et al. 2017). At the same time, there is no discussion on the large impact policies can have in influencing energy-efficient consumption patterns by consumers and accelerating sustainable practices. The current estimation is that 60% of the consumer energy emission reductions can be directly influenced or mandated by governments, as norms, policies, incentives and infrastructures determine the way people behave (IEA 2023). It is thus necessary to gain a strong understanding of how energy efficiency policies work and what truly drives the adoption of energy-efficient appliances. This way India's progress in providing a secure and sustainable energy supply for its citizens is accelerated.

However, the adoption of energy-efficient appliances in India's residential sector is influenced by a complex combination of factors beyond just policy (Debnath, Bardhan et al. 2019). Socio-economic factors play a critical role as higher purchase powers typically correlate with greater appliance adoptions and electricity consumption (Singh, Mantha et al. 2018). Next to that, technological advancements can influence adoptions. As appliances evolve, newer, more energy-efficient models become available. Furthermore, market forces, consumer awareness, and cultural attitudes can influence appliance adoptions as well. Household appliance trends can be very context-specific. Even within a country, rural and urban development patterns may differ substantially (Richmond, Agrawal et al. 2020). Between urban and rural areas, there are significant differences in appliance adoption patterns with large variations in energy access (Pelz, Chindarkar et al. 2021). A comprehensive understanding of these various influences on the adoption of energy efficient appliances is essential to develop effective future strategies and interventions to promoting energy-efficiency.

1.2. Knowledge Gap & Research Questions

Within energy efficiency, there is a noticeable asymmetry in research focus and depth, especially in the Indian context. With the country-level performance evaluations present in literature often resulting in estimations of energy savings, a knowledge gap exists in understanding the differences of adoption patterns of energy-efficient appliances across Indian states. This discrepancy is particularly evident when comparing the granular country-specific research conducted in the European Union to the broader, less detailed studies available for India. The limited availability of state-specific analysis in this domain and context imply an opportunity for contributing to the understanding of energy efficiency adoption in India. Another significant observation is the scarcity of evaluations on energy efficiency policies, specifically for energy-efficient appliances in the residential sector. This shows a need for focused research to the policy effectiveness in promoting energy-efficient practices in homes.

Given this setting, this research project aims to investigate into the factors that influence the adoption patterns of energy-efficient appliance adoption in India's residential sector, presenting both household level and state-level patterns. Literature has shown that there is limited research available of state-level analysis of such patterns for appliances in the residential sector in India, while this could have significant potential for energy saving gains. Additionally, there is limited information on energy efficiency policy evaluations for energy-efficient appliances in the residential sector. These two knowledge gaps lead to the main research question of this master thesis article.

What are the socio-economic, geographic, energy and policy drivers and barriers behind state-level adoption of energy-efficient appliances in the residential sector in India?

1 What socio-economic, geographic and energy variables determine the adoption of energy-efficient appliances in the residential sector in India? *(Literature review & desk research)*
2 What are key energy efficiency policies for the residential sector in India, and how is responsibility for implementing these policies allocated across institutions and states? *(Literature review & desk research)*

3 How do socio-economic, geographic, energy and policy variables influence differences in the adoption of energy-efficient appliances across states in India? *(Quantitative analysis)*
4 What contextual factors further influence the drivers and barriers behind adoption of energy-efficient appliances in the residential sector in India? *(Qualitative analysis)*

The subsequent literature review and policy conceptualization will explore the first two sub-questions in much greater detail. Hereby it will set the stage for a thorough mixed methods investigation of energy efficiency adoption in the Indian residential sector.

1.3. Social and Scientific Relevance

The adoption of energy-efficient appliances in households is essential for India to succeed in reaching its sustainability goals (Garg, Maheshwari et al. 2020). Beyond the clear and immediate benefits of energy conservation and cost reduction it can generate, acceleration of energy-efficient appliance adoption marks a transformative shift. It reflects a world transitioning from a consumption-focused approach towards one centred on conservation, aimed at protecting the planet (Hansen and Coenen 2015).

This research sheds a new light on the integrated dynamics driving energy-efficient appliance adoption in India’s residential sector. By conducting a mixed methods approach, combining a quantitative regression with qualitative expert insights, a nuanced and holistic picture is created. Both generic and context-specific drivers have been found, previously underexplored in literature. The results of this study are relevant for policymakers and researchers within the energy efficiency domain, who need to understand what drives the adoption of energy-efficient technologies in the residential sector to make more effective interventions. As the findings give both generic and context specific information on the adoption of energy-efficient appliances, insights might be used to accelerate these technologies around the world. Thus, the findings of this research will also be relevant to develop similar understandings in other countries especially those with similar socio-economic circumstances as India. The CoSEM program aims to equip its students with a deep understanding of complex societal technology systems and the ability to develop tailored solutions to address its problems. Insights such as the socio-economic, energy and policy drivers of this research focused on technology adoption in a complex society embody the interdisciplinary CoSEM program perspective.

1.4. Relevance To the CoSEM Program

This Master Thesis project, focused on the adoption of energy-efficient appliances in Indian households, aligns with the objectives and competencies set out by the Complex Systems Engineering and Management (CoSEM) study guidelines. The project's framework and its outcomes adhere to the CoSEM program's emphasis on designing solutions for complex socio-technical problems by considering a mix of technical, institutional, economic, and social aspects.

The study offers a scientific contribution to the field of energy efficiency, a critical aspect in sustainable development and environmental management and necessary to create a sustainable world. Especially in the context of India's growing energy demands and the global need for sustainable living, this topic is highly relevant.

Throughout the master thesis, knowledge and skills acquired during the CoSEM program have been applied. A fundamental skill is systems thinking, that is developed during both the bachelor and master program. Next to that, the project leveraged modeling skills, particularly in the logistic regression analysis, using R. The first basis for these skills was developed in the computational text analysis course under the guidance of Dr. Goyal. In the 'Mixed Research Methods for Multi-actor Systems' course, the principles for mixed methods research design have been taught. This course showed how blending methodologies could ensure a richer, multi-dimensional understanding. Next to that a high-quality, structured literature review was conducted according to TU Delft standards, involving a systematic examination of literature to provide a solid scientific foundation.

The project analyses complexities of the socio-technical system, examining how various elements such as consumer behavior, policy frameworks, and technological options interact within the context of energy efficiency in India. It explores institutional and managerial aspects by evaluating the role of policies, responsibilities, and state-level interventions in driving appliance adoption.

To address the study objectives, an integrated research design was developed where the adoption of innovative energy-efficient appliances in the complex socio-technical system of Indian households was evaluated. To this end, the research consisted of a mixed-methods approach combining quantitative analysis (logistic regression) and qualitative insights (expert interviews), alongside a comprehensive literature review and desk research.

The research evaluates and discusses potential consequences of interventions, such as policy changes or awareness campaigns, within India to investigate how these interventions might influence appliance adoption rates. Furthermore, potential broader implications of accelerated adoption are discussed. Together, the research steps have led to an integrated research paper, in which informed recommendations and future research opportunities are identified.

Therefore, this research adheres to the goals of the CoSEM program by offering a solution-oriented approach to a large and complex socio-technical challenge.

1.5. Report Structure

To create an understanding of both the state-of-the-art scientific research base and the local Indian context, an in-depth literature review is conducted supplemented with desk research, in Chapter 2. Here, the full knowledge gap is explored and the relevant Indian state-level policy dynamics that require further exploration are displayed. Together, these insights are used to select a set of variables that are used for the quantitative model. In Chapter 3, an overview of the research approach is given, in which the selected methods and datasets are explained. Chapter 4, the first step of the mixed methods approach, presents the quantitative research step in which a logistic regression model is developed in R, used to assess the influence of the set of household- and state-level variables on the adoption of energy efficiency appliances in the residential sector across states. Additionally, in Chapter 5, qualitative research has been conducted consisting of semi-structured interviews to gain insights into the stakeholders' perceptions of the identified policy problems, experiences with the current policies and views on bottlenecks and improvement opportunities. The focus of this research step was on confirming and contextualizing observed state-level differences in adoption patterns and policies. In the discussion in Chapter 6, an integration of the quantitative and qualitative approach is presented, with the identification of future research opportunities and policy recommendations for new energy efficiency policy design. Lastly, the research concludes in Chapter 7, with direct answers to the research questions, showing the deeper understanding that has been created.

2. Literature Review and Policy Conceptualization

The upcoming chapter serves as a critical foundation for our research. It aims to thoroughly explore the existing academic literature and find contextual information relevant to the adoption of energy-efficient appliances in India's residential sector. This chapter is specifically designed to address the first two sub-questions of our study. In the first part of this chapter, we conduct an in-depth literature review where we identify and examine the various socio-economic, geographic, and energy factors that are linked to how households in India adopt energy-efficient appliances. Our goal is to uncover a key section of variables that influence this adoption process. The second part of the chapter shifts focus to the policy context of energy efficiency in India to find out what the policy landscape looks like and how these influence energy-efficiency adoption.

By blending an analysis of both empirical research and policy frameworks, this chapter sets a foundation for our investigation. It aligns our study with theoretical insights and real-world policies, ensuring a well-rounded basis on which the mixed methods research can be conducted.

2.1. Literature Review Approach

In this chapter, a literature review is developed that investigates the current scientific knowledge on energy efficiency in the residential sector, household appliance adoption, and policymaking in India. The key concepts of this article are *energy efficiency policy, India, residential sector, energy-efficient appliances, policy implementation, state-level differences.* These concepts are used throughout the analysis and synthesis of this research as they cover all relevant relationships between factors that can influence adoption patterns and new policies.

To review the state-of-the-art scientific literature around the key concepts and to identify the current knowledge, a systematic analysis of scientific article is presented. First, a global overview of relevant literature has been analysed using the key concepts in different combinations across Scopus and Google Scholar. This initial search provided the needed context to judge papers on usefulness for the specific context of this research paper.

For the literature review search terms have been developed to filter through the massive number of papers and select relevant research. For this task, the following queries have been used:

- “Energy efficiency policy” AND “India” AND (“residential” OR “household”)
- “Energy efficien*” AND (“India” OR “residential” OR “household” OR “policy”) *in title*

The literature review has only considered scientific research papers that have been published in peer-reviewed journals, have been cited at least once and that have been written in English. This search resulted in 138 papers. To develop a final selection, the search process is followed by a manual inspection of title and/or abstract to only include papers that describe studies related to the performance of India in the field of energy efficiency, energy efficiency in the residential sector or the development of energy efficiency policies. This thorough scan resulted in a final selection of 44 articles discussed in the literature review.

2.2. Literature Categorization

The papers that have been evaluated are reviewed in a systematic approach. The papers have been categorized according to the research focus. This categorization can be found in Table 1. The selection of articles is aimed at providing a comprehensive and in-depth knowledge base of the current energy efficiency policy literature.

Table 1: Literature review article categorization

	India	International
Residential Sector	(Chandel, Sharma et al. 2016) (Yu, Tan et al. 2017) (Debnath, Bardhan et al. 2019) (Reddy 2003) (Singh, Mantha et al. 2018) (Singh, Mantha et al. 2018, Yu, Evans et al. 2018) (Khosla and Janda 2018)	(Mundaca, Neij et al. 2010) (Berardi 2017) (González-Torres, Pérez-Lombard et al. 2022) (Santos, Fagá et al. 2013) (Hesselink and Chappin 2019) (Thomas, Thema et al. 2018) (Nejat, Jomehzadeh et al. 2015) (Economidou, Todeschi et al. 2020) (Blumberga, Bazbauers et al. 2021) (Morton, Wilson et al. 2018)
Appliances in the residential sector	(Singh, Henriques et al. 2019) (Debnath, Bardhan et al. 2019) (Singh, Henriques et al. 2018)	(Hesselink and Chappin 2019) (Kim and Brown 2019) (Schleich 2019)

	(Mukherjee, Gibbs et al. 2020) (Richmond, Agrawal et al. 2020) (Parikh and Parikh 2016) (Garg, Maheshwari et al. 2020)	
General energy efficiency policy	(Bansal and Rahul 2021) (Alola, Özkan et al. 2023) (Jain 2015) (Jain 2023) (Franco, Mandla et al. 2017) (Dasgupta and Roy 2015) (Singh 2020) (Bardhan, Debnath et al. 2019, Malhotra, Mathur et al. 2022) (Singh, Henriques et al. 2019) (Bhandari and Shrimali 2018) (Sarangi, Mishra et al. 2019)	(Revinova and Gomonov 2023) (Liu, Wei et al. 2019) (Dunlop 2019) (Safarzadeh, Rasti-Barzoki et al. 2020) (Hansen and Coenen 2015)

The articles cover multiple elements of energy efficiency policy research. As the focus of the research paper is the policy environment of India, more effort has been put in collecting country-specific insights. Still, for the residential sector, a much larger number of papers have been found that cover a broader range of countries.

Articles focusing on energy efficiency for appliances are more limited, as the search queries are aimed at the residential sector and the adoption of energy efficiency policies in this field. Literature on the adoption of appliances in the residential sector is relatively limited. There is ample of more general research on energy efficiency policy in the Indian context. These studies are highly relevant due to the complex policy context of the country and the large variety of policy instruments that can be used to achieve energy efficiency gains.

2.3. Theoretical Perspective

2.3.1. Policy Evaluations

A large variety of articles are focused on the evaluation of specific energy efficiency policy designs. Literature in this field focuses on quantitative analyses of policy through the development and usage of different modelling techniques (Mundaca, Neij et al. 2010, Yu, Evans et al. 2018, Singh, Henriques et al. 2019, Blumberga, Bazbauers et al. 2021). These papers are performed on different scales and with different modelling techniques such as energy-economy models, Global Change Assessment Model, Input-output lifecycle assessment, system dynamics modelling. These model applications vary across regions and sectors.

A different approach is taken in more exploratory analysis where statistical energy consumption data from public records is analysed (Reddy 2003, Singh 2020, Bansal and Rahul 2021), where quantitative surveys are used (Thomas, Thema et al. 2018, Revinova and Gomonov 2023) or a combination of both (Bhandari and Shrimali 2018, Mukherjee, Gibbs et al. 2020). In these exploratory analyses the dynamics of policy implementation and design are investigated, and through evaluation of their characteristics and effects the articles aim to advise future policy improvements. All these analyses, however, are conducted on a national level, and more granular and local insights cannot be derived from this.

Additionally, several works focus on the development of energy efficiency policies over time (Bardhan, Debnath et al. 2019, Economidou, Todeschi et al. 2020, Safarzadeh, Rasti-Barzoki et al. 2020). These researches aim to identify the variety of policy measures taken, the impact of these policies on a national or global scale and show improvement opportunities across nations. This literature is very insightful to create context on the larger policy environment in which India is aiming for energy efficiency but does not show the direct impact certain policies have on energy savings.

2.3.2. Energy Efficiency Performance

Quantitatively measuring the performance of energy efficiency policies and investigating energy consumption patterns is another focus theme of the literature selection.

Some articles focus on the quantitative estimation of realized or potential energy savings through policies. These papers are aimed at determining the quantitative outputs of energy saving strategies over time (Singh, Mantha et al. 2018, Liu, Wei et al. 2019, Jain 2023) and advocate for a broader perspective on energy efficiency than just energy consumption (Santos, Fagá et al. 2013). Other papers investigate energy efficiency trends and performance on a national level. Here, articles aim to identify drivers of energy consumption in the residential sector to determine what influences energy demand (Dasgupta and Roy 2015, Nejat, Jomehzadeh et al. 2015, Berardi 2017, González-Torres, Pérez-Lombard et al. 2022). Investigated performances are often compared to other countries such as China and the United States to determine differences in energy drivers. These articles highlight the urgency to adopt stricter energy efficiency measures to curb the increasing energy consumption of different sectors in India but give limited insight into what elements across sectors can be improved.

As India is a very large country with the world's largest population, large differences in energy efficiency patterns across the country can be expected. A few articles search for more granular energy efficiency insights. For example, (Yu, Tan et al. 2017) investigates the state-level energy efficiency policy effects through the application of the Global Change Assessment Model in the construction sector. Both this research and (Singh, Mantha et al. 2018) differentiate across three different climate regions in the country. There is currently a empirical research recognising penetration of energy-efficient appliances in India's residential sector (Garg, Maheshwari et al. 2020). Furthermore, research towards spatial difference in residential energy efficiency policies has been conducted for the United Kingdom (Morton, Wilson et al. 2018). For India, even larger varieties in these adoption patterns can be expected. Research towards the adoption patterns of energy-efficient appliances has been conducted in different forms. Some articles do not focus on a specific local context, but on general patterns (Hesselink and Chappin 2019, Solà, de Ayala et al. 2020). The article of (Parikh and Parikh 2016) investigates the energy-efficient appliance stock forecasts in India and their effect on energy consumption. The overview created in this article can serve as guideline for choosing what appliances can be selected as being energy-efficient. However, the projection in this article is not made on a regional scale. The only local differentiation that is made this regard for India so far, is between rural and urban areas (Parikh and Parikh 2016, Singh, Mantha et al. 2018, Richmond, Agrawal et al. 2020). The research by Schleich does identify local differences throughout European Union and shows that policies aimed at the lower income population need to be designed differently than for wealthier regions (Schleich 2019). This insight could potentially apply for the Indian context as regions have very different economic situations but has not been investigated yet.

In Figure 1, a funnel diagram is presented of the articles investigated in the literature, scoping down to the research focus. It can be seen that the academic literature contains a very narrow base with only three articles in the direction of our research, indicating a clear lack of knowledge.

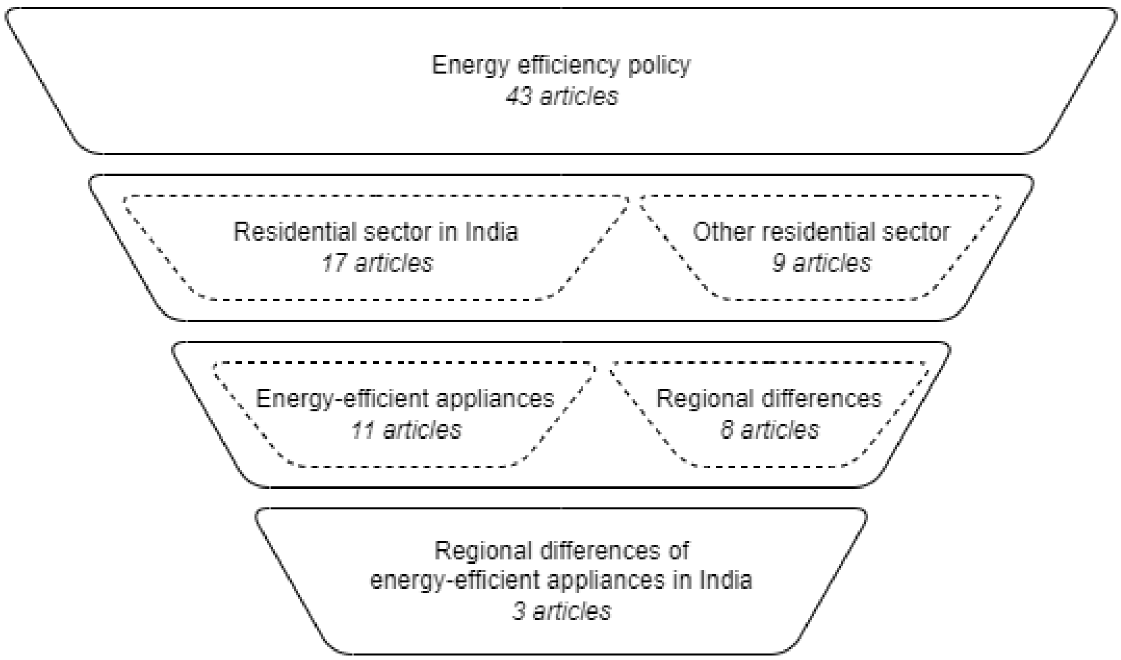

Figure 1: Funnel diagram of literature review focus

The literature review reveals that not all elements of energy efficiency have been equally investigated. Current energy efficiency policy evaluations mostly focus on measuring energy efficiency performance of entire countries, with less investigation of specific individual policy effects or regional differences. While the evaluations present in literature often result in estimations of energy savings, a clear gap exists in understanding the differences of adoption patterns of energy-efficient appliances across Indian states. In contrast to individual nations of the European Union, the diverse and expansive landscape of India has not been analysed as thoroughly. The heterogeneity and scale of the Indian context make state-level analysis of the same level of granularity as country specific research in the EU context. Furthermore, the effects of specific policies that have been modelled quantitatively so far should be investigated on state-level differences to obtain more tailored and effective region-specific policy recommendations. The literature review has shown that that there is a knowledge gap in the understanding of drivers of adoption patterns of energy-efficient appliances in the residential sector in India.

2.3.3. Variable Selection

To answer the first research question and develop the first step in the analysis process leading up to the quantitative research phase, a list of variables is compiled. Here, the academic selection is analysed to determine what factors are commonly used to describe adoption patterns and its drivers and barriers. It can be seen from literature that there is a large variety of variables. As visible in Table 2, the full list of variables is developed and checked for their presence in the literature. These variables are divided into three distinct categories: socio-economic, energy, and geographic. This variable selection emerged from a collaborative process with the graduation committee, to ensure a comprehensive and multidimensional framework reflective of both the academic understanding and the diverse factors. Across the categories, it can be seen that some variables are very prevalent in the literature.

Within the socio-economic category, the household income, usually quantified in Indian Rupees per month or per annum, is referenced in 17 articles of the literature selection. This frequency shows its perceived importance in adoption behaviours. The socio-economic variables further consist of education levels, the age, the state-level population size and density, the household size, home ownership status, social caste, environmental attitudes, housing type and size, appliance ownership and the expenditures.

The energy variables capture both the micro and macro perspective of energy usage. Household-level energy prices and consumption levels offer granular insight into household energy behaviour. With household energy consumption being cited in almost half of the reviewed literature, it's clear that this factor is important in determining how households engage energy related technologies. State-level energy consumption data further provide a broader context, with energy dynamics that might influence household decisions.

Geographic variables provide insights in the physical context of households. Climate zones and the urban-rural divide are investigated here. The rate of urbanization is very often cited as highly influential for the adoption patterns of energy-efficient appliances. Based on this variable list, the operationalization in Chapter 3 is developed.

Based on this variable list, the operationalization in Chapter 3 is developed. In addition to this list of variables, policy variables are added to the quantitative model with state-level implementation. Together, the socio-economic, energy, geographic and policy variables shed light on the dynamics behind the adoption of energy-efficient appliances in Indian households.

Table 2: Selection of Indicator Variables for research

	Units	Articles
Socio-economic variables		
Household Income	Indian Rupees per month	17
Education levels	Years of education completed	2
Age	Years	2
Population size (state level)	Number of inhabitants	6
Population density (state level)	Inhabitants per square kilometre	4
Household Size	Number of individuals	8
Home ownership	Categorical (owners or tenants)	3
Environmental attitude	Scale (high, medium, low)	5
Caste Background		
Housing Type	Categorical (apartment, standalone house, etc.)	6
Housing Size	Square meters	8
Appliance ownership	Number of electronic devices owned	8
Cost of expenditures	Indian Rupees	5
Energy variables		
Energy prices (household level)	Indian Rupees per kWh	6
Energy consumption (household-level)	kWh per month	16
Energy consumption (state-level)	kWh per month	9
Electrification (household-level)	Percentage	9
Geographic variables		
Climate zone (state-level)	Categorical (north, middle, south)	5
Urban/Rural Home (household-level)	Categorical (urban or rural)	10

2.4. Policy Conceptualization

2.4.1. Energy Sector Governance in India

Energy efficiency governance is the combination of legislative frameworks and funding mechanisms, institutional arrangements, and coordination mechanisms, which work together to support implementation of energy efficiency strategies, policies, and programmes (Singh, Henriques et al. 2019). Energy governance in India is critical to advancing the nation’s economic situation while addressing the unique challenges of its urbanizing population and achieving sustainable growth. Energy efficiency is one of the central pillars of this governance structure, as it helps to reduce consumption, manage costs and limit environmental impacts. As India is very large and highly populated, its governance system can be seen as a high-level federal system comprising of 29 states and 7 union territories holding legislative and executive powers distributed among the Union and state governments. Energy governance in India is multi-level; the union government and the state governments are concurrently responsible for decision-making, implementation, and monitoring and evaluation (Goyal 2021). The national level government is responsible for setting the course and developing the policies. State- and lower-level governments are mostly responsible for implementation and tailoring. The Indian energy governance landscape is organized in a selection of institutions and instruments. The governance on a national level of energy in India is allocated across five ministries. These are the Ministry of Power (MoP), the Ministry of Petroleum and Natural Gas (MoPNG), the Ministry of New and Renewable Energy (MNRE), the Ministry of Coal (MoC) and the Department of Atomic Energy (DAE). The central governmental institutions responsible for the electricity sector are the Ministry of Power and the Bureau of Energy Efficiency (BEE) (IEA 2020). These organizations are responsible for formulation of long-term strategies, policies and instruments. The BEE was established under the 2001 Energy Conservation Act to drive energy conservation benchmarks and promote energy efficiency. The BEE assist the government in developing policies and strategies (Malhotra, Mathur et al. 2022). Additionally, in 2008 the National Action Plan on Climate Change launched (TERI 2023). Here, energy efficiency was given a central role being one of the 8 pillars of the plan called 'The National Mission for Enhanced Energy Efficiency' (NMEEE). The NMEEE mission focuses on promotion of competition and the creation of market mechanisms to increase the cost-effectiveness of energy-efficient appliances and systems and eventually transform the energy market.

Furthermore, there are several sector specific organizations such as the Central Energy Agency (CEA) and the Central Electricity Regulatory Authority (CERA) involved through supervision, technical assistance and regulatory activities. For policies regarding the residential sector, the Ministry of Housing and Urban Affairs is also a vital body (IEA 2020).

2.4.2. Main Energy Efficiency Policies in India

The central government has actively promoted energy efficiency measures across different sectors such as building, industries, transport and municipal facilities. Numerous critical initiatives have been launched across the country (IEA 2020).

In the NMEEE initially, four initiatives have been created:

- The Perform Achieve and Trade Scheme (PAT), a market-based mechanism to increase the cost effectiveness of improvement efforts for energy efficiency in energy intensive industries through the certification of energy savings, that can be then traded.
- Market Transformation for Energy Efficiency (MTEE), aimed at accelerating the shift to energy-efficient appliances through implementation of several innovative measures that increase the affordability of more sustainable products.
- An Energy Efficiency Financing Platform (EEFP), to create mechanisms that can assist in financing demand side management programs in all sectors by capturing future energy savings.
- A Framework for Energy-Efficient Economic Development (FEEED), for the development of fiscal instruments to promote the implementation of energy efficiency.

In the residential sector, the MTEEE and EEFP have been implemented on a large scale. The Bureau of Energy Efficiency (BEE) has further developed several programs aimed at reducing energy intensity in buildings (BEE 2023). These are:

- The Energy Conservation Building Code (ECBC), that sets standards for commercial and residential buildings with a connected load of 100 kW (The Energy and Resources Institute 2014).
- A Standards and Labelling program that measures energy performance and provides labels for household appliances and equipment. Furthermore, the Energy Conservation Building Code (ECBC) sets standards for the building industry.
- The UJALA scheme has been launched to accelerate the adoption of energy-efficient lighting in households.

2.4.3. Institutions Responsible for Energy Efficiency Policies

Responsibility for implementing energy efficiency policies is allocated across institutions on both national and state levels. The Energy Conservation (EC) Act established a two-tier structure for energy efficiency in India, appointing the Bureau of Energy Efficiency (BEE) as the central nodal agency and State Designated Agencies (SDAs) at the state level (BEE 2023).The BEE is the central organization responsible for coordination, regulation and implementation of the main energy efficiency policies, state-level governments also have a significant role in the governance of energy. Each state has a State Designated Agency (SDA) that is responsible for implementing central government policies and developing state-specific policies themselves. Additionally, enforcement and regulation of initiatives are organized on a state level as well (Goyal 2021). Across India's 36 States/UTs, the nature of these SDAs varies, with 16 States using Renewable Energy Development Agencies, 7 appointing their Power Departments, 7 utilizing Electrical Inspectorates, and 4 assigning Electricity Distribution Companies (DISCOMs) as SDAs, while Andhra Pradesh and Kerala have established standalone SDAs dedicated to energy efficiency (BEE 2023). The SDAs are also responsible for developing local awareness around energy efficiency projects and the positive impact it may have on citizens (BEE 2023).

Furthermore, the Energy Efficiency Services Limited (EESL) is a powerful institution as well. This is a joint venture of four public-sector organizations under the Ministry of Power and functions as the creator and promotor of (new) markets for energy efficiency. The UJALA program is designed by the EESL and has been instrumental in promoting and accelerating the adoption of energy-efficient LED lights across India (IEA 2020).

Lastly, there are local authorities that are responsible for implementing policies, but their role tends to be more operational than strategic. Local authorities are often responsible for the implementation of energy efficiency measures in municipal facilities such as schools and public infrastructure.

2.4.4. National Development and State-Level Implementation

At the national level, energy efficiency policies are usually broader and aimed at establishing standards and incentives that are applied uniformly across the country. These policies, such as the Energy Conservation Act (the launch of the BEE) provide a regulatory framework and sets a strategic direction.

State-level policies on the other hand, are designed to cater to local needs, resources and demographics of states. Differences can exist between urban and rural states in what programs are promoted, based on the expected outputs.

It is also seen that in residential energy-efficiency, the mayor policies are developed on a national-level but need to be enforced at a state-level (Mir, Doll et al. 2020). As the SDAs have the organizational responsibility for this, there is a difference in performance across states. Not every SDA is equipped to the same extent and thus not able to enforce in similar manners.

2.4.5. Specific Policies Targeting the Residential Sector

As mentioned, the main national energy efficiency programs aimed at energy-efficient appliances are the Standards and Labeling (S&L) Program and the UJALA scheme. These are both aimed at accelerating efficient usage. The two policies are aimed at the specific appliances that are in-scope for this research: The UJALA scheme focused solely on LED lighting, and the S&L program focused on ceiling fans, among other household appliances. The UJALA scheme has been implemented for households across 120 cities in India and has over 100 million LED lamps installed (IEA 2020). The EESL is responsible for procuring LED lights in large quantities and distributing them to consumers at subsidized rates. This demand aggregation approach has led to significant reductions in manufacturing costs due to economies of scale and paying all cost for the development of local LED light production facilities upfront (EESL 2016, Mir, Doll et al. 2020). Furthermore, these subsidized rates were complemented by two payment options for consumers. Households could choose to pay the purchase prices upfront, or pay 20% upfront and the rest through a slight price increase of the electricity bill (Mir, Doll et al. 2020).

The Standards and Labelling program’s overarching objective is to guide consumers in understanding the energy-saving potential of different appliances, subsequently leading to cost savings (BEE 2023). The Standards and Labelling programme is identified by the Indian government as one of the key activities for energy efficiency improvements(The Energy and Resources Institute 2014). As of the time of our dataset, ceiling fans fall under the voluntary regime of the S&L scheme. This implies that ceiling fan manufacturers have the option to participate in the star labeling program. Importantly, the star label serves as an indicator of the ceiling fan's energy efficiency. The assumption for our research is that at the time of our data set, ceiling fans with star labels are thus more energy-efficient than their traditional counterparts.

As previously mentioned, the Ministry of Power has developed the Market Transformation for Energy Efficiency Program (MTEE). This further exists of two programs: The Bachat Lamp Yojana (BLY) which is aimed at transforming lighting to more efficient sources. However, this program is outflanked by the policy efforts of the UJALA scheme (Mir, Doll et al. 2020). Secondly, they have created the Super-Efficient Equipment Program (SEEP). This program is designed to transform the market for energy-efficient appliances by providing financial stimulus. These programs have been developed across the country and in separate states. For example, the Delhi government also introduced tax reductions on LEDs to stimulate purchases (The Energy and Resources Institute 2014). To investigate what their effect is on the adoption of energy-efficient appliances, the differences between states need to be considered.

In this chapter, an overview of the variables behind adoption of energy-efficient appliances is developed and insights in the policy dynamics in this domain have been generated. In the subsequent sections of this report, we investigate the implications of both the household-level variables that have been discovered in the literature review and the state-level differences between the adoption, implementation and execution of the described policies.

2.5. Synthesis of Literature Review and Policy Conceptualization

The literature review of this research has discovered significant disparities in the depth of investigation across elements of energy efficiency. A visible trend in the existing studies is their focus on assessing the overall energy efficiency performance at a national level. These evaluations typically give estimates of energy savings for entire countries, but they are insufficient in assessing the impact of individual policies or understanding regional variances. This general approach has left a distinct gap in the comprehensive understanding of energy-efficient appliance adoption patterns and their variations across the diverse Indian states.

In contrast to the European Union, where individual member nations have been the subject of detailed energy efficiency analyses, the Indian context has not received equal attention. The necessity for state-level analysis in India is critical, as India is a very large country with a unique heterogeneity and scale. The scale of state-level analysis in India is similar to country-level research in Europe, given the vast regional differences within India in terms of population size, culture, economic status, and energy infrastructure.

Moreover, while some quantitative modeling research has been done of the effects of specific policies, these papers have not yet sufficiently addressed regional differences within India. There is a need for more nuanced research that can help to enabling the formulation of more region-specific and effective policy recommendations.

In summary, our literature review highlights a significant knowledge gap in understanding the drivers behind the adoption of energy-efficient appliances in India’s residential sector, particularly at a state-specific level. This gap shows the need for research that not only addresses a broad, national policy evaluation but also delves into the granular nuances that influence appliance adoption in the Indian context.

In the policy conceptualization section, the critical role of energy efficiency was investigated within the broader framework of Indian policymaking. This way, the key energy efficiency policies and responsibilities were discovered. It was shown that energy efficiency is a cornerstone element in Indian energy policy, highlighted by its inclusion as one of the eight pillars of 'The National Mission for Enhanced Energy Efficiency'. The Bureau of Energy Efficiency (BEE) is the principal body responsible for formulating, enforcing and monitoring energy efficiency policies at the national level in India. To ensure the effective translation and implementation of these policies at the state level, State Designated Agencies (SDAs) assist the BEE.

Two specific policies are particularly relevant to the residential sector in India and directly influence this research. First, the UJALA scheme, aimed at promoting LED lighting adoption, is a direct intervention aimed at improving energy efficiency in lighting. This scheme has had significant implications for household-level adoption levels of their most used appliance, making it a crucial element of the Indian energy-efficiency policy. Second, the Star Labeling program focused on providing standardized information on the energy efficiency of a broad range of household appliances, helping consumers to make informed decisions. The dynamics between institutions, policy frameworks, and specific initiatives like the UJALA scheme and Star Labeling program are crucial in shaping the energy efficiency improvements of India.

3. Methods

This chapter describes the research methodology followed in this research paper. The chapter consists of four main sections. First, an explanation of the methodologies that are used is given to explain the value of the multitude of methods. Secondly, an overview of the data collection approach is given, with an introduction to the data sources and adaptations. Thirdly, a deep dive into the quantitative methodology is presented, with an explanation of the process behind the development of the logistic regression. Finally, the qualitative analysis method is analysed, with an explanation of the chosen survey and an introduction of the Indian expert panel. These four sections lead to an understanding of the research approach and are essential for future reproduction or expansion of the research. Here, an understanding of the current state of energy efficiency policy across India is developed to evaluate state-level adoption patterns of energy-efficient appliances in Indian households. Furthermore, this research is used to give insights for policymakers to speculate on future policy improvements.

3.1. Mixed Methods Design

In this paper, a mixed research method approach with a quantitative and qualitative analysis combination is chosen. By definition, mixed methods is a procedure for collecting, analyzing, and integrating both quantitative and qualitative data within a single study for the purpose of gaining a better understanding of the research problem (Creswell, Clark et al. 2003). This method allows the research to utilize the strengths of multiple research methods to give a broader perspective on the relevant issues at hand and includes the requirements of different stakeholders to achieve satisfactory results (Creswell. J.W. and Creswell 2017). Both research methods can independently lead to conclusions, but the combination of these multiple methods leads to a stronger and more thorough analysis that provides better insights into complex multi-actor problems (Greene, 2007). Neither quantitative nor qualitative methods are sufficient, by themselves, to capture the full details of the situation, such as quantifying effects of policy differences or understanding unobserved behavioural dynamics of Indian consumers. Using a mixed methods approach allows for a more robust analysis, taking advantage of the strengths of each research method (Ivankova, Creswell et al. 2006). A mixed methods approach can thus provide a more nuanced understanding of the complex dimensions between multiple policy environments and their influence on the adoption of energy-efficient appliances.

There are about forty mixed-methods research designs (Teddlie and Tashakkori 2003) . One of the most popular designs is the mixed-methods sequential explanatory design. It is highly popular among researchers and implies collecting and analyzing first quantitative and then qualitative data in two consecutive phases within one study (Creswell, Clark et al. 2003). This design is used in this research project. The set-up of this mixed methods project is an explanatory sequential design in which a quantitative regression model is made first, with qualitative research as validation and elaboration of the findings as a connecting step (Fetters, Curry et al. 2013). By choosing an explanatory sequential mixed methods design, the priority is given to the quantitative analysis phase of the study as this is the first main research step. Its results and findings are further investigated in the following qualitative analysis phase (Ivankova, Creswell et al. 2006). By conducting interviews, contextual field-based explanations of the statistical analysis can be found that explain why certain factors significantly or not significantly influence adoption patterns (Greene and Caracelli 1997). First, the broad patterns are identified in the quantitative analysis, and then the reasons behind these patterns are further explored in the qualitative analysis. This approach enables cross-check confirmation of whether the measured quantitative findings are aligned with qualitative experiences from local experts. Additionally, qualitative research can help to better interpret why certain correlations exist in the quantitative model and explain what contextual or political factors can further influence shown patterns. Where the quantitative research provides descriptive and inferential statistics, the qualitative research can help understand differences at lower-scale levels (Johnson and Schoonenboom 2016). Together, the quantitative and qualitative research steps can create a more robust and holistic understanding of drivers and barriers behind energy-efficient appliances in the residential sector in India.

In Mixed Methods research, flexibility and creativity are important elements. While traditional, monomethod designs offer a fixed menu of designs, researchers should mindfully create designs that can effectively answer the research questions (Teddlie and Tashakkori 2009). The physical presence in India of the researcher has led the mixed methods approach to be more iterative than the traditional sequential approach as described by (Creswell 2013). A challenge in mixed methods research is the lengthy duration required for both phases (Teddlie and Tashakkori 2003). The necessity to first collect and interpret all quantitative data before starting the qualitative research phases can be complicated by time constraints. In this study, this led to the adoption of a slightly more pragmatic iterative approach. Some results of the qualitative analysis were cross-referenced in the quantitative analysis to check whether the findings were true, instead of the quantitative phases being fully interpreted before conducting the qualitative analysis. Through this adaptation, we have used an advanced mixed methods design in which an adaptation from the basic design is developed based on the resources of time and participants (Creswell 2013). This way, the strengths of both research methods can be utilized within given time constraints and an overarching set of nuanced findings can be found.

The interviews develop insights that are more elaborate, in-depth and nuanced than the regression could demonstrate. As mixed methods research gives the luxury of triangulation of insights by using the other method to corroborate insights in one method, this was done both after the first quantitative research phase and with another briefer quantitative research phase after the interview process. This way, some elements of the interview phase can be seen to have a feedback loop back into the quantitative model. This shows the importance of adaptability in research as this could lead to better and more relevant outcomes. In Figure 2 the process is shown, with a feedback loop from the qualitative results back to the quantitative analysis.

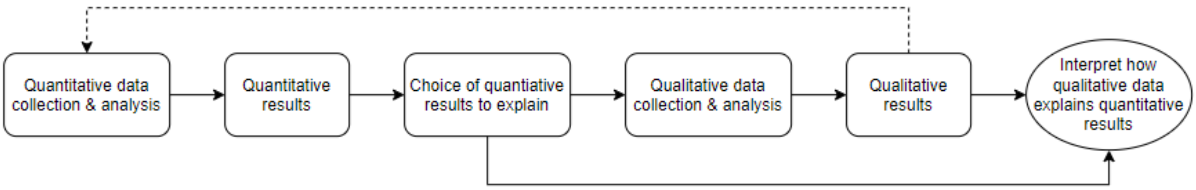

Figure 2: Mixed Methods Research Approach

3.2. Data Sources

The mixed research methods approach requires both quantitative and qualitative data and this is obtained through different sources. The data collection for this paper consists of a multi-step process in correspondence with the analytical approach. First, a systematic review of academic and non-academic sources was done to collect insight in adoption patterns, its drivers, and the Indian specific context. To collect data that can be transformed to input variables for the quantitative analysis, multiple databases have been utilized.

3.2.1. CEEW – The India Residential Energy Survey

The main database used for household-level characteristics is The India Residential Energy Survey (IRES) (Agrawal 2021). This is a study conducted every 5 years, aimed at understanding the energy consumption patterns, consumer behaviour and other socio-economic indicators of households across 21 Indian states. The survey is executed by the CEEW and commissioned by Niti Aayog. The variables used in this survey serve as inputs for the logistic regression model to analyze relationships in the quantitative research. The 21 states included in the dataset are shown in green in Figure 3 (Shodhan 2015).

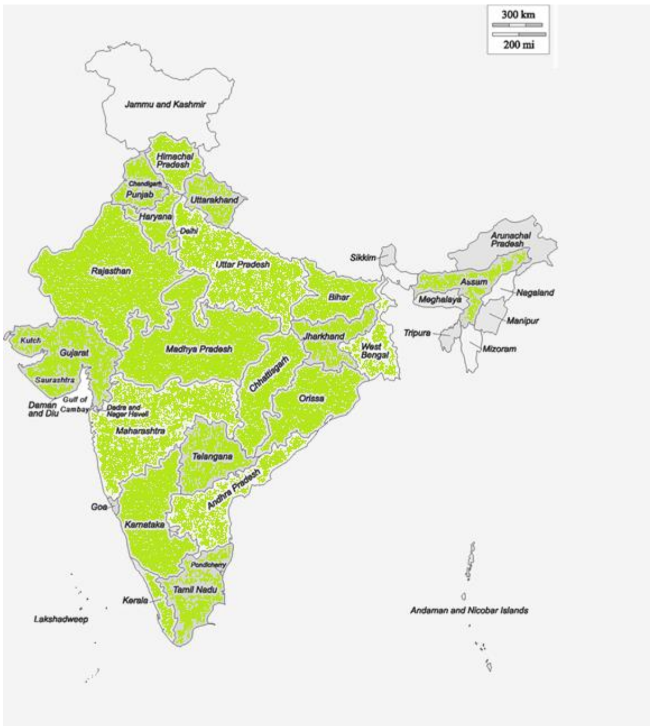

Figure 3: Map with green-coloured states in research scope

3.2.2. AEEE – State Energy Efficiency Index

The State Energy Efficiency Index of the Alliance for and Energy-efficient Economy (AEEE) is a benchmarking tool that provides a comprehensive state-by-state analysis of energy efficiency policies and performance across 36 Indian states (Kumar 2021). It differentiates throughout sectors and comprises of around 100 indicators. This tool can be used to provide a picture of the current state of the policy development and implementation across India. There is a variable section in this index specifically focused on the building sector. Its indicators can show what policy elements are drivers or barriers that cause different adoption patterns. The building sector index subdivides state-level scores into *Policy and Regulation, Financing Mechanisms, Institutional Capacity, Adoption of EE Measures and Energy Savings*. Indicators based on appliance programs, lightning programs, cooking fuel and star ratings are included in this index as well. These scores serve as an aggregated view of the energy efficiency policy landscape across different states in India. These indicators, combined with consumption pattern scores can show where energy efficiency measures have the most impact. For the purposes of this research paper, we have used the 2020 version of The State Energy Efficiency Index to correspond with the most recent edition of the IRES survey.

3.2.3. Climate Zone Data

In addition to the CEEW survey and the AEEE index, this research incorporates climate zone differentiation data (Bal, Ramachandran et al. 2016). This helps to contextualize the adoption of energy-efficient appliances across different climatic conditions in various Indian states as the living conditions and energy usage of certain household appliances are strongly influenced by climatic factors such as temperature.

3.2.4. Demographic Statistics

Furthermore, some state-level demographic statistics have been added to the dataset such as population, density and electricity consumption statistics (NITI Aayog 2023). These help to fill gaps in the dataset where limited household-level information is available.

3.2.5. SDA Capacity

To grasp the human resources capacity of the energy-efficiency tasks on a state level, the capacity of the Standard Designated Agency is added to the model (BEE 2018). This gives granular, empirical insight in the allocation of responsibility for energy-efficiency.

3.3. Data Distribution Across India

In Table 3, an overview of the data distribution of the IRES dataset across the 21 investigated Indian states is presented. This representation is compared to the distribution of the Indian population (NITI Aayog 2023). It can be seen that the respondents in our data set display a well-balanced representation across the Indian states, mirroring closely the realistic population distribution. However, it's worth noting that Uttar Pradesh is notably underrepresented in comparison to its actual population and Delhi and Haryana are quite overrepresented.

Table 3: Data distribution across India

State	Distribution in dataset	Distribution in Reality
AP	3%	4%
AS	3%	3%
BR	9%	9%
CH	3%	2%
DL	3%	1%
GJ	5%	5%
HP	3%	2%
HR	3%	1%
JH	3%	3%
KA	5%	5%
KL	3%	3%
MH	9%	10%
MP	6%	6%
OR	4%	4%
PB	3%	2%
RJ	7%	6%
TN	7%	6%
TS	3%	3%
UK	3%	1%
UP	10%	17%
WB	7%	8%

3.4. Quantitative Research Method

In the context of this research, the quantitative logistic regression is an essential component of the sequential mixed methods approach. Starting with a quantitative analysis, the logistic regression offers a statistical exploration of the relationships between the adoption of energy-efficient appliances and the predictor variables. The results of this phase will then inform and shape the subsequent qualitative phase.

3.4.1. Dataset Variables

It is necessary to create a foundational understanding of the variables that are used in the dataset and their characteristics. In Table 4, the variables are introduced in the way they are implemented in the dataset. In the original dataset, the variable names are different from the ones displayed in the table. The original variable names can be found in Appendix A. The variables have been structured into two categories, household-level variables and state-level variables.

Table 4: Variable overview and definition

Variables	Explanation
Household Level	
Rural – Urban	The binary variable determining whether the respondent lives in an urban or rural area
Age Primary Income Earner	The age of the primary income earner of the household
Education Level Primary Income Earner	The education level of the primary income earner of the household.
Caste Type	This categorical variable states the caste types the respondent identifies as. Here a ranking of lower caste to general caste is made.
No. members in household	The number of members in the household
Housing structure type	Specifies the material the house has been built with. Kachha homes are constructed using traditional building materials and typically non-permanent, whereas pucca homes are designed to be permanent and solid
House – Apartment	Variable to determine the type of house a household lives in, whether it is an apartment or an independent house
Ownership of House	Indicating whether the respondents own the house they live in
Plot Area	The total area of the plot of the household
Monthly Expenditure	The total monthly expenditures of the household in Rupees
Job type	The occupation of the primary income earner. A categorial variable with multiple job types
Monthly Income	The monthly income of the household. A variable with multiple income levels, that has been transformed to numeric values
Electricity grid connection	A binary variable checking whether the respondent is connected to the electricity grid
Electricity Meter	A categorical variable checking whether there is an electricity meter installed (and connected) at the household
Star Label Awareness	A binary variable checking whether the respondent is aware of star labels, the energy efficiency labeling scheme
Environmental Friendliness Awareness	A binary variable checking whether the respondent perceives environmental benefits as a perk of purchasing energy-efficient appliances
Monthly Electricity Consumption	The monthly billed units of electricity the household have been charged in kWh
Average Electricity Price	The average price per kWh the household has paid for its electricity, transformed from the total amount of Rupees the household was charged
Number of Lights Owned	Variable present in lighting dataset only, checking the total amount of lights owned by that household
Number of Ceiling Fans Owned	Variable present in ceiling fan dataset only, checking the total amount of ceiling fans owned by that household
State Level	
State Fixed Effect	This variable notes the abbreviation of the state in which the respondent lives and is included to show the unobserved state fixed effects
Population Density	A state-level variable determining the average density of states across India
Smart Meter	A binary state-level variable whether there is a smart meter program in a state.
Policy & regulation score	Variable that scores the energy efficiency policy & regulations that are noted across states
Institutional capacity	Variable that scores the institutional capacity for energy efficiency across states
Adoption of EE measures	Variable that scores the implementation of energy efficiency measures across states
Financing mechanisms	Variable that scores the energy efficiency financing mechanisms across states.
EE programs for residential buildings	Variable that scores the energy efficiency programs in states dedicated to the residential sector
Climate Zone	India is divided into six different climatic regions. The states in the dataset have been categorized according to these climate zones.
SDA Staff	The empirical value of the number of SDA officers in states. Similar to Institutional Capacity but gives insights in the differing allocation of responsibility as well.

3.4.2. Policy Variables Operationalization

In building on the discussion of energy efficiency policies in India, it is crucial to link the conceptual understanding of the policy environment with the main policy initiatives to the empirical aspect of this research. The aim here is to shed light on the interaction between these policy dimensions and socio-economic, geographic, and energy variables to influence the adoption of energy-efficient appliances in Indian households. However, the fragmented nature of energy efficiency policy data and the lack of granular, state-level insights for specific policies present a challenge. To address this issue, this research uses a more aggregated approach by incorporating an adaptation of policy related scores that are developed by the AEEE. A score model can be utilized to show differences in performance on multiple policy variables.

To ensure comparability across states, the AEEE has developed a score model that investigates state-level energy efficiency performance (Kumar 2021). Part of this energy efficiency index gives insights in differences and improvements of policies across India. The AEEE index shows the strong differences between states in terms of their adoption of energy efficiency policies.

An adaptation of part of this score model is used to operationalize the policy variables in this research. From the AEEE state-level energy efficiency index we can derive four distinct variables that provide a robust and multidimensional view of the policy environment across India. The energy efficiency index shows that there are large variations in the level of dedication states put in adopting energy-efficiency measures (Balachandra, Ravindranath et al. 2010). This approach is taken instead of using the overall energy-efficiency score of the AEEE because the AEEE score does not give a specific overall score for the residential sector (Kumar 2021). To ensure that only the state performance in this sector is taken, the following variables have been developed.

- **Policy & Regulation**: This variable captures the extent and effectiveness of state-level energy efficiency policies and regulations. This captures state's commitments to promote energy efficiency through legal frameworks and dedicated policies. State scores are dependent on the existence of programs focused on the penetration of energy-efficient lighting and appliances in buildings. To further grasp this sector, it gives scores for the adoption of BEE star rating systems in given states. Furthermore, it measures the implementation of the ECBC across states and the incorporation of this code into building bylaws.
- **Financial Mechanisms**: This score is dependent on the existence of several financial incentives in the building sector. Here, states should provide incentives for the procurement of energy-efficient appliances, the construction or retrofit of green buildings and the conduction of energy audits. For the procurement of energy-efficient appliances, states can provide soft loans, electricity rebates or subsidies.
- **Institutional Capacity**: The institutional capacity score investigates whether states have assigned entities focused on the enforcement and certification of the ECBC. Additionally, this score is dependent on the whether there is budget allocated to the SDA specifically focused on the enhancement of energy efficiency in buildings.
- **Adoption of Energy Efficiency Measures**: Here, the score is dependent on the adoption and penetration of the ECBC in buildings across the state and what percentage of buildings can be classified as green or have BEE star rating certifications. Additionally, it looks at whether there are benchmarking practices in place in this state.

These four variables serve as proxies that represent a spectrum of policy, institutional and financial aspects that shape the energy efficiency environment across India. These scores are used as input variables for our logistic regression model in Table 4 to enable us to bridge policy analysis and the actual adoption of energy-efficient appliances in Indian households. This combination of policy analysis and empirical research could lay the groundwork for a nuanced understanding of drivers and barriers behind the adoption of energy-efficient appliances, thereby reducing the gap between policy intents and real-life actions.

3.5. Logistic Regression Model

The way of going about quantitatively identifying the drivers and barriers behind the adoption of energy-efficient appliances is chosen to be a logistic regression in which the dependent variable is a binary variable. The binary variable predicts whether a household does or does not own a certain energy-efficient appliance. Logistic regression hereby predicts the probability of this ownership occurring, given the dataset. This way, the dependent variable directly models the probability of the adoption of energy-efficient appliance. This provides a clear interpretation of the effect of the independent variables on the probability of adoption. Additionally, the binary adoption variable only investigates the choice of adoption energy-efficient appliances and not the subsequent decisions to adopt more of the same. These subsequent decisions could be influenced by other unknown factors such as convenience of use or the perceived effectiveness. Furthermore, a logistic regression model can handle non-linear relationships. In a complex and multi-factor dynamic such as the adoption of energy-efficient appliances, the relationship between predictors and the outcome variable might not be linear or straightforward. As the dataset consists of a variety of continuous, binary and categorical predictor variables, a logistic regression can provide a more focused perspective on the key factors influencing the adoption of energy-efficient appliances in Indian households.

3.5.1. Mathematical Model

The goal of implementing the variables into an empirical model such as a logistic regression process is to identify the relationship between the variables collected in the dataset and the predicted adoption levels of energy-efficient (LED) lighting and ceiling fans. For our research, this model can be mathematically expressed as follows:

Logit(P(Adoption_of_Appliances)) = $\beta 0$ + $\beta 1$ * Socio_Economic_Variables + $\beta 2$ * Energy_Variables + $\beta 3$ * Geographic_Variables + $\beta 4$ * Policy_Variables + error term

Where,

- Adoption_of_Appliances is the binary dependent variable, taking the value of 1 if a household has adopted an energy-efficient appliance and 0 if it has not.
- Socio_Economic_Variables represent the socio-economic factors that influence the decision of households to adopt energy-efficient appliances such as education levels, employment levels, age, population size, population density, household size, home ownership, environmental attitude, housing type, housing size, comfort levels, appliance ownership, and cost of investment.
- The Energy_Variables represent aspects related to household energy use and energy-related behaviours that can affect the adoption decision. These variables are energy prices, energy expenditure, household-level energy consumption, state-level energy consumption, the degree of renewable energy integration, and the rate of electrification.
- The Geographic_Variables capture geographic and climatic influences, which ranges from urban-rural differences to variations in climate across states.
- The Policy_Variables encompass the scores related to policy and regulation, institutional capacity, adoption of energy-efficient measures, and financing mechanisms as provided by the State Energy Efficiency Index.
- In the equation, $\beta 0$ represents the intercept baseline log-odds of adoption when all predictor variables are set to zero. The coefficients $\beta 1$, $\beta 2$, $\beta 3$, and $\beta 4$ are vectors, representing the coefficients of variables in that category that are estimated. The estimates are the expected change in log-odds of the dependent variable for a one-unit change in the corresponding independent variable, assuming all other variables are constant.
- The error term represents unobserved factors that might influence the decision to adopt energy-efficient appliances that are currently not captured by the quantitative model.

3.5.2. Logistic Regression Tool

The quantitative analysis is conducted with statistical software packages of R. The construction of correlation matrices and regression models that are needed to execute this econometric analysis is accommodated by R, that has a wide range of statistical techniques and strong data visualization capabilities. R can handle the different databases used in this study and manipulate this data. The dplyr package is used for manipulation of data and the tidyr package is used for cleaning of the dataset. To model the dependent variable as a binary variable in a logistic regression, a generalized linear model is used. In R this is called the glm () function. To ensure that the binary nature of the dependent variable is included, the 'family' argument is indicated as 'binomial'.

After conducting the regression, several diagnostics have been performed to ensure reliability and therefore affirm usability of the model. These steps have led to an interpretation of the predictor coefficients to determine the influence of the predictors.

This method aims to capture causalities in the advancement of energy efficiency policies and provide insight into what drives the adoption patterns in the residential sector in India.

3.6. Qualitative Research Method

The qualitative research phase is essential for generating high-quality insights in this research project. Quantitative analysis such as the logistic regression used in this paper, lacks the depth and nuance required to fully understand participants' behaviours and choices (Cridland, Jones et al. 2014). To go beyond just the identification of correlations between variables and observations, this study aims to find potential reasonings for such observed behaviour. Qualitative research is an approach that can achieve this. Furthermore, as this study is executed on a geographic and cultural environment previously unknown to the researcher, the qualitative research phase can be used to test hypotheses of the local environment and dynamics by the researcher to better understand Indian phenomena and provide a more detailed picture of the subject.

The qualitative data collection aims to provide contextual and detailed insights into the views and perceptions of expert stakeholders related to energy efficiency policy development in India. Interviews are used to further investigate the observed patterns and trends of the quantitative analysis phase. Interviews can elaborate on observed state-level differences and identify what contextual or implementation variables and policies might be influential other than the modelled variables.

In a qualitative research setting, it is of very high importance that the researcher has a solid understanding of the research matter. In this research, the previous stages of literature review, desk research and quantitative analysis ensure that both the local context and adoption dynamics are understood. Qualitative research can leverage quantitative insights for an even deeper understanding of the subject (Kallio, Pietila et al. 2016).

3.6.1. Semi-Structured Expert Interviews

Semi-Structured interviews are the chosen qualitative data collection method. Such an approach is especially effective when studying perceptions and opinions of complex or sensitive matters. By staying flexible with a semi-structured approach instead of a structured approach, a broader range of perceptions is considered. By staying flexible and at the same time close to a clear set of questions, the interviews can generate comparable and higher quality insights (Cohen and Crabtree 2006).

A structured interview guide has been developed to be used for the data collection. This interview guide consists of a list of questions spanning multiple areas of the research: state-level insights, quantitative model insights, policy insights. These subsections are made to steer the conversation towards the main research topics. These research questions in this order ensures that the interviews maintain a logical, coherent and structured flow.

3.6.2. Participant Selection

The selection of participants is a vital step in the qualitative research section. The chosen individuals are selected based on their expertise, diversity and interest. To ensure an expert group with deep sector knowledge, the selection process began with a comprehensive stakeholder mapping exercise, in which the dimensions that encompass this complex societal system of energy efficiency in Indian households have been explored in-depth.

The semi-structured interviews have been conducted with experts. This is a conscious research design choice as this is a complex techno-societal subject. Household-level insights are already generated in the survey used for the quantitative analysis, and to better understand the high-level implications of these insights and to shed light on the observed trends, expert knowledge is required.

Experts who are interviewed need to have a deep understanding of the subject, with a variety of perspectives required. This variety of perspectives is essential as different stakeholders in complex systems have different observations and information. Due to the nature of this mixed methods approach and the inaccessibility of Indian experts for a Dutch student, time and availability are constraints for this research phase. By conducting interviews with high-level experts, the information density of interviews is generally much higher than for consumers. While consumers provide valuable information on their personal experiences, experts can offer strategic perspectives with regard to trends and patterns and understand possible underlying systemic issues.

To gain access to high-level Indian experts and get a deep and contextual understanding of the Indian local context, the researcher has conducted a self-organized internship for six weeks at The Energy and Resources Institute (TERI) and the Embassy of The Netherlands in India. This combined internship experience has significantly improved the participatory enthusiasm of expert interviewees.

Several interrelated dimensions of knowledge can be provided by the expert interviews (Alhojailan 2012). Firstly, there is technical subject knowledge, relating to specific details concerning operations, relevant regulations and other factors governing the domain. Through interacting with think tanks, the foundational constructs, norms and operations of policies can be understood. Industrial experts can provide knowledge of consumer behaviour choices and practical implications of policies. The following organizations are indicative of the participants approached for the expert-interview panel backgrounds.

Governmental Entities in Energy Efficiency

- Ministry of Power: Responsible for India's power sector, instrumental in setting the broad policy strategy.
- Bureau of Energy Efficiency (BEE): Playing a central role in developing and stimulating energy efficiency initiatives.
- NITI Aayog: A highly influential policy think tank of the Indian government, offering frameworks, writing policies and providing guidelines.
- Energy Efficiency Services Limited (EESL): A joint venture of public sector organizations in the electricity market responsible for the UJALA scheme design

Independent research institutes / think tanks.

- The Energy and Resources Institute (TERI): a globally renowned institute focused on developing in-depth research insights on sustainability and energy.
- Council on Energy, Environment and Water (CEEW): another highly regarded research institute focused on the energy sector in India.

- Alliance for an Energy Efficient Economy (AEEE): Thinktank supporting energy efficiency policies and initiatives throughout India and responsible for the State Energy Efficiency Index.

Industry organisations

- Regional Distribution Companies (DISCOMs): responsible for understanding the supply chain of electricity in India and the challenges that the electricity sector faces.
- Manufacturers and retailers of energy-efficient appliances
- Consumer behaviour organisations

This comprehensive list of stakeholders has been used to identify participants the semi-structured interviews.

3.6.3. Participants Analysis

With the coordination assistance of TERI and The Netherlands Embassy in India a total of 10 expert interviews have been conducted for this research project in Delhi and Chennai, Tamil Nadu.

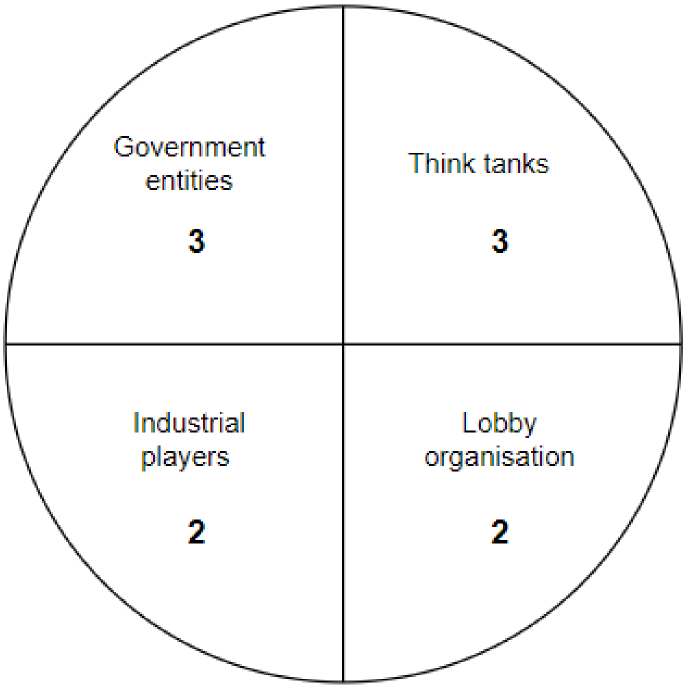

Figure 4: Subdivision of interview participants

Think tank experts.

- Expert in modelling: Providing in-depth knowledge on the current modelling frameworks and able to provide insights related to local energy consumption and efficiency patterns in Indian households. This expert specializes in Energy-Economy modelling, so this participant was able to substantiate insights on consumer behaviour models. This participant has conducted similar behavioural studies.
- Expert in Energy Efficiency: Vital for insights into recent trends and challenges in energy efficiency advancements in India and able to give insights into local and global best-practices.
- Expert in Governance: Can contextualize the overarching governance structures, regulations, and frameworks that influence energy efficiency in Indian households. Specifically, insights in the interrelations between different governance levels and institutions are generated from this interviewee.

Lobby organization

- Consumer action group: These experts provide an understanding of local needs and consumer behaviour patterns. Experts in consumer behaviour with deep knowledge of what drives Indian consumers to make sustainable choices.

Government entities

- Experts on Energy Efficiency Policy: Crucial to create a better understanding of India's national policy direction and local differences. These experts are responsible for developing policy and strategies in different regions of India Will give insights in challenges faced in policy decision-making and implementation processes.
- International government entity. This expert, specialized in innovation policy, offers a perspective on innovative practices, and strategies implemented by the Indian government. This interview can shed a light on India in comparison to other comparable economies elsewhere. Additionally, insights in global best practices that can be applied in the Indian context can be derived.

Industry experts

- Appliance manufacturer: This expert provides insights that help in understanding consumer behaviour, preferences, and barriers when it comes to adopting energy-efficient appliances.
- Electricity grid expert: To provide insights on electricity access, energy tariffs and affordability issues. This expert explains challenges that are faced in providing efficient power distribution and stimulating sustainable consumption.

In Figure 5, an overview of the interview participants is presented in a Power-Interest Grid. A Power-Interest Grid, is a valuable tool to comprehensively understand the relevant stakeholders, their needs, and their objectives (Grimble and Wellard 1997). This grid provides a visual representation of stakeholders' positions, which helps in understanding their influence and engagement. The Power dimension assesses stakeholders' abilities to influence the outcome of projects or policies in the given context. It is a measure of their control, authority, resources, or decision-making capacity. The dimension of Interest reflects the extent to which outcomes might affect them or align with their goals, values, or responsibilities (Reed, Graves et al. 2009).

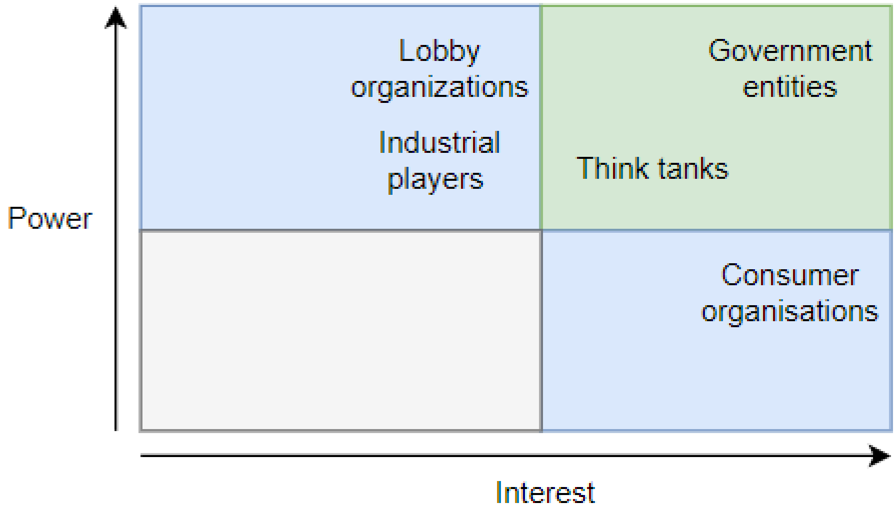

Figure 5: Power-Interest grid of interview participants

3.6.4. Interview Design

The chosen approach for the interview design of this semi-structured interview process is as previously mentioned a subdivision into three different research elements. The final questionnaire can be found in Appendix B. First, an understanding of the local context and state-level knowledge is generated by asking for insights that dive into local nuances and interesting local contexts. To this end, adoption drivers and barriers are asked, before mentioning the outcomes of the model. This way, the participants are not steered in their answers and can more independently deliver information to reduce a confirmation bias.

Additionally, in this phase, the diversity of expertise of the interviewees can come forward due to the option to steer their answers towards their field of work. Next, the interview goes into the insights that have been generated by the quantitative analysis to corroborate and contextualize these findings. In this section there is room to explore possible reasons behind the statistical findings, providing a more comprehensive understanding of the model. Through the open-ended questions, the participants are invited to comment on potential oversights or limitations of the quantitative model as well. Hereby enabling future improvements and refinements.

The third and final section of the interview goes into policy challenges. The intricacies of the Indian policy dynamics are highly complicated. While the policy conceptualization phase and the operationalization of policy variables in the model shed some light on the effects of energy efficiency policy in India, insights from local policymakers and policy advisors are very insightful. While policies on paper can seem very well developed, the implementation phase is often not captured as well in data. The opportunity to discuss such challenges helps create a better understanding of the policy landscape. Lastly, this phase encourages participants and the researcher to discuss existing policies and their implementation and speculate on possible future policy improvements.

The interview design is meant to elicit a variety of perspectives from the different interviewees. As their expertise varied across the domain, this leaves the opportunity to address subjects that are more within their field of expertise. This flexibility leads to diverse, yet exhaustive interview content.

3.6.5. Data Collection Approach

The qualitative research consisted of in-person and online interviews, depending on the availability and preference of the participants. For administrative purposes, personal information about respondents such as names, employers and job titles have been collected. The interview process started with an informed consent form that can be found in Appendix C. The informed consent form requested permission for the use of the interview data for this study. Interviewees could at any point withdraw from the interview or request their responses to be deleted from the research. The interviews were audio recorded and together with detailed interview notes used to develop anonymous discussion summaries, which can be found in Appendix D. The summary is presented to the participant before inclusion in the thesis project. One month after completion of the research project the personal data of the participants is destroyed.

In determining the number of interviews to conduct, our research adopted the data saturation approach. This method focuses on basing the number of interviews on whether they provide new themes, insights or information from the discussions (Fusch and Ness 2015). Using this approach in a varied expert panel ensures that our mixed methods approach aligns with best practices in qualitative research and captures the nuances of the Indian energy efficiency domain (Francis, Johnston et al. 2010). After completion of a series of ten interviews, we reached a point of data saturation. This number was deemed sufficient as the last interviews began echoing previously identified themes and insights, confirming that we had explored the diverse perspectives in-depth. The number of interviews our research conducted is in line with the optimal bandwidth based on the literature (Miles, Huberman et al. 2014, Hennink and Kaiser 2022).

3.6.6. Data Analysis Process

The qualitative analysis leads to a variety of insights from many different perspectives. To systematically extract information from these interviews that can be used to substantiate the quantitative analysis, it is essential to use a structured analysis approach. To ensure that we rigorously collect the interview insights, thematic analysis was used. Thematic analysis is a widely acknowledged method used to find common trends that arise during interviews (Braun and Clarke 2006). Thematic analysis is a comprehensive process where numerous cross-references between the data the research’s evolving themes can be found. It provides flexibility for approaching the research patterns and helps determine the true relationship between variables (Alhojailan 2012).

As the questionnaire of the qualitative research is based on the findings of the quantitative phase, qualitative phase is bound to be explanatory, with thematic analysis as a common tool (Ivankova, Creswell et al. 2006). As the objective of the qualitative research phase is to delve into the dynamics behind the observed findings of the quantitative analysis, thematic analysis is a useful way of distilling these varied perceptions and nuances (Lamont, Brunero et al. 2015).

3.7. Integration of Quantitative and Qualitative Methods

The mixed methods explanatory research employed in this research is developed according to a sequential design (Creswell, Clark et al. 2003). This design inherently gives priority to the quantitative approach as it precedes the qualitative phase in the sequence and often forms the bulk of the data collection process (Ivankova, Creswell et al. 2006). This methodology ensures that the qualitative phase is grounded in empirical findings, providing a space to explore unexpected or nuanced results that have emerged from the quantitative data (Morse 1991).

In this research design, the data is collected over the period of time in multiple phases. Thus, a researcher first collects and analyzes the quantitative data. Qualitative data are collected in the second phase of the study and are related to the outcomes from the first, quantitative, phase. The decision to follow the quantitative-qualitative data collection and analysis sequence in this design is dependent on the research questions seeking for the contextual field-based explanation of the statistical results (Greene and Caracelli 1997).

Integration refers to the stage or stages in the research process where integration of the quantitative and qualitative methods occurs (Creswell, Clark et al. 2003). The integration in a mixed methods design can been done in multiple stages of the research; the design stage, the intermediate stage and the interpretation stage(Teddlie and Tashakkori

2003, Ivankova, Creswell et al. 2006). With embedding the analysis, the datasets link at multiple points through narrative, data transformation, and joint display (Fetters, Curry et al. 2013). By integrating the methods at various stages, such as the design phase, with the incorporation of both quantitative and qualitative research questions, and the interpretation stage, both statistical insights and contextual knowledge are demonstrated (Ivankova, Creswell et al. 2006).

In our research project, the methods have been integrated across the research phases. In the study design phase, both quantitative and qualitative research questions have been introduced. Another connecting point occurred in the development of the qualitative data protocol based on the results from the quantitative phase, to investigate those results in more depth. Furthermore, the quantitative and qualitative research findings are integrated in the interpretation of the outcomes of the study. The integration of both the quantitative and qualitative findings helped explain the statistical results and ensured a more comprehensive understanding of the subject matter, underscoring the purpose for a mixed-methods sequential explanatory design (Creswell, Clark et al. 2003, Ivankova, Creswell et al. 2006)

4. Results of Quantitative Analysis

In this section, the quantitative analysis is conducted, and an understanding of the drivers and barriers is generated. This addresses the third research question: "*How do socio-economic, geographic, energy and policy variables influence differences in the adoption patterns of energy-efficient appliances across states in India?".* Given the diverse nature of the investigated region, the data presents a very heterogeneous population. To ensure that the quantitative results can be used to answer the research question and provide input for the qualitative phase, this section aims to illustrate the techniques used to understand the statistical meaning of the logistic regression data. Several techniques have been utilized to ensure an unbiased and accurate interpretation of the data.

4.1. Descriptive Statistics

Before diving into the core analysis, it is essential to get familiar with the primary features of the dataset. In this descriptive statistics section, an overview is given of the variables and their characteristics. Here, our target variables are has_LED and has_EE_CF, representing respectively the LED lighting adoption and the ceiling fan adoption choice.

4.1.1. Penetration Rate of Appliances

To get insights into the dynamics behind the adoption of energy-efficient appliances, we need to understand what the general adoption rates of appliances in Indian households are. In table 5 the considered appliances are shown: lighting, ceiling fans, table fans, air conditioners, geysers, and water pumps. Of these appliances, only lighting and ceiling fans have an average penetration rate that exceeds 15% across India. The penetration of these appliances is very high, as 97% of the respondents owns at least one light. On a similar note, the ceiling fan penetration is registered as 87%.

While air conditioners (AC) are significant in the field of energy efficiency due to their high energy consumption, they were excluded from this study for two primary reasons. The overall penetration rate of ACs in India is only 12%. This reduces the potential to generalize findings across the broader domain, hampering the depth of the study insights. Furthermore, the use of ACs is heavily skewed towards specific regions, with an especially high concentration in the Delhi Union territory. While such a narrow regional focus does not fit this research, future investigations can be done on the state-specific dynamics or compare adoption patterns between two (or more) states.

This observed high penetration of lighting and ceiling fans is an indication of their fundamental roles in the Indian residential sector. The strong prevalence of these appliance categories presents two main implications for our research.

1. **Relevance**: By emphasizing lighting and ceiling fans, the applications that dominate the domestic sector are investigated. This ensures that our research remains focused on appliances that are strongly integrated into Indian life and gives us the opportunity for realistic implications of our findings for this region.
2. **Feasibility and precision:** A focus on the dominant appliances that have extensive adoption across all regions ensures a higher granularity in our data analysis. Given these adoption rates, we can extract more nuances in consumer behaviour patterns. This way, the drivers and barriers behind the adoption of energy-efficient appliances will be found more accurately.

To understand the energy efficiency adoption within households, a concrete operationalization of this definition is essential. In the context of this study, the adoption of energy efficiency in households has been specifically operationalized as the choice of adopting energy-efficient appliances over their traditional, non-efficient counterparts. Specifically, this research has been scoped down to assess the adoption of two essential appliances of lighting and ceiling fans for Indian households.

For lighting, this report investigates the adoption of LED lighting over non-LED lights. LEDs (Light Emitting Diodes) are more energy-efficient, more durable and energy-saving compared to both Incandescent Light Bulbs and Compact Fluorescents (CFLs). While it must be noted that CFLs are already more sustainable than incandescent lights, the large difference between LED and CFLs has caused CFLs to be noted as non-efficient lighting. In the logistic regression, this adoption is operationalized in the binary variable "has_LED", where households using LED lighting are coded as '1' and the rest as '0'.

Ceiling fans are a very common household appliance across India, as seen in Table 5. The benchmarking process of the Indian government in determining whether appliances are energy-efficient is the star labelling approach. For some appliances, this is already a mandatory scheme, but for others such as ceiling fans, this is a voluntary process at the time of this research. Therefore, ceiling fans that have a star label in the dataset, are purposely equipped with this star label to show their higher efficiency in comparison to non-rated appliances (Agrawal and Aggarwal 2020).

By focusing this paper on these two specific adoption choices, the study offers a narrowed-down and practical view of the adoption of energy efficiency in Indian households. While these appliance choices represent only a fraction of the energy efficiency choices households can make, they can be seen as indicators of broader energy efficiency trends and preferences. The way these variables are operationalized in direct and concrete choices ensures grounded and observable consumer behaviour research.

Table 5: Penetration rates of appliances in Indian households

State	#respondent	Lighting	Ceiling fan	Table fan	AC	Geyser	Water pump
AP	498	100%	97%	12%	9%	3%	13%
AS	399	99.7%	88%	18%	1%	3%	17%
BR	1346	97.3%	82%	12%	5%	1%	10%
CH	386	95.8%	82%	18%	17%	1%	3%
DL	395	99.7%	99%	4%	55%	21%	54%
GJ	798	98.9%	92%	11%	4%	4%	11%
HP	384	100%	79%	8%	1%	24%	8%
HR	383	89.8%	87%	4%	20%	5%	3%
JH	386	97.7%	69%	15%	5%	1%	6%
KA	788	96.8%	83%	9%	3%	4%	6%
KL	385	100%	89%	26%	1%	1%	61%
MH	1409	99.5%	97%	18%	15%	5%	7%
MP	964	93.5%	76%	7%	21%	1%	3%
OR	586	96.7%	81%	23%	18%	0%	10%
PB	397	100%	98%	28%	21%	8%	10%
RJ	973	93.1%	87%	7%	25%	3%	8%
TN	969	97.7%	93%	20%	2%	1%	19%
TS	493	99.7%	98%	6%	27%	1%	26%
UK	384	98.9%	84%	8%	8%	10%	20%
UP	1548	92.3%	82%	10%	14%	3%	10%
WB	980	96.9%	91%	26%	1%	3%	7%
Total	**14851**	**97%**	**87%**	**14%**	**12%**	**4%**	**12%**

4.1.2. Basic Descriptive Statistics

Here, we present the basic descriptive statistics for the variables incorporated into our regression model. For numerical variables, this includes their units, the number of observations, mean values, standard deviations, and the minimum and maximum values observed. For categorical variables, the focus is on the number of observations and the distribution of these observations across the different levels. This detailed overview, given in Tables 6 & 7 provides a foundational understanding of the data characteristics, providing essential context for the analysis and interpretation of the regression model findings.

Table 6: Numeric variables descriptive statistics

Variables	Unit	N	Mean	Standard Dev.	Min	Max
Age Primary Income Earner	Years	5441	43.5	11.2	18	100
No. members in household	#	14851	5	2.2	1	25
Plot Area	m^2	14851	850	85035	0	12e6
Monthly Expenditure	NRP	14851	8177	5384	1000	10e4
Monthly Income	NRP	14031	14e3	11e3	2500	18e4
Population Density	$/km^2$	14851	810	1772	123	11297
Smart meter AEEE 2021	-	14851	0.31	0.46	0.00	1.00
Policy & regulation score	-	14851	5.46	2.27	2	10
Institutional capacity	-	14851	0.96	0.62	0.00	2.50
Adoption of EE measures	-	14851	2.57	1.37	1.00	6.00
Financing mechanisms	-	14851	0.936	1.08	0.00	4.00
EE programs for residential buildings	-	14851	0.45	0.49	0.00	1.00
SDA Staff	#people	14851	7.06	3.49	3	16
Monthly Electricity Consumption	Units/ Month	4150	131.30	147.48	0.80	2305
Average Electricity Price	Price/ Unit	4003	29.16	149.49	-5.10	4941
Number of Lights Owned	#	14851	4.6	2.56	0	28
Number of Ceiling Fans Owned	#	14851	1.68	1.14	0	8

Number of observations

It can be seen in Table 6 that the number of observations in the data set is mostly very high. As the survey has been conducted across 14851 respondents, only a few of the predictor variables have limited respondents. These are the age of the primary income earner, and information regarding their electricity consumption/ average price for the numeric variables. For the categorical variables, these are the type of home they live in and the acknowledgement of the environmental benefits of energy-efficient labelled appliances. For the age and the electricity statistics, this reduced number of observations might be explained by a lower willingness to disclose such information. The environmental benefits variable and the housing type variable are only answered in the survey by people who have positively answered the previous question. For the housing type variable people who live in a puccha home have not answered the question relating to whether they live in an apartment and for the environmental benefits respondents must be aware of energy efficiency labels to begin with. As a result, in the regression for these two variables, all non-responses have been coded as 0, indicating a no.

An approach with only variables with the maximum numbers of observations was considered and tested as well. However, this strategy did not result in a better-performing model. More importantly, variables with a lower number of observations, like electricity price and consumption, are important to the study. The literature review has shown that electricity price and consumption, for instance, are indicators that might directly influence consumer behavior and decision-making. Therefore, while recognizing the importance of a robust sample size, this study maintains a comprehensive approach, considering all relevant variables.

Mean values and standard deviations

The mean values of the variables with the corresponding standard deviations showcase the large variety of variables across India. The stat relationship between the mean values and the standard deviation is that approximately 68% of the results fall within one standard deviation (σ) range of the mean (μ). So, between $\mu - \sigma$ and $\mu + \sigma$, about 68% of the results can be found. For example, an insight that can be generated from this is that 84% of the dataset has a primary income earner older than $\mu - \sigma = 43.5 - 11.2 = 34.3$ years old.

Furthermore, the plot area has a very large standard deviation, meaning that there is a very broad range of sizes of the plots, with many plots much larger than the average. Lastly, it can also be seen that the average household has 4.6 lights and 1.68 ceiling fans in their home. This is of course referring to the total number of appliances and not energy-efficient appliances.

Level distribution of categorical variables

The categorical variables are given in Table 7. Here, the different levels are indicated with the distribution of responses in the dataset. For example, 66% of the respondent population lives in rural areas, and 34% in urban areas. Furthermore, 80% of the respondent population lives in (semi-)permanent houses. Another interesting insight that can be taken from this table is the high average electricity grid connection across India, with over 97% of respondents' households connected to the grid.

Table 7: Categorical variable descriptive statistics

Variables	N	Levels
Rural – Urban	14843	Rural: 66% Urban: 34%
Education Level Primary Income Earner	14843	No formal education: 20% Primary education: 7% Middle school education: 22% High school education: 37% College or graduate degree: 13%
Caste Type	14512	Scheduled or Tribal Caste:33% Other backwards caste: 35% General caste:32%
Housing structure type	14843	Kachha: 20% Pucca/Kachha mix: 29% Pucca: 51%
House – Apartment	11639	Independent traditional: 20% Independent modern: 29% Apartment:50%
Ownership of House	14843	No: 7% Yes: 93%
Job type	14581	Agriculture: 34% Labour: 20% Government: 4% Private Job: 26% Shop owner: 9% Business/trade: 4% Passive income: 3%
Electricity grid connection	14843	No connection: 3% Connected: 97% Connected, not working: 0.4%
Electricity Meter	14333	No: 7% Yes: 91% Yes, but not working: 2%
Star Label Awareness	14399	No: 75% Yes: 25%
Environmental Friendliness Awareness	3629	No: 75% Yes: 25%
Climate Zone	14851	Peninsular: 21% West Central: 16% North West: 20% North Central: 29% North East: 9% Northern Hilly: 5%

4.1.3. State-level electricity price differences

In understanding our dataset, an interesting factor that has emerged is the significant variation in average electricity prices across different states. In Table 8, the different state-level averages for the electricity prices are shown. Among the states that have been researched, there are notable differences in the average electricity prices, with several states having very high prices, such as Assam and Odisha (28 and 38 rupees per unit, respectively), and others maintaining significantly lower prices, including Delhi, Jharkhand, Kerala, Tamil Nadu, and Uttarakhand, all with prices under 1 rupee per unit. Households in states with high electricity prices may have an increased incentive to invest in energy-efficient technologies, as they might reduce their electricity consumption and therefore their electricity bills. Furthermore, these state-level gaps in electricity prices show the importance of developing energy efficiency policies and incentives that address the unique contexts of the electricity system of each state.

Table 8: State-level average electricity prices

	state_abbv	average electricity price
1	AP	6.7968786
2	AS	28.6256993
3	BR	5.4086606
4	CH	3.3673443
5	DL	0.3747384
6	GJ	4.0379163
7	HP	0.1386479
8	HR	4.3328423
9	JH	0.4679842
10	KA	11.1850065
11	KL	0.5307819
12	MH	10.8590105
13	MP	12.089511
14	OR	38.3132391
15	PB	3.1342084
16	RJ	5.7499242
17	TN	0.1341311
18	TS	12.7258204
19	UK	0.7539868
20	UP	5.3230966
21	WB	2.4261908

4.1.4. Diversity in Socio-Economic Variables

A comprehensive descriptives table for both LED lights and ceiling fans are developed that can be seen in Appendix E. An examination of these descriptives tables, outlining the means of all our selected variables – consisting of socio-economic, energy, geographical, and policy dimensions – for all states and comparing them with the overarching national mean values offers insightful preliminary observations. To accentuate patterns and facilitate an improvement of visibility of dynamics the state-level variables are color-coded in comparison to the overall mean. Delving into the nuances of this table, we can observe a few trends.

- **Heterogeneity in socio-economic metrics.** A first look at the socio-economic variables included in the model shows that states portray a large variety among them. From states with higher development to states that are still struggling to get there, the spectrum is wide. Additionally, there does not appear to be a clear clustering opportunity due to this heterogeneity among states and variables. However, this exact diversity shows the need for state-specific and tailored policy interventions. A one-size-fits-all approach seems to be too simplistic for the large variety of India.

- **There seems to be an interlinkage between education levels, income category levels and LED lighting penetration**. A trend emerges across states where higher educational levels correspond with higher income brackets. This is quite a straightforward relationship as income and education are correlated around the globe (Psacharopoulos and Patrinos 2018). Intriguingly, these very states also register an elevated penetration of LED lights. This observed relationship hints at the possibility of education not merely as an enabler of better income opportunities but also as an influencer of energy-efficient choices. Education, seemingly, influences individuals to recognize and act upon the long-term benefits of LED lighting.
- **Electricity grid connection and LED lighting adoption.** A potentially intuitive observation emerges from the descriptives table showing a correlation between higher-than-average penetration rates of grid connection and LED lighting adoption. With already an average of 92% state-level grid connection this statistic still stands out. A robust electricity connection is a vital prerequisite for the adoption of energy-efficient appliances. There still seems to be a challenge in enabling the grid infrastructures in states still lagging.

To summarize, this descriptive table maps out the current landscape of the country and shows some apparent interplay between variables. These preliminary insights will be further enriched and validated as we delve into the logistic regression step.

4.2. Multicollinearity Descriptives

Collinearity, or the high correlation between independent variables, could pose a threat to the validity and interpretability of our logistic regression analysis. Therefore, it is necessary to scrutinize the extent of collinearity within our dataset. This way we can ensure the robustness of the model. The collinearity diagnostics are presented in Figure 6 & 7.

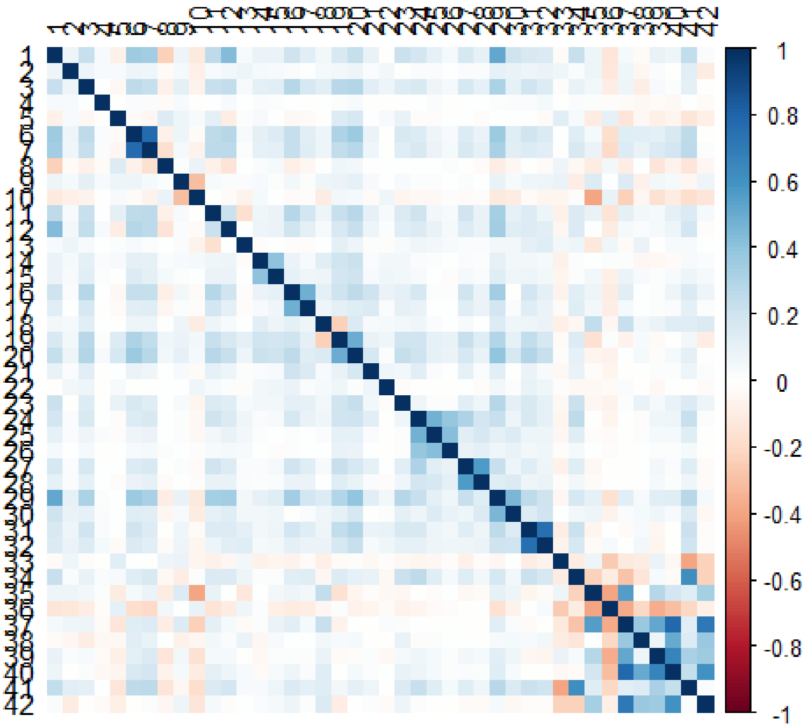

Figure 6: Collinearity diagnostics of entire dataset

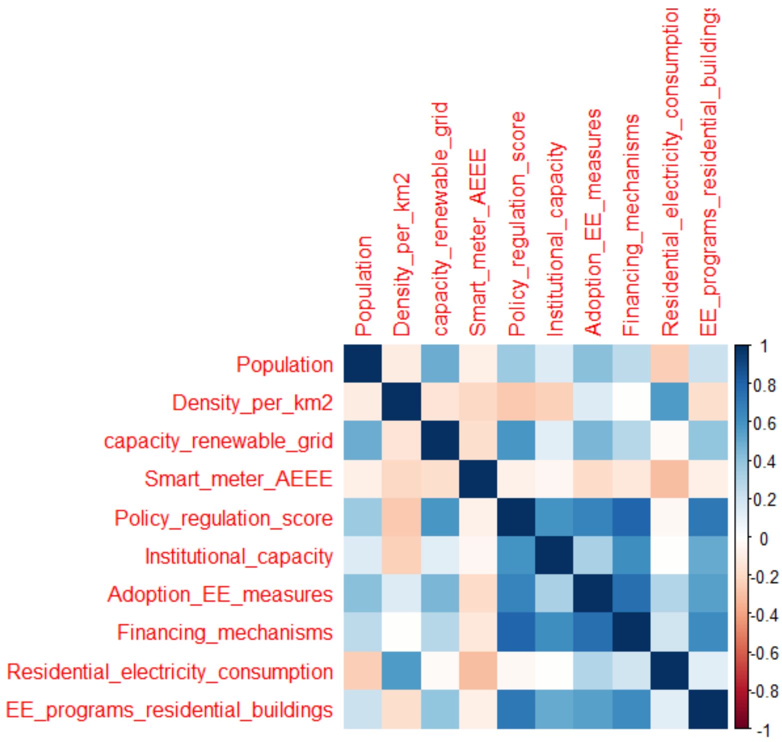

Figure 7: Collinearity diagnostics of state-level variables

From this, we can differentiate between the two types of variables that have been included in the model.

- **Household-level variables** exhibit a generally low level of collinearity and a very high level of diversity. Such a pattern is very useful for logistic regression, as it implies that every variable contributes uniquely to our dataset. This creates a very rich dataset that can capture the broadness of India's characteristics and increases the granularity of findings. A slightly higher collinearity exists between variables representing ownership of appliances and ownership of energy-efficient appliances. This is relatively straightforward as households that have decided to adopt an appliance are inherently more likely to consider the energy-efficient version of it than households who have not adopted the appliance at all.
- **State-level variables** do tend to display increased levels of collinearity. This can be explained by the inherent design of these variables. As there are only 21 unique data points for the different state-level variables (representing the 21 included states), every respondent within a given state shares the same state-level variable values. This inevitably leads to limited variability in values and that can lead to increased collinearity. Furthermore, the state-level variables that show particular interconnection are those representing the AEEE 'energy efficiency scores'. States that score high on policy & regulation tend to display similar scores on implementation and financial & institutional capacities. This interdependence indicates that states that excel in one policy domain tend to excel in others as well and display a holistic approach to energy efficiency policy.

From these collinearity insights, we can conclude that the granular findings of the logistic regression on the household-level variables need to be taken as a base for our insights that can be contextualized and deepened with the broader patterns of the state-level variables. The observed high collinearity of the state-level variables does necessitate caution as their intertwined nature poses challenges in dissecting individual effects. It is more suitable for observing macro perspectives.

4.3. Variable Transformations

Income category

The income category variable is a categorical in our dataset. However, to achieve better insights into the relation of higher income with energy efficiency choices, this categorical variable is transformed into a numerical variable in which the value of the respondent's income is given by the mean of the bracket in which their response is noted. Furthermore, to address the strong right-skewness of the income variable, a logarithmic transformation of the variable is implemented in the regression model, like the monthly expenditure variable.

Income type

The variable for income type is a category variable in which different types of income streams are represented. To achieve a better interpretation of results, the income type variable levels have been reduced. There are currently seven different levels of income streams. People can work in agriculture, general labour, government, private jobs, shop ownership, business/trade or earn passive income.

Education level

Like the income type variable, the number of levels for the education level variable have been reduced. The levels present in the dataset are no formal education, primary education, middle school education, high school education and college/graduate education. This way there is a logical flow of increased education levels without too much specification according to different schooling systems.

Caste type

The caste types have been reduced in levels to better represent their socio-economic status, achieve a ranking order and remove non-answers. There are three levels present in the dataset: Scheduled Caste & Scheduled Tribe, other backwards caste, and general caste.

Policy variables

To address the high collinearity that has been shown in the multicollinearity table in Figure 7, an approach is taken that integrates the different policy variables and composes a combined score. To this end, multiple approaches are possible such as a PCA, or a composite score. It is important to understand that the insights into individual policy elements have been removed by taking this approach. A composite score is easier to interpret than a PCA, and as research has shown that there cannot be an order of importance in policy development and implementation, these elements are given equal importance in the model (Golubchikov and Deda 2012). The policy score used in the final model is a standardized composite score. Standardization is necessary, as the different policy elements are measured on different scales.

Plot area

The plot area is another variable for which transformation of the data is required. As the survey of the data has been conducted across India, there are many differences in the measurement units of the dataset. To address this issue, all units of the data have been transformed into square meters, based on multiple sources that give guidelines for traditional Indian measuring units such as Bigha, Biswa, Dhura and Kattha (Shrivastava 2017).

Monthly expenditure

There is a large group of respondents with an expenditure level just under the mean and a very small group with extremely high spending levels. To address this, in the regression, the logarithm of this variable is taken. For interpretation, it is essential to understand that this transformation has an implication. In logistic regression, a one-unit increase in a predictor leads to a change in the odds of the outcome by a factor of the coefficient, holding other variables constant. The results of the coefficients of this variable in the regressions now relate to percentage changes of the variable rather than absolute unit changes.

Standardized policy score

The presence of significant multicollinearity among the four independent policy elements presented challenges, distorting both the outputs of our model and their subsequent interpretability. To address these issues and enhance analytical clarity, in the regression, the four policy parameters have been consolidated into a composite metric, termed the "standardized policy score." This unified index serves to streamline the policy variables of Policy Regulation, Institutional Capacity, Financial Mechanisms, Adoption of EE Measures, and EE Programs for Residential Buildings into a coherent standardized score, ensuring a more robust and interpretable set of results.

Furthermore, to supplement the standardized policy score, with more granular insights, the SDA Staff variable was included in the dataset. The SDA Staff' variable offers a unique and direct insight into the human resource aspect of energy efficiency implementation at the state level. This element is critical, as the number and expertise of personnel dedicated to energy efficiency within SDAs could be a key determinant of policy effectiveness and implementation success. While there is some overlap between this variable and the Institutional Capacity, this component is included in the analysis to recognize the complexity of policy implementation on a state-level.

4.4. Logistic Regression Results

This section dives into the results of the logistic regressions. Separate models have been constructed for LED lighting and energy-efficient ceiling fan adoption to account for the distinctive drives of adoption for each appliance.

The results of regressions for both appliances are presented together in Tables 8 and 9. In Tabe 8, the regression without fixed effects is presented and in Table 9, the regression is shown where state fixed effects are taken into account. The coefficients of the state-fixed effects themselves can be found in Appendix F. In our analysis, we present models both with and without state-fixed effects. These fixed-effects capture unobserved state-level heterogeneity (Hill, Davis et al. 2020). The combination of both models gives a strong analysis. Since our models have many variables, it is difficult to observe effects truly separately. To capture the state-level heterogeneity, these fixed effects have been included. Combined with the other regression, this gives a completer picture. To interpret the regression tables, three metrics are of importance: the estimate, standard error and significance level. The direction of estimates shows whether variables are positively or negatively correlated with the adoption of the energy-efficient appliance. The magnitude of the estimate provides insight into the strength of this correlation. Keep in mind that the coefficient of a predictor represents the change in log odds that is associated with a one-unit change in the predictor.

Monthly Income

The relationship between the income levels variable (q236_income_category) and the adoption of energy-efficient appliances is positive and significant for both models, highlighting the trend that higher income levels can be linked with a higher probability of adopting such appliances. As this applies to both models, this finding could be cautiously generalized to state that higher income levels might correlate with a higher adoption rate of energy-efficient appliances. This would be very plausible as there still exist price differences between energy-efficient appliances and their traditional counterparts, for which financial constraints could be of importance. It must be noted that the relationship seems very small for ceiling fans as it has an Odds Ratio of 1.001892. This means that for each additional Rupee in income, the odds of adopting a ceiling fan increase by a factor of 0.19%. While this increase appears minimal for a single Rupee, it's important to remember that monthly income is typically measured in hundreds or thousands of Rupees. In Table 6, it can be seen that the average monthly income is 14.000 IRP. Therefore, the effect of income on the likelihood of adoption becomes more substantial when considering larger, more realistic increments of income.

Urban - Rural

The variable that measures urbanization (q103_survey_type) shows a clear difference between the dynamics of both appliances. While it seems that an urban area has a positive effect on the adoption of both appliances, with positive coefficients, the predictor for LED lighting adoption is not significant.

For ceiling fans, the positive effect or urbanization is statistically significant. The odds ratio is 1.45 for the regression with state-fixed effects, implying that the odds of adopting ceiling fans is 45% higher when a household lives in an urban area. This suggests that urban households are more likely to adopt energy-efficient ceiling fans than their rural counterparts when other variables are held constant. To illustrate this finding, an extra insight is shown in Table 9 with the probability of adopting energy-efficient ceiling fans tested for urbanization as the only predictor variable. Here, it can be seen once more that the probability of adopting energy-efficient ceiling fans is approximately three times larger when households live in urban areas.

Table 9: Difference in adoption probability between rural and urban households

Adoption probability	LED	Energy-efficient Ceiling Fan
Rural	83.3%	2.2%
Urban	90.1%	6.4%

Age primary income earner

The age of the income earner (q205_priminc_earner_age) presents an interesting dynamic across the models as well. For the LED lighting model, the statistically significant negative coefficient indicates that with a higher age, the likelihood of adopting LED lighting decreases slightly. The odds ratio of 0.98 implies that for a one-unit increase in age, the odds of the adopting LED lights decrease with 2%.

However, for ceiling fans the opposite seems to apply. There, a statistically significant positive coefficient is found for the influence of age on adoption. With an odds ratio of only 1.01, the effect of a one-year increase in age is an increase in odds of adoption of factor 1%. It's important to note that both odds ratios indicate a relatively small effect size, and the decrease and increase in odds associated with age might not be substantial.

Primary income earner education level

When looking at the LED lighting model, a trend can be observed where individuals with some form of education, such as primary education, when compared to those without formal education, are more likely to adopt LEDs. With odds ratios of 1.63 and 1.45 across the models in comparison to the reference level of no education, these lower education levels show a significant increase in adoption probability.

On the other hand, for ceiling fans only the highest educational brackets consisting of college and graduate holders, show a significant positive relation with an odds ratio of 1.94 in the regression with state-fixed effects and 1.96 in the model without state fixed effects. This shows that the households who have a high education degree have a significantly higher odds of adopting energy efficient ceiling fans. Even though the education variable is not significant on all levels, the estimates do show a positive relationship between increasing education and the adoption of energy appliances for almost all levels.

Caste type

The caste variable presents an intriguing pattern. For LED lighting, caste doesn't seem to play a significant role in adoption, as no caste level is statistically significant. However, for ceiling fans, there's a statistically significant positive effect with a coefficient of 0.3611 and a corresponding odds ratio of 1.36. This odds ratio implies that when households differ between the lowest and the second-to-lowest caste the probability of adopting ceiling fans increases with a factor 1.36. This can also be seen as odds increase of 36%. This might suggest that specific unobserved social dynamics within these castes may influence the adoption of energy-efficient ceiling fans.

Job Type

What type of occupation the household's primary income earner is in (q235_income_type) could potentially influence the adoption of energy-efficient ceiling fans. The statistical significance of having a government job, level 3, implies an influence. With an odds ratio of 1.59, this seems to be a significant effect. However, it must be noted that the variable is just barely statistically significant. Such a positive correlation between government jobs and adoption probability is interesting. Government officials have to set an example. Furthermore, government officials might be more exposed to energy-efficient appliances as public facilities such as government offices are obliged to purchase energy-efficient appliances already (Kumar 2021).

Electricity grid connection

The presence of an electricity grid connection at the household (q301_electricitygrid_yn), shows a strikingly positive and significant relationship with LED lighting adoption. With an odds ratio of 60 in the model without state fixed effects and 85 with state fixed effects. This means that the odds of adopting LED lights is a factor 60 to 85 higher when they have been connected to the electricity grid. This very high odds ratio would imply that LED lighting is such a basic appliance that it might be directly related to the adoption of electricity in general.

For energy efficient ceiling fan adoption, the effect of electricity grid connection is not statistically significant. The value of the odds ratio, however, is extremely high with a value of 60.000. The lack of statistical significance in the logistic regression may be due to the extremely small sample size of people without an electricity grid connection who adopted energy-efficient ceiling fans. When there are no cases in a specific category, statistical tests struggle to detect associations or differences (Brzezińska 2015). Even though the relationship is not statistically significant in our dataset, the very high odds ratio does suggest that there is a substantial difference in adoption rates between the two groups.

Housing Structure

For the variable that shows the type of housing households live in (q216_housetype_pucca_kachha), a significant increase in the likelihood of adopting energy-efficient appliances is observed. Living in a 'pucca' (permanent) home or even a semi-pucca (semi-permanent) home significantly increases the adoption of energy-efficient appliances when compared to those residing in 'kachha' (non-permanent) homes. The odds ratios for both LED lighting adoption and energy efficient ceiling fan adoption are 4 or higher, meaning that compared to living in traditional, kachha homes, living in (semi-)permanent homes correlates with at least a factor 4 higher adoption odds.

Star Label Awareness

The awareness of star labeling is shown to be a significant predictor for the adoption of energy-efficient ceiling fans. With an odds ratio of 7.32 the effect seems to be very strong. Combined with a very small p-value of 10^{-6}, this shows that there is a strong correlation between star label awareness and adoption rates of energy efficient ceiling fans. While it is hard to observe what the direction of this correlation is, there are households with and without star labelled ceiling fans who are aware of the star labels. However, for LED lighting this star label awareness doesn't seem to play role. The coefficient is not statistically significant. This might show that the awareness of star labeling is not a driver behind the adoption rate and that other factors influence its adoption or that the star label awareness cannot be seen as a proxy for the awareness of energy efficiency in general.

Environmental Friendliness Awareness

For LED lighting the odds ratio is 2.33, meaning that the odds of adopting LED lighting is a factor 2.33 higher when people are aware of the environmental friendliness of these appliances. For energy efficient ceiling fans, this environmental friendliness variable has a lower odds ratio, with a value of 1.30. While it is still a significant increase in adoption probability, this lower value could be caused by the fact that part of the awareness is already partially captured in the star label awareness variable. The regression models indicate that households that are aware of the environmental benefits of energy-efficient appliances (q403_bee_benefits_env_friendly) are more likely to adopt them, a trend holding for both LED lighting and ceiling fans. On the whole, this shows that environmental awareness can have an influence in shaping consumer choices.

Monthly Electricity Consumption

The quantity of electricity billed to a household (q610_b_billed_units), showing their electricity consumption, appears as a significant predictor for adopting energy-efficient ceiling fans, but not for LED lighting. The odds ratio of 1.26 suggests that, for every one-unit (kWh) increase in monthly electricity consumption (assuming all other variables in the model are held constant), the likelihood of a household adopting energy-efficient appliances increases by 26%. This indicates that households with higher electricity consumption are more likely to adopt energy-efficient ceiling fans.

Average electricity prices

In the regression results, it is seen that the average electricity price does not seem to play a significant role in the adoption of LED lights and energy efficient ceiling fans. With both very small coefficients of 10^{-4} and non-statistically significant results, the effects appear negligible. While the regression results indicated minimal and statistically insignificant coefficients for average electricity prices, these findings should not be viewed in isolation and as with other predictor variables they need to be seen in the broader context.

Climate zones

The positive effects of various climate zones on the adoption of both LED lighting and ceiling fans point towards potential geographic or climatic drivers behind adoption of energy-efficient appliances. The climate zones of North West, North Central, North East and Northern Hilly have a positive and statistically significant higher probability of adopting LED lighting. Energy efficient ceiling fan adoption odds is increased for households in North West and North East. With odds ratios around 3, households in these areas have up to a factor 3 higher probability of adopting energy efficient ceiling fans. While the climate zone variable is a state-level variable and thus only visible in the regression without state fixed effects, it points to potential differences between regions with certain climate zones and their lighting or cooling needs or differences in time spent indoors, leading to adoption differences.

State fixed effects

In Table 10, the state-fixed-effect have been considered. Their overview can be found in Appendix F. It can be seen that some states have fixed effects that are significant for one of the regressions. The state of Haryana has estimates greater than one and is statistically significant for both appliances. This might indicate that certain factors of living in Haryana increase the odds of adopting both LED lighting and energy-efficient ceiling fans. The model estimates of Odissa offer an interesting picture that contrasts between the appliances. For the LED lighting model, the state-fixed effect is statistically significant and positive, suggesting that, controlled for other variables, households in Odissa are considerably more likely to adopt LED lighting. However, this increased adoption likelihood does not appear in the ceiling fan model. Furthermore, there is disparity in how many states have significant fixed effects across the appliances, where 14 states show significant effects for ceiling fans and only 4 for LED lighting. This could imply that unobserved state-level differences have a stronger effect on energy-efficient ceiling fan adoption than on LED lighting adoption.

Standardized Composite Score

An interesting phenomenon is observed in the logistic regression model of the energy-efficient ceiling fan. Upon removing the ‘awareness of star label’ variable (q401_bee_star_label_awareness_yn), the standardized policy score variable becomes positively statistically significant. While it is important not to overextend conclusions here, a plausible argument could be that awareness initiatives are to a certain extent correlated with specific policy measures. When awareness is not accounted for directly by removing the variable from the dataset, the comprehensive impact of policy measures – which could include awareness – might become more evident. The 'awareness of star label' variable was answered by every household in the dataset, and its removal did not lead to a change in the sample size or composition. This observation shows that the relationship between policies and awareness might be further intertwined. Furthermore, it shows that the standardized policy score is indeed an important determinant of ceiling fan adoption. This finding underscores the complexity of understanding the dynamics between policy measures and awareness initiatives in shaping consumer behavior and emphasizes the need for a more in-depth and nuanced analysis than our statistical analysis alone.

Table 10: Model without State Fixed Effects

	LED lighting				EE Ceiling Fans			
Regression Without State Fixed Effects	**Estimate**	**Std. Error**	**OR**		**Estimate**	**Std. Error**	**OR**	
(Intercept)	-6.26E+00	1.24E+00	0.00	***	-1.95E+01	3.67E+02	0.00	
Rural – Urban	1.72E-01	1.67E-01	1.19		3.86E-01	1.55E-01	1.47	*
Age Primary Income Earner	-1.73E-02	5.72E-03	0.98	**	5.73E-03	2.66E-03	1.01	*
Education Level Primary Income Earner Level 2	4.51E-01	1.72E-01	1.57	**	-2.13E-01	3.91E-01	0.81	
Education Level Primary Income Earner Level 3	3.36E-01	1.62E-01	1.40	*	2.69E-01	2.57E-01	1.31	
Education Level Primary Income Earner Level 4	3.39E-01	2.54E-01	1.40		3.47E-01	2.41E-01	1.41	
Education Level Primary Income Earner Level 5	2.92E-01	2.66E-01	1.34		6.71E-01	2.61E-01	1.96	*
Caste Type Level 2	-7.10E-02	1.58E-01	0.93		3.19E-01	1.56E-01	1.38	*
Caste Type Level 3	1.38E-01	1.63E-01	1.15		-2.52E-01	1.54E-01	0.78	
No. members in household	-6.17E-02	2.96E-02	0.94	*	-1.09E-03	2.98E-02	1.00	
Housing structure type Level 2	2.02E+00	9.92E-01	7.54	*	1.42E+00	5.15E-01	4.14	**
Housing structure type Level 3	1.94E+00	1.01E+00	6.96	.	1.38E+00	5.50E-01	3.97	*
House – Apartment Level 2	-1.73E+00	9.89E-01	0.18	.	-1.19E+00	4.74E-01	0.30	*
House – Apartment Level 3	-1.86E+00	1.02E+00	0.16	.	-9.75E-01	4.98E-01	0.38	.
Ownership of House Level 2	-2.50E-01	2.66E-01	0.78		-3.81E-02	2.16E-01	0.96	
Plot Area	8.86E-05	1.11E-04	1.00		3.16E-07	7.66E-06	1.00	
Monthly Expenditure	-2.26E-02	2.18E-02	0.98		-1.65E-05	9.52E-06	1.00	.
Job type Level 2	1.38E-01	1.82E-01	1.15		-4.33E-01	2.45E-01	0.65	.
Job type Level 3	-6.34E-02	3.95E-01	0.94		4.52E-01	2.41E-01	1.57	.
Job type Level 4	2.61E-01	1.83E-01	1.30		-2.56E-01	1.92E-01	0.77	
Job type Level 5	8.39E-02	3.06E-01	1.09		-2.37E-02	2.27E-01	0.98	
Job type Level 6	3.41E-01	4.92E-01	1.41		7.44E-02	2.71E-01	1.08	
Job type Level 7	-2.40E-02	4.13E-01	0.98		-6.58E-02	3.63E-01	0.94	
Monthly Income	2.76E-01	1.07E-01	1.32	**	9.51E-06	4.04E-06	1.00	.
Electricity grid connection Level 2	4.11E+00	7.86E-01	60.95	***	1.32E+01	3.67E+02	540364.9	
Electricity grid connection Level 3	2.77E+00	1.06E+00	15.96	**	-1.21E-01	1.08E+03	0.89	
Electricity Meter Level 2	4.54E-01	2.18E-01	1.57	*	8.27E-02	3.68E-01	1.09	
Electricity Meter Level 3	4.39E-01	5.07E-01	1.55		1.49E+00	5.01E-01	4.44	**
Star Label Awareness	-4.87E-02	1.98E-01	0.95		2.00E+00	1.56E-01	7.39	***
Environmental Friendliness Awareness	8.47E-01	4.04E-01	2.33	*	2.72E-01	1.45E-01	1.31	.
Population Density	-6.01E-05	5.87E-05	1.00		7.61E-05	2.79E-05	1.00	**
Climate Zone Level 2	1.19E-01	2.89E-01	1.13		3.69E-01	3.51E-01	1.45	
Climate Zone Level 3	6.88E-01	2.26E-01	1.99	**	1.11E+00	2.08E-01	3.03	***
Climate Zone Level 4	1.36E+00	2.12E-01	3.90	***	-1.09E-01	2.66E-01	0.90	
Climate Zone Level 5	1.64E+00	3.17E-01	5.16	***	1.08E+00	2.57E-01	2.94	***
Climate Zone Level 6	1.74E+00	4.78E-01	5.70	***	3.42E-02	3.47E-01	1.03	
Monthly Electricity Consumption	2.86E-04	8.36E-04	1.00		2.14E-01	5.68E-02	1.24	***
Average Electricity Price	4.61E-04	1.21E-03	1.00		2.82E-05	5.07E-04	1.00	
# Lights Owned / # Ceiling Fans Owned	3.96E-01	4.38E-02	1.49	***	-1.02E-03	2.25E-03	1.00	
SDA Staff	-7.91E-03	3.00E-02	0.99		3.10E-02	3.53E-02	1.03	
Standardized Composite Score	-4.60E-02	1.32E-01	0.96		-8.67E-02	1.25E-01	0.92	

Signif. codes: 0 *** 0.001 ** 0.01 * 0.05 . 0.1

Table 11: Model with State Fixed Effects

	LED lighting				EE Ceiling Fans			
Regression With State Fixed Effects	**Estimate**	**Std. Error**	**OR**		**Estimate**	**Std. Error**	**OR**	
(Intercept)	-7.196	1.532	0	***	-20.16	366.3	0	
Rural – Urban	0.1694	0.1738	1.18		0.3734	0.1586	1.45	*
Age Primary Income Earner	-0.01831	0.005847	0.98	**	0.006609	0.002776	1.01	*
Education Primary Income Earner Level 2	0.487	0.1754	1.63	**	-0.2063	0.3927	0.81	
Education Primary Income Earner Level 3	0.371	0.166	1.45	*	0.3214	0.2596	1.38	
Education Primary Income Earner Level 4	0.3454	0.2562	1.41		0.3368	0.2441	1.40	
Education Primary Income Earner Level 5	0.3153	0.2685	1.37		0.6642	0.2637	1.94	*
Caste Type Level 2	-0.2061	0.1639	0.81		0.3611	0.1601	1.43	*
Caste Type Level 3	0.1125	0.171	1.12		-0.1696	0.1576	0.84	
No. members in household	-0.06977	0.03096	0.93	*	0.00189	0.03031	1.00	
Housing structure type Level 2	2.15	1.013	8.58	*	1.357	0.5356	3.88	*
Housing structure type Level 3	2.05	1.029	7.77	*	1.357	0.5686	3.88	*
House – Apartment Level 2	-1.72	1.012	0.18	.	-1.226	0.4928	0.29	*
House – Apartment Level 3	-1.824	1.044	0.16	.	-1.093	0.5144	0.34	*
Ownership of House Level 2	-0.1867	0.2714	0.83		0.03467	0.2204	1.04	
Plot Area	-0.0002658	0.000342	1.00		8.353E-07	0.000008708	1.00	
Monthly Expenditure	-0.02832	0.02271	0.97		-0.00001395	0.000009702	1.00	
Job type Level 2	-0.1785	0.1967	0.84		-0.3344	0.2511	0.72	
Job type Level 3	-0.1966	0.4046	0.82		0.4611	0.2442	1.59	.
Job type Level 4	0.2077	0.1871	1.23		-0.2578	0.193	0.77	
Job type Level 5	-0.0724	0.3136	0.93		-0.01916	0.2296	0.98	
Job type Level 6	0.2511	0.5046	1.29		0.08318	0.274	1.09	
Job type Level 7	-0.07177	0.437	0.93		-0.1225	0.37	0.88	
Monthly Income	0.3384	0.1091	1.40	**	0.0000073	0.0000042	1.00	*
Electricity grid connection Level 2	4.44	0.8464	84.77	***	13.13	366.3	503832.9	
Electricity grid connection Level 3	2.104	1.147	8.20	.	0.1695	1071	1.18	
Electricity Meter Level 2	0.4501	0.2261	1.57	*	0.08853	0.3791	1.09	
Electricity Meter Level 3	0.2173	0.5135	1.24		1.723	0.5129	5.60	***
Star Label Awareness	-0.07245	0.2018	0.93		1.99	0.1578	7.32	***
Environmental Friendliness Awareness	0.8475	0.41	2.33	*	0.2602	0.1473	1.30	.
Population Density	NA	NA	NA		NA	NA	NA	
Climate Zone Level 2	NA	NA	NA		NA	NA	NA	
Climate Zone Level 3	NA	NA	NA		NA	NA	NA	
Climate Zone Level 4	NA	NA	NA		NA	NA	NA	
Climate Zone Level 5	NA	NA	NA		NA	NA	NA	
Climate Zone Level 6	NA	NA	NA		NA	NA	NA	
Monthly Electricity Consumption	0.0001169	0.000848	1.00		0.2273	0.05953	1.26	***
Average Electricity Price	0.00008082	0.001194	1.00		-0.0001923	0.000537	1.00	
# Lights Owned / # Ceiling Fans Owned	0.4131	0.04554	1.51	***	-0.001279	0.002529	1.00	
SDA Staff	NA	NA	NA		NA	NA	NA	
Standardized Composite Score	NA	NA	NA		NA	NA	NA	

*Signif. codes: 0 *** 0.001 ** 0.01 * 0.05 . 0.1*

4.4.1. State-level Adoption of Energy-Efficient Appliances

Exploring state-level differences in the adoption of energy-efficient appliances is a critical step in understanding the diverse landscape of India's residential sector. This aspect of analysis shows clearly what the stark contrast in adoption rates between LED lighting and energy-efficient ceiling fans is. Such disparities show the need for a nuanced comprehension of regional dynamics. To better visualize the state-level variations, an analysis was conducted to compute state-average adoption probabilities for LED lighting and energy-efficient ceiling fans. This approach provides a more granular view of adoption across states, reflecting the average likelihood of households to adopt these technologies.

By comparing the state-level descriptive statistics, that are displayed in appendix E, with overall state performances, we can begin to understand the factors that characterize high-adoption states. This comparative analysis allows us to identify patterns and trends in the data.

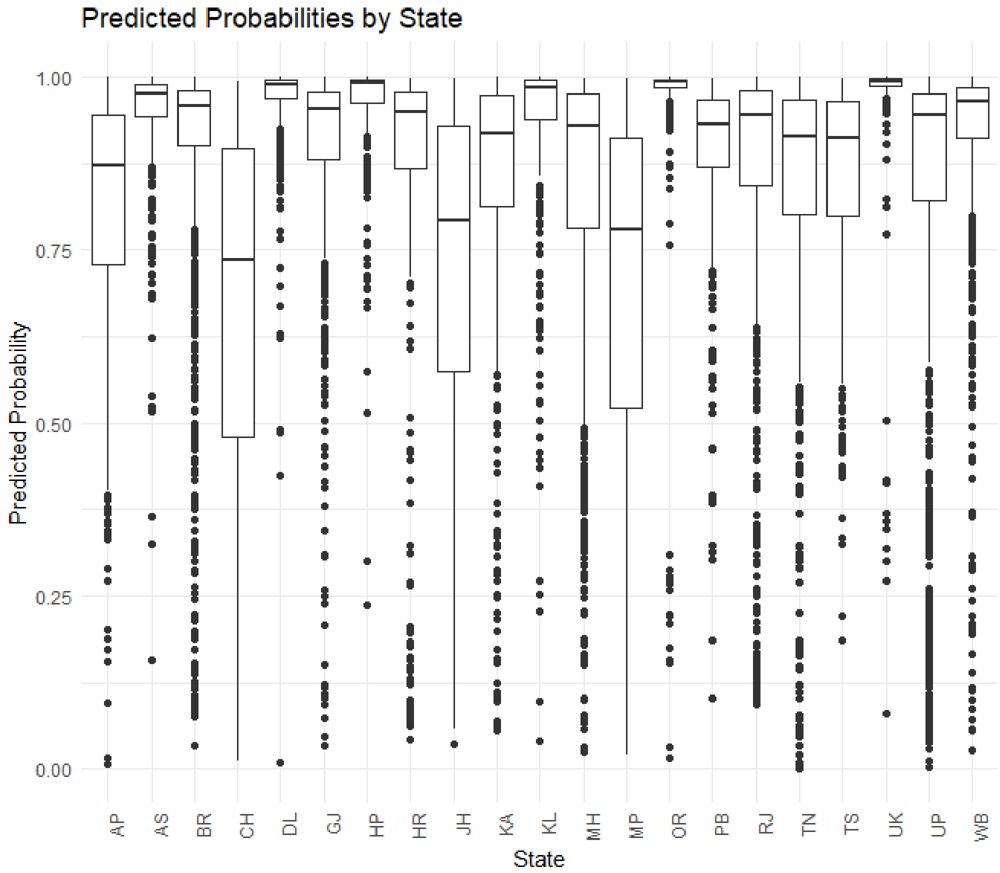

Figure 8: State-level probability of adoption of LED lighting

In Figure 9, the state-level probability of LED light adoption is shown. Here, a great variety in the adoption of LED lighting across Indian households is visible across the country. While most states do present quite high adoption levels, there are some strikingly negative performances of states. The states of Chhattisgarh, Jharkand and Madya Pradesh are displaying much lower adoption rates, with a larger spread of the box plot as well. If this probability figure is then compared to the state values descriptive statistics figure in Appendix E, some similarities between these states can be identified.

The Underperformance of Chhattisgarh, Jharkand and Madya Pradesh can possibly be explained by several factors. These are states with the lowest ‘energy efficiency policy scores' especially underperforming in both institutional and financial capacity. Furthermore, they display low environmental benefits awareness, low electricity tariffs and high overall expenditures.

At the same time, there appears an outperformance of Delhi, Himachal Pradesh, Maharashtra, Odisha and Uttarakhand. These states demonstrate very high grid connection levels, and most of these states also display above average income levels. However, their policy scores do not show a clear influence on performance. This is demonstrated in the regression as well, where the influence of grid connections shows to be a more influential predictor for adoption levels. What is interesting to note is that not only income levels are higher in this state, but that monthly expenditures show much higher averages.

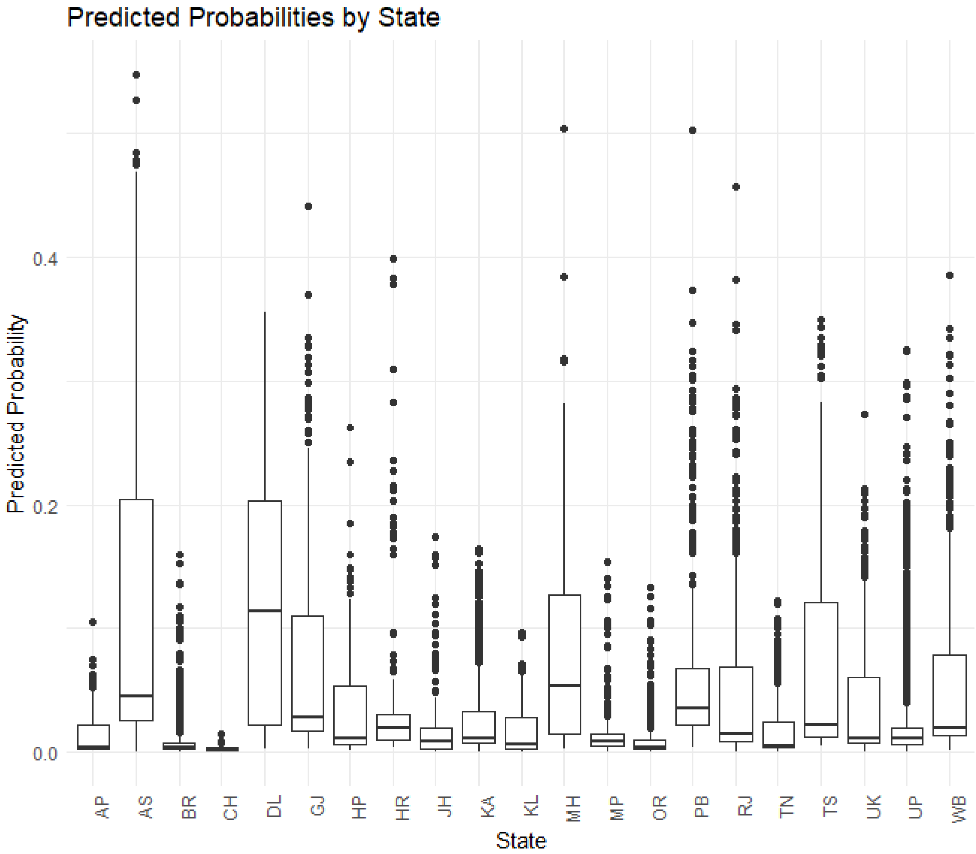

Figure 9: State-level probability of adoption of energy-efficient ceiling fans

In Figure 10 the state-level probability of adopting energy-efficient ceiling fans is displayed. While analyzing the variety across various states toward adopting energy-efficient ceiling fans, it becomes evident that only a handful have an adoption probability exceeding 5%. States such as Assam (AS), Delhi (DL), Maharashtra (MH), and Punjab (PB) outperform others, each registering a median probability of 5% or higher. Several commonalities can be identified among these states based on the comparison with the state-level descriptives in Appendix E. The most interesting feature is the socio-economic difference these states observe in comparison to other states. These states not only display higher than average income levels but also increased monthly expenditures, indicative of a potential capacity to invest in energy-efficient appliances. Furthermore, these states display higher-than-average education levels which confirms the observed relationship between education levels and adoption. Zooming further into the outperformance of both Delhi and Maharashtra, some distinct characteristics of these states emerge. These states both have much higher urbanization rates, which seems to accelerate ceiling fan adoption. A potential explanation for that would be the higher accessibility of such equipment in urban areas. Besides the aforementioned elements, these states also display higher environmental benefits awareness. This heightened awareness might be of relatively high importance when choosing energy-efficient ceiling fans over their traditional counterparts.

4.5. Model Fit Assessment

4.5.1. Model Fit Tests

Here, we present multiple Pseudo-R^2 tests that are used to assess the validity of our logistic regression models and ensure the robustness of our inferences. These tests are essential components of quantitative analysis, designed to offer a comprehensive evaluation of the models' performance on the dataset.

By assessing the goodness of fit, these tests demonstrate whether our models effectively capture the underlying relationships between predictor variables and the likelihood of energy-efficient appliance adoption. They enable us to determine whether the inferences derived from our models are valid representations of the underlying data patterns or whether they may be artifacts of the selected models.

Pseudo-R^2 values in logistic regression are attempts to provide an equivalent measure to the R^2 value in linear regression. However, they are not directly interpretable as the proportion of variance explained by the model, as is the case in linear regression. Instead, it indicates goodness of fit.

1 The log-likelihood for the fitted model: **LLH** indicates how well our model predicts the observed outcomes. Higher values are better, but it's often more useful when comparing between models or to a baseline (like the null model).

2. The log-likelihood for the null model **LLH0** (model with no predictors). This is the baseline used to compare to our fitted model.

3. **G2** is the likelihood ratio chi-squared. When the model is a good fit, this value is large.

4**. McFadden**'s Pseudo-R^2 indicates the proportional improvement of the log-likelihood value when moving from the null to the fitted model. Values closer to 1 suggest a better model fit, though, in practice, values are often much lower than you'd see in linear regressions.

5. The maximum likelihood R^2: **R2ML** is another type of Pseudo-R^2 with a calculation different from McFadden's.

6 The Cragg-Uhler R^2: **R2CU** is another pseudo- R^2 computed differently from the other two.

These measures are used as relative indicators of fit. and are more informative when comparing multiple models rather than interpreting their absolute values. For this reason, we use them to compare the models with and without state-fixed-effects.

4.5.2. Model Fit Results

In Table 12 the pseudo R^2 test results are displayed for both appliances and compared for the models with and without state fixed effects.

Table 12: Model fit tests

	EE Ceiling Fans		**LED lighting**	
	With state fixed effects	**No state fixed effects**	**With state fixed effects**	**No state fixed effects**
LLH	-394.601	-415.471	-879.716	-926.347
LLH0	-584.672	-584.672	-1232.72	-1232.72
G2	380.1415	338.4011	706.0184	612.756
McFadden	0.32509	0.289394	0.286365	0.248537
R2ML	0.107274	0.096081	0.189415	0.166615
R2CU	0.364074	0.326087	0.364476	0.320603

For ceiling fans, the Log-Likelihood (LLH) of -394.6, compared to the null model Log-Likelihood (LLH0) of -584.7, indicates a substantial improvement when the predictors are included. For LED lighting, the LLH of 879.7 and LLH0 of 1232.7 again show improvement with the inclusion of the predictors.

For ceiling fans, with a G2 of 380, the test statistic is substantial, but it is essential to consider it in relation to the degrees of freedom. Typically, a lower value of G2 relative to the degrees of freedom (52) suggests a better fit. The G2 for LED lighting, at 706 with the same degrees of freedom, also represents a significant improvement from the null model, but indicates that while the model fits the data reasonably well, there may still be unexplained variance.

McFadden's R-squared values for both models are considerably above the threshold of 0.2, which is often cited as indicative of a good fit in logistic regression models, reinforcing the models' adequacy.

The R2CU values, which consider the upper limit of the R-squared that could be achieved given the model's inherent unexplained variance, are particularly informative. With both models having R2CU values above 0.36, this indicates that a substantial proportion of the variability in adoption decisions is captured by the models.

In summary, the results of the fit tests suggest that both the Energy Efficient Ceiling Fan and LED lighting models have a sufficient fit to the data. There is a moderate to strong relationship between the predictor variables and the adoption outcomes, validating the use of these models in understanding the factors driving the adoption of energy-efficient appliances in India.

In evaluating the regression models, an essential step was the determination of the impact and relevance of state-fixed-effects on the fit of our regression models. These state-fixed effects account for unobserved state-level characteristics, which might influence further variations across states. The model fit tests show significant improvement in the log-likelihood and pseudo-R^2 values. This shows that the state-fixed effects should not be ignored in our further analysis.

4.6. Synthesis of Quantitative Findings

The quantitative analysis has shown important dynamics driving the adoption of energy-efficient appliances in Indian households across different states. Here, an overview of the key findings of this research phase is given.

A consistent pattern between household income levels and adoption levels emerges. As income rises, the likelihood of adopting energy efficient appliances, especially LED lights increases. Furthermore, households connected to the electricity grid have a much higher likelihood of adopting LED lights as well. However, for energy-efficient ceiling fans, the extremely high odds ratio, while noteworthy, lacks statistical significance. This may be due to the absence of households without grid connections adopting these fans. Another residential factor that influences adoption is the permanent nature of the building structure. It appears that households are more inclined to invest in energy efficient appliances when living in permanent homes.

Urbanization plays a significant role in energy-efficient ceiling fan adoption where a strong positive effect is observed. For LED lighting the influence of urbanization seems apparent but not statistically significant. This suggests a greater relevance for urbanization on energy-efficient ceiling fan adoption. In the qualitative analysis, these dynamics aim to be further be explained.

An obvious link between awareness and adoption is observed. Awareness, specifically observed as awareness of the star labelling program and environmental friendliness awareness, has a considerable effect on energy efficient appliance adoption. This finding shows the importance of awareness initiatives on consumer choices.

As education level rises this also seems to influence the adoption of energy efficient appliances. The transition from no education to lower formal education levels is linked to LED adoption, while for ceiling fans, the shift occurs from lower/middle education levels to higher education. This duality in the relationship requires further explanation in the qualitative phase.

Higher electricity consumption is positively linked to adoption levels, while electricity price lacks an observable association. Notably, large observed state-level differences in electricity prices requires a closer look in the qualitative research phase.

The influence of state-level policies on adoption presents a more diffused picture. While they do seem to play a role in the adoption rate, their impact is less pronounced than that of socio-economic factors. The significance of fixed effects for the states however suggests that there might be unobserved state-level differences such as specific policies or cultural differences that our regression has not captured. A deeper understanding of these dynamics will be sought in the qualitative research phase.

Lastly, a stark contrast in adoption rates between the different appliances is found. While LED lighting demonstrates very high adoption rates, energy-efficient ceiling fan adoption is still lagging. The qualitative research phase aims to understand why this stark difference persists.

The quantitative research phase has generated several very interesting drivers behind the adoption of energy efficient appliances. The upcoming qualitative research phase consisting of semi-structured expert interviews will delve deeper into the dynamics behind the observed drivers and serve as corroboration and contextualization of these findings. In the discussion section, the findings of both research phases will be integrated and interpreted.

5. Qualitative Analysis Results

The second research phase of our mixed methods research consisted of semi-structured expert interviews. Here, we aimed to identify what the experiences of experts in the Indian energy efficiency policy domain are and what their views are on accelerating energy-efficient appliances The primary objective of these interviews was threefold:

1. Create a better understanding of the dynamics of energy efficiency policy in India on different levels (national, state, regional).
2. Offer a contextual understanding of observed consumer behaviour patterns throughout the country, enhancing the depth and scope of our model.
3. Explore potential strategies to further accelerate adoption levels of energy-efficient appliances in Indian households.

Each semi-structured interview spanned approximately 45-60 minutes, with questions organized around three central themes: state-level and appliance-level differences in adoption levels, discussion of modelling insights and policy recommendations.

5.1. Description of Interview Sections

The interviews have been coded along the flow of the interview with the different interview sections and their corresponding themes. As mentioned, while the initial plan was to conduct a rigorous sequential analysis, due to time constraints, the final mixed methods analysis became a more iterative process with parallel research approaches. The interview aimed to contextualize the found drivers and barriers and determine factors that influence them. The qualitative analysis went further than that with the observations of drivers and barriers as well. Based on the quantitative analysis and the qualitative analysis phase, an integrated conclusion will be presented.

The interview elements fell into five different categories. These sections are purposefully designed to further investigate key aspects that emerged as central during our quantitative analysis. They consist of the general drivers behind energy efficiency adoption, distinctions at the appliance level, variations across states, the dynamics of the Indian electricity system, and conclude in the elicitation of informed policy recommendations:

- General drivers of energy efficiency adoption in India
- Appliance-level differences
- State-level differences in adoption
- Indian electricity system and policies
- Policy recommendations

The first three sections are aimed at corroborating the findings of the quantitative research, while the section on the Indian electricity system provides crucial context for understanding the systemic factors that influence household adoption of energy-efficient appliances as the quantitative results were less conclusive on that section.

The depth and expertise of the interview participants allowed for a nuanced exploration of the drivers and barriers, both in and outside of the previously identified drivers and barriers. The five interview elements have been coded to discern the different themes that follow from the different interview perspectives. Within each of the themes, drivers and barriers have been identified. While it is tempting to generalize these drivers to give a holistic picture, the immense variety across India and the dataset requires a deeper exploration. In line with the multi-level approach taken in the quantitative analysis with both household-level and state-level variables, three different layers of drivers have been identified. These layers are:

General drivers – A perspective on drivers that are overarching and offer a pan-India perspective. These are broader powers across India.

Appliance-specific drivers – Insights into unique factors that influence the adoption of individual appliance types, recognizing the limitations of a one-size-fits-all approach.

State-level drivers – Showing the diversity across Indian states and the influence this variation has on adoption. This level shows the importance of considering local contexts and nuances in research.

5.2. Interview Data Visualization

Besides rigorous coding of the dataset, R has been used as a tool to visualize themes and words that have been used across the qualitative analysis phase. These visualizations were used as a tool to discover patterns in interview notions. Both a word cloud and a co-occurrence plot have been developed. These visual representations are tools to develop insights from our qualitative data. A word cloud captures the most frequently used terms, showing primary themes of the interviews. By exploring the co-occurrence of terms, we can identify patterns and associations that might not be immediately apparent

The word cloud, with the representation of the most frequently occurring words is shown in Figure 10 with our interview data. In our analysis, 'awareness' emerges as the most prominent term, reflecting the central role that awareness plays in our respondents' discussions. The equal prevalence of 'income' and 'cost' shows the balance between financial considerations in adopting energy-efficient appliances. The recurrence of terms such as 'long-term,' 'policies,' 'program,' and 'implementation' highlights the broad elements that are related to the policy developments of energy-efficient programs and the dynamics behind their implementation across India. Additionally, the presence of terms like 'tariffs,' 'consumption,' and 'scheme' within the word cloud provides a glimpse of the discussions regarding the Indian electricity system section of our interviews.

Figure 10: Word cloud of detailed interview summaries

The co-occurrence plot, displayed in Figure 11, reveals relationships between terms in the qualitative data. It shows words that frequently appear together in the text, suggesting their thematic connection. Observable co-occurrences include 'per-capita-income,' highlighting the discussions about income levels, and 'distribution-companies,' indicating link between Indian energy distribution companies and the drivers behind energy efficient appliance adoption. Furthermore, 'Long-term' emerges as a recurrent concept, indicating a commitment to energy-efficient initiatives in India focussing on long-term solutions.

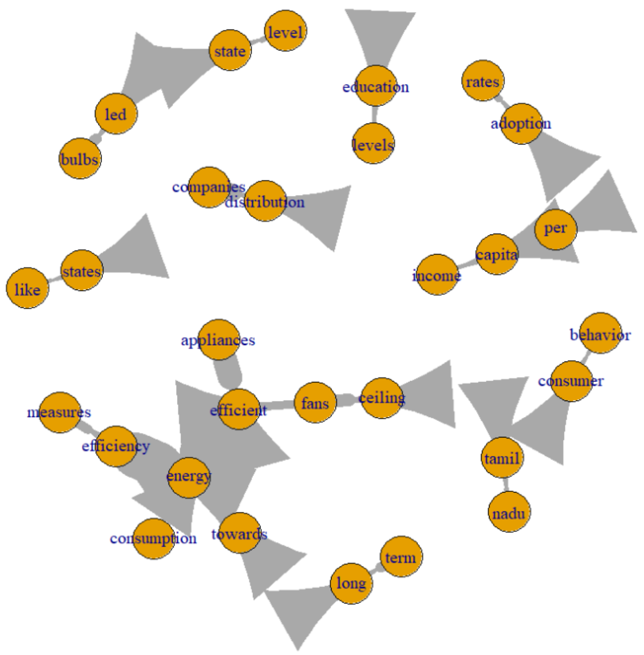

Figure 11: Co-occurrence plot of interview summaries

5.3. Thematic Analysis

By navigating the three layers of drivers across the determined themes, this research aims to comprehensively understand the variety of factors influencing energy-efficient appliance adoption in Indian households. Within each theme, an investigation of the different driver levels is done. An in-depth and rigorous examination of the interview codes has led to the identification of four main themes, each with a significant contribution to better understanding drivers and barriers. The themes are economic factors, socio-cultural factors, policy landscape and environmental contexts. These themes emerged as the interviews were progressively coded, aligning with the sections that were discussed during the expert interviews. The thematic sections consist of both the observed conclusions that arise from the interviews, and highlights nuances that were put forward during the discussions.

5.3.1. Economic Factors

General drivers: Across India, the basic economic dynamics of a heavily price-driven society emerge. In general, energy-efficient appliances have higher upfront investments than traditional appliances, which is challenging in a population that generally has strong budget constraints. This relationship has been demonstrated in the quantitative analysis as well, where the interview observation can be seen as a triangulation of that finding. According to the interviews, a highly important predictor for energy-efficient appliance adoption is household income. Furthermore, as the Indian government cross-subsidizes the electricity, thereby lowering average household electricity prices, the true cost of electricity is not felt. In India, opposite to most western countries, the electricity prices for the industrial and commercial sector are significantly higher than for consumers. These variations cause consumers to pay less than the true cost of their electricity. This might diminish the incentive to purchase more efficient appliances for cost savings. Some experts argue that the higher investment costs might be difficult to redeem through cost savings due to the perceived lower incentive of the electricity bill. Furthermore, one expert mentioned that appliance selling companies make higher commissions on energy-efficient appliances, as they are more often bought by households with means to afford more expensive equipment. These higher margins could potentially be a barrier for wider spread adoption of energy-efficient appliances.

Appliance-specific drivers: The biggest observed difference between the appliance types of lighting and ceiling fans is the purchase price. Furthermore, the price gap in absolute terms between the energy-efficient and non-efficient options is much larger for ceiling fans. This leads to a limited affordability of energy-efficient ceiling fans, and this may cause lower adoption levels. The financial accessibility of energy-efficient ceiling fans is thus lower than LED lighting. Next to the price difference, the life cycle of ceiling fans is much longer than that of lights. This product-specific difference leads to a slower adoption of energy-efficient ceiling fans, as the replacement rate is much lower. While the star labeling scheme has been around for a while, many of the Indian households had already bought a traditional ceiling fan before that time. One of the experts claimed that he owned a ceiling fan that had been in use for over 30 years. At the same time, this notion of longer durability of the equipment is a good thing as well. While this research is focused on the energy efficiency of the appliances when they are used, the sustainability of the material use needs to be kept in mind as well. The observed slower uptake of energy efficient ceiling fans might have been partially caused by the longer equipment lifetime as well.

State-level drivers: In line with the general finding of increased income leading to higher adoption rates, the states with higher average per capita incomes are thought to have higher adoption rates as well. But this increased income apparently leads to higher state incomes as well, as it means that a larger fraction of the community is able to pay taxes. These increased state incomes might lead to more opportunities for states to expand their energy efficiency policies as well. In interviews, it has been mentioned that richer states have more opportunities for subsidizing energy efficiency, and this might lead to an acceleration of adoption. Some states have specific subsidizing schemes in place, often organized by distribution companies in collaboration with state governments, that aim to increase financial accessibility of energy-efficient appliances through subsidizing or by spreading upfront investment costs out over electricity bills. Especially for LED lighting, these subsidizing schemes have been developed and executed. Multiple experts noted that now would be the time to develop similar financial incentives for energy efficient ceiling fans.

The differences in electricity tariffs - that are set on the state level - might influence adoption differences according to the interviews as well. As said, since India has a system of cross-subsidization in their electricity bill with lower consumer prices, the true cost is not paid by consumers. To expand on this insight, experts argued that some states have distribution companies with very limited financial opportunities due to poor management and consumption patterns that changed faster than expected. This reduces their opportunities to provide state-level financial incentives for energy efficiency. Lastly, a consumer behaviour modeler argued that consumer behaviour in hilly regions in India is notoriously different than in the rest of the country, with lower adoption of electrical equipment and different consumption patterns.

5.3.2. Socio-Cultural Dynamics

General drivers: The strongest socio-cultural element that the interviewees observed is the awareness of energy-efficiency. Understanding the benefits associated with the purchase of energy-efficient equipment is deemed an essential driver for the purchasing choice. This relationship has been demonstrated by both the quantitative and the qualitative analysis.

According to the expert panel, awareness it a multifaceted driver. The concept of awareness can be subdivided into awareness of personal benefits and awareness of societal benefits. For some of the experts, it is deemed that the understanding of personal benefits is sufficient for making consumers adopt energy efficient appliances. One expert noted that the purchase of an energy efficient appliance is always a good choice for the consumer on the long term. It was argued that the personal benefits of energy-efficient appliances lie in several elements. Energy efficient appliances have lower energy costs, leading to long-term reductions in monthly spending, in extended lifetimes and better performances in general. For the appliances in the scope of this research, better performances can be seen as more light generated by LED lights and better cooling qualities for energy-efficient ceiling fans.

The other element of awareness is the understanding of societal benefits. These benefits lie predominantly in lowering the electricity consumption and thereby the environmental pressure of household appliances. Hereby, households who purchase energy-efficient appliances help the environment with their conscious choices. While some experts argued that this environmental awareness is essential for consumers to make energy-efficient decisions, this view was not shared unanimously. Some experts said that Indian households never purchase an equipment to help the environment, and that it is just a fortunate extra if they do. At the same time, the quantitative analysis found a correlation between environmental awareness of energy-efficient appliances and higher adoption levels, arguing for the relationship between both. The holistic understanding of the multiple elements of awareness is important to bring across to households. Both public and private organizations aim to accelerate this knowledge through education and awareness campaigns. Where in the quantitative analysis the education levels of households showed as important predictor of adoption levels, the qualitative analysis saw this as an integrated factor of knowledge and awareness. Knowledge and awareness can be strengthened by an increased accessibility of information. Furthermore, one expert argued that higher education levels are usually correlated with higher incomes, and not necessarily with a better understanding of the world around them.

Lastly, where the quantitative analysis indicated a correlation between caste and adoption rates, the qualitative analysis revered this as a possible element of the intersectionality of socio-cultural dynamics. Where the caste influences both economic and social contexts in which households behave, it does not function in isolation. Choices might be influenced by social contexts and peer influence as well, factors difficult to observe directly, as concepts such as status might cause ripple effects in adoption rates.

Appliance-specific drivers: Socio-cultural dynamics around the specific appliances are harder to distinguish according to the qualitative analysis. An appliance-specific element that was posed as a potential influence on adoption rates is the complexity of the appliance and the corresponding consumer understanding of that appliance. While lighting is a relatively easy product, ceiling fans consist of several highly technical elements such as a motor, capacitor and rotors. Households often have a limited understanding of this equipment and the way it functions. This limited understanding might lead to a more risk-averse position of consumers, with a lower incentive to switch brands or products and maintain a stronger brand loyalty. Another potential influence that was mentioned is differences in living styles. While people who live predominantly indoors during the day might be more inclined to purchase energy-efficient ceiling fans as this an equipment that might be much more used by these households.

State-level drivers: A state-level socio-cultural dynamic that experts noted as having a potential influence on adoption differences could be a language barrier. While the majority of India speaks Hindi and/or English, there are numerous indigenous local languages. If the entirety of the Indian population is to be informed about the existence and benefits of energy-efficient appliances, this information needs to be translated into 26 languages. Currently, most governmental information is given in Hindi. This implies that information campaigns might miss local nuances and contexts. By better tailoring the way information is information disseminated across the nation, they might increase adoption levels. Furthermore, some experts highlighted the difference between rural states and urban states, as socio-cultural norms here might differ, and the way consumers make purchase decisions might be more based on social norms as well. This explanation shows that the urban-rural divide in India is a multifaceted force behind adoption levels.

5.3.3. Policy Landscape

General drivers: The policy elements introduced in Chapter 3 aim to accelerate the adoption of energy-efficient appliances. According to the interviews, awareness campaign, demand aggregation and financial incentives have the largest policy effects on adoption levels. According to the experts, the Indian government is well aware of the importance of these elements and the potential effect they can have. The reason we're able to perform this research is because of the policy efforts that led to the star labeling program. According to some experts, the awareness campaigns currently focus too much on environmental awareness and too little on the nuanced personal benefits of energy-efficient purchases. Providing more easily accessible calculation tools for cost savings calculations might further enhance willingness to adopt. All think tank experts found that the importance of energy-efficiency needed to be better understood by policymakers and government officials as well, so that they are more inclined to really act on these proposed measures.

A policy element that is not yet integrated into the Indian energy efficiency domain enough according to the expert panel is the monitoring and benchmarking of improvements. Across India, performance baselines should be clear and comparable. While there are currently such benchmarks for producers in the star labelling scheme, this should also apply to consumers themselves who need to be able to understand how their electricity consumption compares to their peers. Furthermore, there are still electrical appliances that currently do not participate in the star labelling scheme. To ensure the full benefits of this program think tank experts find it important to expand this program to more appliance types. A government expert noted that there currently lies a challenge in facilitating an affordable supply of appliances while managing their energy efficiency, as this is a trade-off in the development of such appliances. While energy efficiency on the long-term should pay for itself through cost savings, it is the government's task to convey this narrative and make it explicit for local scenarios. An industry expert further noted that the government should also focus on only allowing sales of equipment that is certified through the scheme. This notion comes from the observation that existing enforcement of the energy-efficiency label system lacks the necessary stringency to prevent producers from manufacturing cheaper, less efficient, and unlabelled equipment, which can lead to instances of free-riding within the market.

Appliance-specific drivers: There have been very different policy approaches to accelerating LED lighting and energy-efficient ceiling fans. As mentioned in chapter 3, LED lighting has seen the introduction and execution of the UJALA scheme, a specific scheme focused on the distribution and accessibility of LED lighting through demand aggregation, awareness campaigns and financial incentives. According to the expert interviews, this has had a tremendous effect on adoption levels. The directive role the central government took in this approach has set in motion the long-term transformation of the Indian lighting sector. Government experts highlighted that this scheme was aimed specifically at lower socio-economic classes and the rural population. This observation is confirmed by the quantitative analysis where urbanization, caste type and monthly expenditure seem to have no statistically significant effect on adoption levels. Furthermore, a lobby organization expert from Tamil Nadu explained that the state-level government there had developed specific LED light campaigns where these bulbs were sold at reduced rates. Not only did this increase the adoption directly, but post-campaign feedback showed that an increased awareness was observed among the wider population as well.

For energy-efficient ceiling fans, the policy landscape has a different focus. According to government experts, demand aggregation and organized distribution similar to the UJALA scheme approach was tried but failed due to technical complexities and logistical challenges. One expert put it as a "logistical nightmare". The policy approach for ceiling fans is the integration in the Start & Labelling Scheme as explained in Chapter 3. While ceiling fans are still in the voluntary scheme at the time of this research period, by the next survey round ceiling fans will be in the mandatory labeling scheme, thereby improving the efficiency comparison for consumers. As the relationship between awareness of the star & labeling scheme and the adoption of energy-efficient ceiling fans has been demonstrated in the dataset, this might indicate that the inclusion of ceiling fans in the mandatory scheme might lead to more energy-efficient purchase behaviour.

State-level drivers: States have different allocations of responsibility for energy efficiency measures. While the relationship between the SDA capacity and energy efficiency adoption is not observed significantly in the quantitative analysis, these differences are deemed relevant according to the qualitative analysis. Where the policy differences in the quantitative analysis have been captured by the standardized score of the different policy elements, the qualitative analysis deemed several higher-level policy elements relevant drivers as well. According to the expert panel, drivers could be the allocation of responsibility across institutions, proactiveness of state-level government institutions and political agendas in favour or against the national narrative. According to think tank experts this leads to fragmentation in the policy implementation in India, as observed in the widely differing policy scores as well. According to the expert panel, this fragmentation is attributed to several factors such as the diverse administrative landscape, differing priorities and capacities at the state level, and varying levels of resource availability. To increase integration in this implementation process, the central authority should focus more on uniform verifications and tracking of impacts. This top-down approach might increase accountability of lower-level governments and reduce the opportunity to shift responsibility.

Lastly, state-level differences in responsibility for the electricity sector are deemed to have a significant influence. Besides electricity tariff differentiation, the electricity sector is handled differently across India. In some states, for example in Odissa, there is increased privatization leading to better sector performance according to experts. For Odissa, this observation seems to be confirmed by a strong positive state fixed-effect outperformance when controlled for the other variables in the dataset.

5.3.4. Environmental Context

General drivers: The urban-rural divide is deemed very important for explaining adoption differences across India according to the expert panel. As mentioned before, this divide encompasses multiple dimensions that collectively impact the adoption rates of these fans. According to the experts, differences in availability and shopkeeper knowledge of these appliances affect easiness to procure for households. In urban areas there is a larger availability of stores with diverse purchase options, improving the procurement process for energy-efficient appliances. Furthermore, a lobby organization expert highlighted the potentially limited awareness of smaller rural shopkeepers of energy-efficient purchase options. The potentially better-informed consumer guidance within urban stores might bridge the information gap and influence purchasing decisions positively.

Awareness of environmental benefits is seen as a significant positive driver for both LED lighting and energy-efficient ceiling fans in the quantitative analysis. In the qualitative analysis, this relationship was met with some scepticism. While environmental awareness was consistently mentioned as a driver for energy-efficient behaviour there seems to be doubt whether purchasing choices for energy-efficient appliances have a direct relationship with awareness of environmental benefits. Furthermore, it is important to determine the broader context in which the acceleration of energy-efficient appliances falls. The rapid adoption of these technologies might also have negative environmental implications, such as material and transportation impacts beyond just CO2 savings. Adoption of energy-efficient behaviour in general is a trend that goes further than purchasing the right appliances. Minimizing waste and making energy-conscious decisions in usage patterns are essential as well.

Appliance-specific drivers: For ceiling fans specifically, both the think tank experts and the lobby organization experts observed that there is a significant difference in usage patterns across India. Ceiling fans are used to battle the heat, and there is a significant fluctuation in average temperatures across the country. India's diverse climate zones lead to varying usage patterns of ceiling fans as some areas have very long and hot summer periods, with others having milder temperatures that reduce the need for cooling equipment. These varying usage patterns have a direct effect on the payback period of energy-efficient ceiling fans. With higher initial investment costs and lower usage cost, the equipment pays itself faster back if it is used often. Thus, in regions with long and intense summers, the potential energy savings from adopting energy-efficient fans are more apparent and can offset the purchase prices more quickly. In contrast, regions with milder climate conditions may witness longer payback periods due to reduced usage. The expert panel argued that a better understanding and measurability of this payback period in different regions of the country might improve the credibility of these statistics and increase adoption levels. Understanding and quantifying these regional differences in payback periods is seen as an essential driver for household decisions regarding energy-efficient ceiling fan adoption. Consumers in areas with shorter payback periods may be more incentivized to make a switch, whereas those in regions with longer payback periods may need targeted awareness campaigns and financial incentives to accelerate adoption. Similarly, areas with more indoor living might have a greater need for LED lighting than others but according to the expert panel this was of less importance due to the smaller price gap for this equipment.

State-level differences: In addition to the potential variations in usage patterns, our experts shed light on how the differing experiences of climate change effects across Indian states might shape consumer attitudes and preferences regarding energy-efficient appliances. According to a lobby organization expert, these households are more exposed to adverse impacts of climate change, and this results in a greater inclination to seek solutions that contribute to environmental sustainability and energy efficiency. Multiple experts put forward that generally, states in the southern regions of India tend to have a stronger environmental consciousness. This heightened environmental awareness is possibly an outcome of their vulnerability to climate change effects, which shows them the urgency of energy-efficient appliance adoption. Whether this generally increased awareness truly leads to increased adoption of energy efficiency measures and appliances remains to be seen according to these experts.

5.4. Synthesis of the Qualitative Analysis

The thematic analysis from the qualitative research identified four key themes: economic factors, socio-cultural dynamics, policy landscape, and environmental context. Economic factors enforced household income as the most influential determinant, highlighting the significant price gap between energy-efficient ceiling fans and traditional models, which contributes to adoption discrepancies. Subsidy schemes like UJALA emerged as true accelerators for the high LED lighting adoption levels. In terms of awareness, the analysis put forward that it should be seen as a spectrum encompassing knowledge of equipment, understanding of personal benefits, and appreciation of environmental impacts.

The qualitative findings provided more clarity on the policy landscape, which appeared complex in the quantitative analysis. It explained the effectiveness of awareness campaigns and demand aggregation programs, while noting inconsistencies in policy implementation across India, with varied responsibility allocation and incentive structures leading to differences in adoption performance.

Lastly, the environmental context, including geographical and climatic variations, was found to significantly influence appliance adoption. Different usage patterns across India might affect payback periods, impacting the attractiveness of energy-efficient options in some regions. The urban-rural adoption gap of energy efficient appliances in India was attributed to differences in the availability of energy-efficient purchase options in urban versus rural areas.

6. Discussion

6.1. Interpretation of Results

The objective of this research project is to examine the socio-economic, geographic, energy and policy drivers and barriers behind the state-level adoption of energy-efficient lighting and ceiling fans in the residential sector in India. To delve into the dynamics of adoption patterns in India, this research has encompassed a diverse set of research techniques integrated in an iterative sequential mixed methods approach.

First, a literature review was conducted that examined the current state of knowledge in-depth. In this research phase, a lack of understanding of drivers behind energy efficiency adoption of both the Indian household domain and for energy-efficient appliances was found. Along with addressing the knowledge gap, an understanding of potential contributing variables was developed, based on an overview of academic research approaches. Furthermore, the literature review focused on building a foundational knowledge of the local Indian context and conducting desk research on the current energy efficiency state of the country.

Next, a policy conceptualization has been developed in which the influential role of the diverse Indian policy environment on energy-efficient consumer choices and markets was investigated. Here, an overview of the policy domain was created to understand what measures it consists of and what their reach and impact are across the country.

In our mixed methods approach, a quantitative analysis is conducted, followed by a qualitative analysis phase that corroborates and contextualizes the findings. The quantitative phase consisted of a logistic regression in which empirical household data coming from multiple datasets such as the IRES survey and the AEEE energy-efficiency index is integrated into a logistic regression in R, showing the influence of important drivers and barriers behind adoption levels across LED lighting and energy-efficient ceiling fans in India. Acknowledging the limitations of quantitative data and the power of triangulation of results, the findings of the quantitative analysis were supplemented with semi-structured expert interviews. For the interviews, the researcher moved to India for six weeks to speak to high-level experts across the sector with knowledge regarding policy processes and consumer behaviour. These interviews were audio recorded and transformed into anonymized summaries. While the methodology envisioned a linear sequential progression from the quantitative to the qualitative phase, a more pragmatic iterative approach was chosen. The interplay between empirical data and expert opinions has enriched the understanding of the research question and ensured a more granular and holistic view of adoption drivers.

Through our logistic regression, we developed several key determinants underpinning the adoption of energy-efficient appliances, our quantitative research highlighted these factors that significantly shape adoption trends and the thematic analysis that followed from the qualitative interviews served to elicit the 'why' behind the quantitative 'what.' Additionally, our qualitative phase brought forth further insights, both at a general level and across both appliance categories. It also enabled further state-level explanations of the diverse socio-cultural dynamics across different regions of India.

Within this section, the findings from both the quantitative and qualitative analyses are synthesized. First the overarching drivers and barriers are presented. Next, the appliance-specific drivers will be presented. Lastly, the nuances of state-level disparities that have been identified will be shared. By synthesising these findings, we leverage the full strength of the mixed methods approach to provide a holistic understanding of the multifaceted factors driving energy-efficient appliance adoption in India.

Central to the findings of this research are factors such as household income, awareness levels, educational backgrounds, and living contexts such as electricity grid connections and urbanization. These elements have a foundational influence on energy-efficient appliance adoption as revealed by our quantitative analysis. However, it is the qualitative analysis that lends depth to this narrative. The qualitative research phase, with a thematic analysis following the semi-structured expert interviews, aimed to contextualize and verify findings in the quantitative analysis, and show further nuanced drivers and barriers behind adoption levels. The four themes presented in the analysis were economic factors, socio-cultural dynamics, policy landscape and the environmental context. By immersing the quantitative drivers within the broader socio-economic and cultural landscape, we gain insight into the 'how' and 'why' of these adoption behaviours. Socio-economic and cultural factors seem to have a more direct influence on adoption than energy or policy drivers. In the following paragraphs we will examine each of these drivers to show the nuances and complexities that underpin their influence on energy-efficient appliance adoption.

The first foundational driver that is put forward is household income. This showed a high correlation with adoption probability the across the regressions. In the qualitative research phase this driver was put forward as the most important determinant behind adoption choices. This shows the importance of financial capacity on the adoption of energy efficiency. This alignment across the mixed research methods emphasizes the central role of the financial capacity of households in the decision-making process. Expanding on the household income and placing it into context shows that this financial determinant influences the adoption in multiple ways. The qualitative insights shed light on these nuanced dynamics, such as how the difference in purchase price between efficient and non-efficient appliances and differences between LED and energy-efficient ceiling fans showcase a large price gap between these appliances. The financial constraints of households is therefore a determining factor in the choice for adopting these appliances. Furthermore, the qualitative research emphasized the effect that local subsidizing schemes can have on adoption rates by reducing the financial constraints of households and reducing the gap between the purchase price of energy-efficient and traditional appliances. The very high adoption rate of LED lighting in comparison to energy-efficient ceiling fans shows that the government push in which demand aggregation led to lower prices and, awareness campaigns and financial incentives for households were combined.

This brings us to the interpretation of the diverse driver of awareness. The regressions showed that awareness is an important driver behind energy-efficient appliance adoption. The findings suggest that both knowing of the existence of energy-efficiency labels and understanding of environmental impact significantly improve adoption. The qualitative phase supplemented this insight by indicating the effect of knowing the personal benefits of energy-efficient appliances such as cost saving and durability. Understanding the breadth of awareness in this context is necessary to be able to design well-performing policies and campaigns.

Awareness is a multifaceted driver, as described both in the quantitative and qualitative analysis. This multifaceted nature is described in the qualitative analysis as the awareness of personal benefits and awareness of benefits for the society. In the regression, this multifaceted nature was already shown through the differences in way awareness presented itself as driver across the appliances. For LED lighting, a higher awareness of environmental benefits correlated with an increase in the likelihood of adoption. For energy-efficient ceiling fans, awareness of the star labeling program in general showed to be a strong driver. The effect of household awareness on adoption rates was further explained in the qualitative analysis, where awareness was recognized as a two-sided element. Awareness was seen as both the understanding of personal benefits and the awareness of environmental benefits. This highlighted that awareness is multifaceted and driven by a combination of personal motivation and societal consciousness. As put forward in the qualitative analysis, awareness also encompasses that households need to understand the appliances before being able to make informed decisions. This shows that awareness is not just about providing information, but also about comprehension and accessibility of knowledge.

The influence of education displayed itself differently across the appliances in the quantitative analysis. For LED lighting, having had official education improved the chance of adoption when compared to no formal education. At the same time, a higher education does not seem to further improve probability of adoption. For energy-efficient ceiling fans, the relationship between education and adoption only starts to present itself at higher education level, where adoption probability improves significantly. The qualitative analysis placed the education levels in the context of the multifaceted awareness. As education is an access to information, increased education might improve the knowledge of energy-efficient appliances and their benefits for both the households and society.

The most prominent positive coefficient in the regression analysis for LED lighting is the one associated with grid connectivity, underscoring a strong correlation between access to electricity and the likelihood of adopting LED lighting. This relationship aligns with the fundamental role of LED lighting as a basic, yet essential, appliance in households. For ceiling fans, the regression did not show a statistically significant result. This absence of significance could be attributed to the potential underrepresentation of households without grid connections that possess ceiling fans within the dataset. At the same time, the relationship between electricity grid connection and an increased adoption of electrical appliances seems apparent. Furthermore, the qualitative insights from the expert interviews complement these statistical findings by reinforcing the premise that electricity grid connection is fundamentally tied to the increased adoption of electrical appliances. This integrated analysis displays the importance of electricity grid connectivity as key driver, not only for basic lighting solutions but also as a cornerstone for the broader adoption of energy-efficient technologies. Another element of the physical living conditions of households that is relevant to adoption is the housing type. Living in permanent homes increases the adoption probability significantly, indicating that households living in more stable and permanent structures are more inclined to make the investment in energy-efficient appliances. This could be due to having the luxury of a longer-term outlook with a permanent home base.

In terms of the environmental, geographical context of households, both the climate zone and the urbanization rate was found to be important. Both the quantitative and qualitative analysis phases emphasized the role of these different environmental contexts. For energy-efficient ceiling fans, a strong relationship between adoption and urbanization was found, showing the potential influence of urbanization on energy-efficient behaviour. These urban-rural dynamics, highlighted by the difference in adoption levels for energy-efficient ceiling fans, imply an influence of differences in accessibility of energy-efficient ceiling fans for households across India. Living in urban areas increased adoption probability and this finding aligned with both the qualitative analysis and literature. As explained in the qualitative analysis this might be caused by an easier procurement in urban areas due to a larger availability of energy-efficient purchasing options. For LED lighting, the relationship between urbanization and adoption was not statistically significant, even though a positive correlation was observed. The qualitative analysis shed light on the dynamics behind the successful policy push for LED lighting (as described before) and how their implementations were focused specifically on targeting rural and lower-class households. The absence of a statistically significant relationship seems to confirm that this dynamic holds true and that the urban-rural adoption gap has been bridged for LED lighting.

The effect of climate zones indicated a potential relationship between geographic location and appliance adoption. The qualitative analysis elaborated on this finding by noting the significant differences in usage patterns across climate zones in India, influencing the needs of consumers and benefits of energy-efficient appliances. These observed differences are contextualized by the thematic analysis explaining differences in usage patterns and the implications these differences have on the personal benefits of energy-efficient appliances. For example, in colder environments, the payback time of energy-efficient ceiling fans might be longer. Furthermore, the quantitative findings of the influence of urbanization on energy-efficient ceiling fan adoption are explained in the qualitative analysis as a driver of accessibility of energy-efficient purchase options, with a broader availability of stores and products in urban areas.

The influence of state-level policy was hard to capture in the quantitative analysis, as the standardized policy score only showed a statistically significant effect after removing awareness from the regression. The qualitative analysis however indicated the importance of several policies focusing on demand aggregation and awareness. A light was also shed on current gaps in the policy landscape, where consistent monitoring and benchmarking appears to be lacking. Additionally, the Indian electricity sector has a very inconsistent policy across multiple levels of governance (Mehta and Sarangi 2022). While a well-designed electricity price can improve investments in energy-efficient appliances, the dynamics of price elasticities of Indian consumers vary significantly by state, rural and urban residence, and income categories (Chindarkar and Goyal 2019). State-level differences in responsibility allocation across states for the electricity market and energy efficiency might lead to varieties in adoption rates according to the qualitative analysis, especially for energy-efficient ceiling fans. This rationale might also explain why fixed effects of states showed unobserved state-level differences. Furthermore, there was a significance of state-fixed effects in the quantitative models of both the ceiling fans and LED lighting model, where 14 states show significant effects for ceiling fans and 4 for LED lighting. A potential reason for this large difference between these models could be appliance characteristic differences such as distribution channels and accessibility, with a potentially more fragmented or state-specific supply chain for ceiling fans leading to variations in adoption rate. Another potential difference could lie in the policy domain with more active campaigns for energy efficiency solutions in some states than others, for example by private organizations such as distribution companies.

In interpreting the results of this study, several important understandings arise. The role of economic capability is central to the adoption of energy-efficient appliances. The role of household income, found important across both research methods, shows that affordability matters. Delving further into the nuances of affordability, the expert interviews highlight the effectiveness of subsidy schemes and demand aggregation strategies, particularly in the LED lighting program. These interventions appear to have levelled the playing field across different social groups, as displayed by minimal differences in castes, a smaller education effect and limited variance across states found in the regression analysis. Beyond the economic capability, the perceived personal value of energy-efficient appliances might differ. Variations in usage patterns can lead to differences in payback periods and therefore differing cost saving potentials. For example, in colder environments, the payback time of energy-efficient ceiling fans might be longer. This leads to an interplay between objective affordability and subjective value judgments. The state-level policy landscape in India proved to be complex and interrelated, with large variations in governance responsibilities. While the regression findings remain inconclusive regarding the effect of state-level policies, a correlation with adoption was observed after removing awareness and implied by the stronger presentation of state-fixed effects for energy-efficient ceiling fans than for LED lighting. The functioning of the Indian electricity sector was presented as driver of energy-efficiency adoption in the qualitative analysis, with Indian households often not paying the true price of electricity leading to reduced investment incentives as well.

Synthesizing both the quantitative and qualitative findings shows the delicate interplay of different factors that drive adoption levels of energy-efficient appliances. Economic capacity, consumer awareness and environmental contexts such as living conditions and geographic locations shape individual household decisions, with policies further influencing state-level differences. The overarching findings following the combination of quantitative regression and qualitative expert interviews provide a deeper understanding of the complex dynamics behind driving energy efficiency forward in Indian households.

6.2. Comparison of Results with Literature

As research aims to improve the status quo of knowledge, it is important to make a comparison between past and present findings, hereby identifying similarities or discrepancies. The cumulative nature of academic research offers the ability to validate and contextualize findings, thus improving the robustness of our insights. To understand the novel insights this research has generated it needs to be contrasted with previous research. As our literature review identified limited empirical research in our specific domain of energy efficiency adoption in Indian households, this research adds a critical dimension to the understanding of dynamics behind such adoption.

A research study towards the adoption of energy-efficient appliances across low-income groups in the EU has shown the role of income in influencing the adoption of energy-efficient appliances (Schleich 2019). Several economic, socio-cultural and policy factors have been put forward in both papers. Both this study in the EU and our empirical findings in India show that higher income correlates with higher adoption rates, thereby indicating the importance of financial capabilities in making energy-efficient choices. Where our contribution extends the current academic understanding is in the application of these income-related insights to the distinctive socio-economic landscape of India, underscoring importance of financial capability across diverse cultural contexts.

Another interesting similarity is in socio-cultural factors, where the acknowledgement of environmental awareness as a predictor for energy efficiency adoption and a negative correlation between age and LED lighting adoption was observed. The existence of a role for housing type was shown by both researches as well, with observed differences between traditional and permanent housing (pucca vs. kachha) in India and detached houses vs. terraced homes in the EU. This cross-geographic similarity strengthens the argument that housing type is a significant predictor of appliance adoption, independent of regional characteristics. Lastly, both the qualitative findings of our research and (Schleich 2019) highlight the importance of subsidizing schemes in bridging the gap between adoption rates, especially for lower-income households. While the investigated geographic regions differ between research, similar insights were generated steering towards an agreement in main drivers. These findings are interesting because the Indian and European context would appear very different, with India being a low-income country and the EU being relatively high-income. Finding strong similarities between energy-efficient appliance adoption drivers and barriers helps us understand these universal patterns better.

Furthermore, (Richmond, Agrawal et al. 2020) showed an interesting dynamic between urbanization and adoption rates. It was observed that the uptake of energy-efficient appliances is much slower in rural areas in India due in part to the fact that household incomes are lower, on average than in urban areas. Wealthier households adopt appliances sooner and diversify their portfolio of appliances earlier, leading to compounding benefits that take more time for lower-income households. They show that factors such as distances from appliance distributors and less exposure to and knowledge of appliances and their benefits are explanations for lower adoption of cooling equipment such as fans. This corroborates the insight that while the income difference between urbanized and rural households might explain adoption in general, for energy-efficient ceiling fans, the accessibility of the equipment and the understanding of its benefits are important as well (Richmond, Agrawal et al. 2020). Our research enhances the narrative by highlighting how accessibility and understanding impact the adoption of energy-efficient ceiling fans, offering a more granular understanding of these appliance-specific adoption patterns. The cornerstone role of electricity grid access as a foundation for appliance adoption was identified in both researches as well, expanding our findings of the influence of electricity grid connectivity as a predictor for energy-efficient appliance adoption.

A literature review study on the drivers behind household energy-efficiency adoption showed a clear adoption gap driven by a lack of awareness of benefits, high initial investment costs and contextual factors such as social class and electricity prices (Solà, de Ayala et al. 2020). Our study's alignment with these findings strengthens the assurance of their relevance across regions. While both the methodology and the geographic region are different between the two pieces of research, we found comparable overarching trends. For example, the importance of informed decision-making was highlighted in both the literature review and our research. The overarching role of awareness—whether it is personal benefits, environmental implications, or simple product knowledge—emerged as a consistent determinant. The paper implied that policies aimed at providing this broad awareness are the most impactful. To test this finding, further research towards specific awareness campaigns will be needed. A discrepancy between our quantitative findings and of (Solà, de Ayala et al. 2020) is that environmental benefits were of little concern in adoption according to the literature review, while our analysis reveals a more complex reality where the awareness of environmental benefits does contribute to adoption decisions in the Indian context. Awareness of environmental benefits seemed to be a significant predictor for our dataset. However, the qualitative research phase highlighted that it might be an indirect behavioural driver, with awareness of personal benefits having a more direct impact on purchase decisions.

In summary, this study enriches the current knowledge of drivers and barriers behind adoption of energy-efficient appliances by providing empirical evidence from a region that was previously understudied. With this research we confirm some globally observable trends while also identifying unique Indian dynamics. This mixed method approach was able to grasp the multifaceted nature of energy-efficient appliance adoption in Indian households, offering implications for both policymakers and researchers aiming to accelerate sustainable energy consumption.

6.3. Recommendations and Implications

6.3.1. Implications for Future Research

In this research project, we addressed the drivers and barriers behind energy-efficient appliance adoption in Indian households. By combining an elaborate literature review with quantitative and qualitative research methods, a holistic view of this topic was created, with deep and nuanced insights. The influence of income, awareness and electricity infrastructure is quite clearly shown across appliances and datasets. Furthermore, the geographic and policy context shows an impact on the diversity of adoption as well, but due to data limitations, the intricacies behind different policy elements have not been shown clearly in the quantitative analysis.

To build further upon the findings of this study, future investigations should encompass comparative case studies. Such studies could be instrumental to create insights into the state-level intricacies in appliance adoption that this current research has begun to touch upon. Developing comparative analyses with state-for-state investigations would allow for a more nuanced understanding of how these regional policies and implementations truly contribute to household-level differences in adoption rates.

The role of SDAs and electricity distribution companies has emerged as a potential research avenue for further exploration. Our qualitative analysis hints at potential explanations for state-level variations in adoption rates, which might be attributed to how responsibilities for energy efficiency and electricity distribution are allocated. However, their quantitative effect on appliance adoption rates currently remains untested. A dedicated examination of states with diverging energy efficiency policies and electricity responsibility is essential. Such an investigation could fill a significant gap in the literature and improve the Indian governance system to be more context-sensitive and effective in driving energy efficiency forward.

Next to that, it is important to note that the landscape of energy efficiency has evolved since our dataset. In this paper, the main household-level dataset comes from the 2020 IRES survey. Between that date and the time of writing this report, the Indian government has implemented substantial changes in their star labeling program, incorporating ceiling fans in the mandatory labeling scheme. We expect that this will significantly improve the adoption of the star-labelled appliances. The new data could provide an empirical assessment of the effectiveness of the revised star labeling program and its influence on consumer behaviour. To see whether the found drivers such as awareness of this labeling program still proves to be a predictor for adoptions of energy-efficient ceiling fans, a repetition of this research for that specific appliance would also be beneficial. The next round of the IRES survey is planned for early 2025, so after that such a study could be developed with up-to-date insights.

Lastly, we would propose to conduct a longitudinal study. Such a research design would be valuable in tracking adoption rates over time, differentiating this by appliance type and across different states. Comparing the results of the new survey round in 2025 with the findings of our regressions (Agrawal 2021). The state-level policy scores that have been developed based on the AEEE energy efficiency index also change on a year-to-year basis (Kumar 2021). In such longitudinal research, the state-level improvements in policy scores and changes in adoption levels could be investigated, such a time-series analysis enables an understanding of the long-term trends and causality of policy interventions, consumer awareness programs, and market developments on the adoption of energy-efficient appliances.

6.3.2. Implications for Policymakers

As our research into the complex system of energy efficiency adoption in Indian households shows, an interrelated group of factors drive these appliances forward. Several factors have shown to be of big importance in the prediction of adoption levels, such as the role of awareness and the profound impact of financial capacities. For policymakers in India, striving for a greener, energy-efficient future of the nation, these insights might advocate a re-evaluation of strategies.

It is essential for future policy interventions to be multifaceted, addressing both awareness and affordability to streamline the transition towards energy efficiency. This research has awareness plays a key role in the adoption of energy efficient appliances. Policymakers could consider expanding energy-efficiency awareness campaigns, ensuring that they encompass a holistic perspective. This holistic perspective means promoting not only the personal benefits, such as cost savings and improved performance, but also leveraging societal advantages like reduced carbon footprints and the alleviation of stress on the electrical grid. In addition, a better understanding of the functionality and maintenance of energy-efficient appliances appears to be able to remove barriers to adoption. Tailoring these campaigns to resonate with diverse social environments across educated and non-educated citizens in or urban and rural landscapes to be inclusive across India. From our research it appears that higher adoption rates of LED lighting than other appliances can, in part, be attributed to a widespread understanding of environmental benefits. Conversely, the adoption of energy-efficient ceiling fans is still lagging, pointing to a possible awareness deficit. Therefore, for an appliance such as ceiling fans, that is essential to the Indian population, campaigns should focus on both personal gains and environmental benefits. Educating the public about the tangible benefits of cost-saving and putting this in realistic, context specific numbers could create a more compelling purchase proposition for households. Beyond personal gains, the campaigns should fall within the environmental narrative. Energy-efficient appliance adoption is a step towards limiting emissions and this dual narrative might help this cause.

While awareness is key, it is not the sole implication for policymakers. On the financial front, economic factors, especially income levels, play a central role. The clear linkage between income and adoption likelihood shows the importance of making energy-efficient appliances, especially energy-efficient ceiling fans, more financially accessible to a broader part of the population. It is necessary to bridge the financial gap between energy-efficient and traditional appliances. Policymakers might consider the implementation or expansion of subsidizing schemes similar to the UJALA program, which has shown great influence in enhancing the adoption of LED lighting. Development of such a subsidizing scheme aimed specifically at energy-efficient ceiling fans might have an instrumental influence. Given the varying climate zones and usage patterns across India and the consequent differences in payback periods, it is crucial that financial mechanisms and awareness campaigns consider regional differences to maintain the credibility and perceived value of these investments. Such a scheme, like the UJALA program for LED lighting, could intend to offset, reduce or spread initial cost differences, making these appliances accessible to a broader public.

By combining robust awareness campaigns with targeted financial interventions, policymakers might be able to overcome the challenges that energy-efficiency adoption in Indian households faces and drive the nation towards a more sustainable future. This is the time to act. The projected growth in appliance adoption in India will significantly impact the energy transition and making the right choices soon enough is key.

In the broader context, it is important to realize that the accelerated adoption of energy-efficient appliances might not only mean the replacement of non-efficient appliance choices. While replacing less efficient appliances is a priority, there is also the need to balance this with the environmental costs of an increased material consumption. Policymakers should encourage the retrofitting of existing appliances where feasible and promote the recycling and responsible disposal of replaced appliances to mitigate the environmental impact. Additionally, considerations for a circular economy should be integrated into policy frameworks to ensure that the drive for energy efficiency does not result in unnecessarily increased the earths scarce resource exploitations. Furthermore, policymakers could choose to incentivize not just the purchase of energy-efficient appliances, but also their maintenance and longevity. By considering these factors, policymakers can help to steer India towards a more sustainable future, where energy efficiency goals are met, in environmentally conscious manners.

6.4. Limitations

This study contributes to the literature by identifying a set of important drivers and barriers behind the adoption of energy-efficient appliances in Indian households and linking them to potential pathways for future improvement. The results of this study should be seen as diagnostics rather than deterministic. However, there are some limitations to this study as well. To understand the comprehensive context and constraints, these limitations need to be acknowledged.

First, as described in the methodology, our research focused on a specific set of appliances within the specific geographic region of India. The regressions were done for a limited number of appliances (lighting and fans), chosen because of their high uptake in comparison to other household appliances. However, it is important to recognize that within the large variety of household appliances, the observed drivers might not extend to other appliances. Our study is quite comprehensive within its geographic scope as it uses the largest pan-Indian household survey. Still, insights from the quantitative and qualitative analysis are limited to India. Parallels that have been drawn with the literature suggest that there might be similarities with other regions, but caution is necessary when generalizing insights to different contexts or appliance sets.

Secondly, due to time constraints, this project had to evolve from the originally planned sequential explanatory mixed methods approach, which usually follows a linear progression. Instead, this research adopted a more iterative approach, that returned to the quantitative analysis after the qualitative research phase. This adaptation might have impacted the integration phase and affected the depth and sequence of insights derived from each method. Furthermore, the project’s timeline restricted the opportunity to delve deeper into interaction effects among variables, which might have unveiled more complex relationships. While we have identified some significant patterns in this research, potential interactions remain underexplored.

Thirdly**,** regarding the methodological choices, we used a logistic regression to investigate adoption drivers. While it is an effective approach to identify associations, choosing this approach means inherently lacking causal identifications. Therefore, our results should be understood as correlations rather than definitive causal evidence. The derived interpretations of potential mechanisms behind the observed effects must therefore be interpreted cautiously. Our research emphasizes patterns and association more than deterministic cause and effect.

Fourthly, we address the data limitations in our research. The quantitative dataset provided limited depth regarding the policy variables. Being limited to state-level policy scores without the specifics of particular policies may have caused potential oversights to delve into the nuanced impacts of specific policy interventions. Additionally, in survey data, there is a risk of response bias. Participants might provide answers deemed socially acceptable or ones they think might be expected of them (Winter 2004). If not properly controlled for, these might skew results. Furthermore, the composition of the expert panels in the qualitative analysis phase is another limitation. The interviews have been conducted with ten experts, predominantly based in Delhi and two coming from Tamil Nadu. This leads to a geographical imbalance in representation. While efforts have been made to cover both national and state-level perspectives, the concentration of respondents in one region might limit generalizability of the findings across the diverse Indian landscape.

The main IRES survey used in this research consisted of a multitude of variables, providing a comprehensive dataset for analysis. This study narrowed down the variables to those with the most substantial impact on the adoption of energy-efficient appliances. Despite this careful process aimed at optimizing the model's explanatory power and aligning with academic variable choices, the breadth of variables initially considered means that certain nuanced relationships may have been overlooked. Future studies might benefit from an even more focused variable selection that could potentially show additional subtle drivers of adoption that are not captured in this analysis.

Lastly, there is a temporal disparity that needs to be considered. The underlying quantitative data has been collected 3 years prior to the qualitative data, which was collected two months before this report publication. This gap could lead to potential (mis)alignments in the integration of the quantitative and qualitative results due to the fast-evolving energy policies, market conditions and public opinions in India. When interpreting trends and patterns that arise from this research, caution is needed, as they might have shifted during these years.

These limitations outline areas for refinement in future academic research and emphasize the need for careful consideration when these findings of this study are applied beyond its immediate scope.

7. Conclusion

This study examined the adoption of energy-efficient appliances across 21 Indian states, analyzing socio-economic, geographic, and energy-related drivers influencing household choices for LED lighting and ceiling fans. This final chapter summarizes the key findings addressing the sub-questions and the main research question discussed in the report.

1. ***What socio-economic, geographic and energy variables determine the adoption of energy-efficient appliances in the residential sector in India?***

Understanding adoption patterns requires examining the factors that influence consumer behaviour in this specific context. These factors span socio-economic, geographic and energy elements. Socio-economic determinants include income, affecting purchasing power and preferences; education, influencing knowledge and potential awareness levels; direct awareness itself; age, potentially influencing willingness to adopt new technologies. Other descriptive influences are the number of household members, the type and size of the house, home ownership, cost of expenditures and cultural aspects like caste. Geographically, urbanization impacts adoption, with urban citizens having more exposure to modern technologies and better access to them, potentially increasing adoption levels. Climate differences might could the priorities of households towards certain appliances due to different cooling or warming needs. State-level density differences might suggest infrastructural, or development differences correlated with adoption rates. From an energy perspective, the cost of electricity might be a driver as higher prices would make adoption more appealing as a cost-saving solution. Furthermore, households energy consumption might determine energy saving potentials. Lastly, grid connectivity is a necessary basis to facilitate appliances.

2. ***What are key energy efficiency policies for the residential sector in India, and how is responsibility for implementing these policies allocated across institutions and states?***

A primary observation following the literature review and desk research is that energy efficiency is a key element in India's energy policy framework. This commitment is shown by the position of energy efficiency as of the eight pillars of the ambitious 'National Mission for Enhanced Energy Efficiency'. Within this national framework, key policies targeting the residential sector have been initiated and implemented.

The Bureau of Energy Efficiency (BEE) has been developed under this framework. It has rolled out several inventive schemes such as the Standards and Labelling program. This initiative seeks to facilitate the consumer shift towards energy-efficient solutions by benchmarking and labeling products. The institutional responsibility for energy efficiency is centred around the Bureau of Energy Efficiency (BEE). They play an important role in formulating and enforcing energy efficiency policies. In collaboration with the BEE, State Designated Agencies (SDAs) have responsibilities of implementation at the state level, ensuring the last-mile delivery of these policies. The dynamic within SDAs across states differs, as some SDAs are integrated within the Ministry of Power and others are independent entities. Additionally, the Energy Efficiency Services Limited (EESL), a Joint Venture of four Indian public-sector organizations, plays an important role, having been the distributor of LED lighting behind the UJALA scheme. The UJALA scheme was key in rapidly accelerating adoption rates of LED lighting through demand aggregation and the provision of financial incentives.

3. ***How do socio-economic, geographic, energy and policy variables influence differences in the adoption of energy-efficient appliances across states in India?***

In the quantitative analysis, correlations between the variables and adoption rates of LED lighting and energy-efficient ceiling fans were investigated. Limited empirical research into state-level differences in policy adoption was available so, based on relative performances of states, policy operationalization variables were developed. Aided by segmentation in the AEEE energy efficiency index (Kumar 2021), policy elements were operationalized across four categories, serving as holistic overview: policy & regulation, institutional capacity, financial mechanisms and adoption of energy efficiency measures.

Central findings are the significant role of household income, awareness levels, educational backgrounds, and living contexts such as housing type, electricity grid connections and urbanization. The positive influence of higher household income on adoption stood out as an overarching driver. This highlights the role of a family's financial capacity in making energy-clever choices. Awareness also played a vital role in adoption. LED lighting appeared to be influenced by environmental awareness and awareness of the star labeling program seems to drive the adoption of energy-efficient ceiling fans. The impact of education varied as well with basic education increasing LED lighting adoption and advanced education pushed ceiling fan adoption. Living contexts that are influential are grid connectivity, urbanization, housing types and climate zones. Grid connection significantly predicts LED adoption. Its effect on ceiling fan adoption was statistically inconclusive, likely due to data representation limits as the probability effects seemed to indicate that grid connection is crucial for appliance uptake. For ceiling fans, living in urban areas seemed to be a key driver.

Very high multicollinearity across independent policy variables led to distortions in the results and their interpretation. To address this, a standardized policy score was developed, that aggregated the different policy parameters into a single measure. Interestingly, this score demonstrated a statistically significant relation with ceiling fan adoption, after removing the 'awareness of star labelling' variable. Therefore, it suggests a potential overlap between observed awareness and policies. Moreover, when including fixed-effect variables for individual states a pronounced significance was observed for ceiling fans. This could point to unobserved state-level drivers, possibly stemming from unique state policies or practices.

4. ***What contextual factors further influence the drivers and barriers behind the adoption of energy-efficient appliances in the residential sector in India?***

The thematic analysis that followed from the qualitative research categorized findings into four overarching themes. Economic factors, socio-cultural dynamics, policy landscape and environmental context. The economic factor reaffirmed the emphasis on household income as a dominant determinant. The consistency of this finding strengthens its significance. Still, it is the qualitative contextualization that shows the nuances. The strong price difference between energy-efficient ceiling fans and their traditional counterparts overshadow the price differences between LED lighting and other lights, leading to an adoption gap. Subsidy schemes such as UJALA were put forward as further accelerators for LED lighting. The broad dimensions of awareness are shown in the qualitative analysis. Awareness is not just a binary variable but should be seen as a spectrum, ranging from knowledge of the equipment, and understanding personal benefits to appreciating broader environmental benefits. This elaboration shows that effective awareness is not just about disseminating information but also ensuring its full comprehension.

The qualitative analysis also sheds light on the policy landscape, a challenging element in the quantitative analysis. Though the standardized policy score showed a correlation between adoption and an intertwined relationship with awareness, the qualitative analysis paints a clearer picture. Here, the importance of policies such as awareness campaigns and demand aggregations were highlighted. Furthermore, the policy landscape has shown to be inconsistent across the country, with large variations in responsibility allocation and variations in incentives. Privatization of the electricity distribution was put forward as a plausible solution, but more research is needed for verification. The environmental context and living situation are the last contextualization of the qualitative analysis. Geographic and climate variations across India appear to play a substantial role, as differing usage patterns might influence payback times across the country, reducing the purchase incentives in some areas. In addition, urban-rural divisions present their nuances, shown by the variance in the regression as well as in the thematic analysis. The divergence in the role of urbanization in LED lighting and energy-efficient ceiling fan adoption was explained as differences in the availability of energy-efficient appliances, with more purchase options in urban areas. An element of less importance for lighting bulbs.

What are the socio-economic, geographic, energy and policy drivers and barriers behind state-level adoption of energy-efficient appliances in the residential sector in India?

In answering the main research question and explain the drivers and barriers behind the state-level adoption of energy-efficient appliances in Indian households, our mixed method analysis shows several key drivers. The role of household income is indispensable for adoption of energy-efficient appliances. Across datasets and research methods, income showed its importance as adoption driver. While financial capability is crucial, there are more factors at play. Awareness and education play a significant role in determining adoption levels. If more people are aware of the existence and benefits of energy-efficient appliances and understand their functioning, they are more likely to adopt them.

Different climate zones in India cause different appliance usage patterns. This implies a difference in payback periods and thus potentially differing incentive levels for investment in these appliances across India. Urban-rural differences, particularly in energy-efficient ceiling fan adoption, seems to be drving accessibility differences. Furthermore, connection to the electricity grid shows to be a core driver, highlighting the importance of a basic infrastructure for appliance adoption.

At the policy level, significant state-level variations in adoption point to underlying governance differences, such as responsibility allocation and electricity distribution mechanisms. Though such effects on adoption levels are less pronounced than household-level characteristics, these elements influence state-level energy efficiency implementation. For LED lighting, state-level differences have largely been overcome, with relatively high adoption levels across the 21 investigated states.

To conclude, our mixed methods research identified several multidimensional drivers and barriers that have a significant influence on energy-efficient appliance adoption in the residential sector in India, across the datasets and the mixed methods. Key factors are household income, awareness of both personal and environmental benefits and household living contexts such as geographic location and grid connection. From our findings, it appears that successful state-level policies might be those that prioritize awareness, enhance financial accessibility for consumers and ensure a broad availability of energy-efficient appliances.

Bibliography

Agrawal, S. and D. Aggarwal (2020). "Awareness and Adoption of Energy Efficiency in Indian Homes Insights from the India Residential Energy Survey (IRES)."

Agrawal, S. M., Sunil; Jain, Abhishek; Ganesan, Karthik; Urpelainen, Johannes, (2021). "India Residential Energy Survey (IRES) 2020." Harvard Dataverse.

Alhojailan, M. I. (2012). "Thematic Analysis: A critical review of its

process and evaluation." West East Journal of Social Sciences **1**(1).

Alola, A. A., et al. (2023). "Role of Non-Renewable Energy Efficiency and Renewable Energy in Driving Environmental Sustainability in India: Evidence from the Load Capacity Factor Hypothesis." Energies **16**(6).

Bal, P. K., et al. (2016). "Climate change projections over India by a downscaling approach using PRECIS." Asia-Pacific Journal of Atmospheric Sciences **52**(4): 353-369.

Balachandra, P., et al. (2010). "Energy efficiency in India: Assessing the policy regimes and their impacts." Energy Policy **38**(11): 6428-6438.

Bansal, S. and M. Rahul (2021). Towards an Energy-Efficient Economy: Policy Measures by Government of India. Sustainable Development Insights from India**:** 183-200.

Bardhan, R., et al. (2019). "Evolution of sustainable energy policies in India since 1947: A review." Wiley Interdiscip Rev Energy Environ **8**(5): e340.

BEE (2018). SDA State-Wise Budget.

BEE (2023). "Energy Efficiency in Buildings." from https://beeindia.gov.in/en/programmes/buildings-0.

BEE (2023). "Standards & Labelling." from https://saathee.beeindia.gov.in/Common/BEEContent?MID=2&SMID=46.

BEE (2023). "State Designated Agency." from https://beeindia.gov.in/en/state-designated-agencies.

Berardi, U. (2017). "A cross-country comparison of the building energy consumptions and their trends." Resources, Conservation and Recycling **123**: 230-241.

Bhandari, D. and G. Shrimali (2018). "The perform, achieve and trade scheme in India: An effectiveness analysis." Renewable and Sustainable Energy Reviews **81**: 1286-1295.

Blumberga, A., et al. (2021). "Unintended Effects of Energy Efficiency Policy: Lessons Learned in the Residential Sector." Energies **14**(22).

Braun, V. and V. Clarke (2006). "Using thematic analysis in psychology." Qualitative Research in Psychology **3**(2): 77-101.

Brown, S. P. and H. G. Huntington (2008). "Energy security and climate change protection: Complementarity or tradeoff?" Energy Policy **36**(9): 3510-3513.

Brzezińska, J. (2015). "The Problem of Zero Cells in the Analysis of Contingency Tables." Zeszyty Naukowe Uniwersytetu Ekonomicznego w Krakowie(5(941)): 49-61.

Chandel, S. S., et al. (2016). "Review of energy efficiency initiatives and regulations for residential buildings in India." Renewable and Sustainable Energy Reviews **54**: 1443-1458.

Chindarkar, N. and N. Goyal (2019). "One price doesn't fit all: An examination of heterogeneity in price elasticity of residential electricity in India." Energy Economics **81**: 765-778.

Cohen, D. and B. Crabtree (2006). "Qualitative Research Guidelines Project."

Creswell, J. W. (2013). "Steps in conducting a scholarly mixed methods study."

Creswell, J. W., et al. (2003). "ADVANCED MIXED." Handbook of mixed methods in social & behavioral research: 209.

Creswell, J. W., et al. (2003). "Advanced Mixed Methods." Handbook of mixed methods in social & behavioral research: 209.

Creswell. J.W. and Creswell, J. D. (2017). "Research Design: Qualitative, Quantitative, and Mixed Methods Approaches." Sage Publications, Inc. **4**.

Cridland, E. K., et al. (2014). "Qualitative research with families living with autism spectrum disorder: Recommendations for conducting semistructured interviews." Journal of Intellectual and Developmental Disability **40**(1): 78-91.

Dasgupta, S. and J. Roy (2015). "Understanding technological progress and input price as drivers of energy demand in manufacturing industries in India." Energy Policy **83**: 1-13.

Debnath, R., et al. (2019). "How does slum rehabilitation influence appliance ownership? A structural model of non-income drivers." Energy Policy **132**: 418-428.

Dunlop, T. (2019). "Mind the gap: A social sciences review of energy efficiency." Energy Research & Social Science **56**.

Economidou, M., et al. (2020). "Review of 50 years of EU energy efficiency policies for buildings." Energy and Buildings **225**.

EESL (2016). UJALA Case Study.

Fetters, M. D., et al. (2013). "Achieving integration in mixed methods designs-principles and practices." Health Serv Res **48**(6 Pt 2): 2134-2156.

Francis, J. J., et al. (2010). "What is an adequate sample size? Operationalising data saturation for theory-based interview studies." Psychol Health **25**(10): 1229-1245.

Franco, S., et al. (2017). "Urbanization, energy consumption and emissions in the Indian context A review." Renewable and Sustainable Energy Reviews **71**: 898-907.

Fusch, P. and L. Ness (2015). "Are We There Yet? Data Saturation in Qualitative Research." The Qualitative Report.

Garg, A., et al. (2020). "Transitions towards energy-efficient appliances in urban households of Gujarat state, India." International Journal of Sustainable Energy **40**(7): 638-653.

Golubchikov, O. and P. Deda (2012). "Governance, technology, and equity: An integrated policy framework for energy efficient housing." Energy Policy **41**: 733-741.

González-Torres, M., et al. (2022). "Activity and efficiency trends for the residential sector across countries." Energy and Buildings **273**.

Goyal, N. (2021). "Limited Demand or Unreliable Supply? A Bibliometric Review and Computational Text Analysis of Research on Energy Policy in India." Sustainability **13**(23).

Goyal, N. (2021). "Policy Diffusion Through Multiple Streams: The (Non-)Adoption of Energy Conservation Building Code in India." Policy Studies Journal **50**(3): 641-669.

Greene, J. C. and V. J. Caracelli (1997). "Defining and describing the paradigm issue in mixed-method evaluation." New directions for evaluation **74**: 5-17.

Grimble, R. and K. Wellard (1997). "Stakeholder methodologies in natural resource management: a review of principles, contexts, experiences and opportunities." Agricultural systems **55**(2): 173-193.

Hansen, T. and L. Coenen (2015). "The geography of sustainability transitions: Review, synthesis and reflections on an emergent research field." Environmental Innovation and Societal Transitions **17**: 92-109.

Hennink, M. and B. N. Kaiser (2022). "Sample sizes for saturation in qualitative research: A systematic review of empirical tests." Soc Sci Med **292**: 114523.

Hesselink, L. X. W. and E. J. L. Chappin (2019). "Adoption of energy efficient technologies by households – Barriers, policies and agent-based modelling studies." Renewable and Sustainable Energy Reviews **99**: 29-41.

Hill, T. D., et al. (2020). "Limitations of Fixed-Effects Models for Panel Data." Sociological Perspectives **63**(3): 357-369.

IEA (2019). Multiple Benefits of Energy Efficiency. Paris.

IEA (2020). India 2020. Paris.

IEA (2023). LiFE lessons from India. Paris.

Ivankova, N. V., et al. (2006). "Using Mixed-Methods Sequential Explanatory Design: From Theory to Practice." Field Methods **18**(1): 3-20.

Jain, M. (2015). "Energy efficiency low-hanging fruit for India." Oxford Energy Forum(99).

Jain, M. (2023). "Estimates of energy savings from energy efficiency improvements in India using Index Decomposition Analysis." Energy for Sustainable Development **74**: 285-296.

Johnson, R. B. and J. Schoonenboom (2016). "Adding qualitative and mixed methods research to health intervention studies: Interacting with differences." Qualitative Health Research **26**(5): 587-602.

Kallio, H., et al. (2016). "Systematic methodological review: developing a framework for a qualitative semi-structured interview guide." J Adv Nurs **72**(12): 2954-2965.

Khosla, R. and K. B. Janda (2018). "India's building stock: towards energy and climate change solutions." Building Research & Information **47**(1): 1-7.

Kim, Y. J. and M. Brown (2019). "Impact of domestic energy-efficiency policies on foreign innovation: The case of lighting technologies." Energy Policy **128**: 539-552.

Knayer, T. and N. Kryvinska (2022). "Evaluation of research performed on energy efficiency in energy-intensive manufacturing companies." Frontiers in Energy Research **10**.

Kumar, S. (2021). State Energy Efficiency Index 2020, Bureau of Energy Efficiency; Alliance for an Energy Efficient Economy.

Lamont, S., et al. (2015). "Collaboration amongst clinical nursing leadership teams: a mixed-methods sequential explanatory study." Journal of nursing management **23**(8): 1126-1136.

Le, T.-H. and C. P. Nguyen (2019). "Is energy security a driver for economic growth? Evidence from a global sample." Energy Policy **129**: 436-451.

Liu, Y., et al. (2019). "Macroeconomic impacts of energy productivity: a general equilibrium perspective." Energy Efficiency **12**(7): 1857-1872.

Malhotra, A., et al. (2022). "Building institutional capacity for addressing climate and sustainable development goals: achieving energy efficiency in India." Climate Policy **22**(5): 652-670.

Mehta, T. and G. K. Sarangi (2022). "Is the electricity cross-subsidization policy in India caught between a rock and a hard place? An empirical investigation." Energy Policy **169**.

Miles, M. B., et al. (2014). Qualitative data analysis: A methods sourcebook. 3rd, Thousand Oaks, CA: Sage.

Mir, D. A., et al. (2020). "Explaining the Diffusion of Energy-Efficient Lighting in India: A Technology Innovation Systems Approach." Energies **13**(21).

Morse, J. M. (1991). "Approaches to qualitative-quantitative methodological triangulation." Nursing research **40**(2): 120-123.

Morton, C., et al. (2018). "The diffusion of domestic energy efficiency policies: A spatial perspective." Energy Policy **114**: 77-88.

Mukherjee, P. K., et al. (2020). "Staying cool: The development of India's pioneering energy efficiency policy for chillers." WIREs Energy and Environment **9**(4).

Mundaca, L., et al. (2010). "Evaluating Energy Efficiency Policies with Energy-Economy Models." Annual Review of Environment and Resources **35**(1): 305-344.

Nejat, P., et al. (2015). "A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries)." Renewable and Sustainable Energy Reviews **43**: 843-862.

NITI Aayog (2017). Draft National Energy Policy. N. Aayog.

NITI Aayog (2023). India Climate & Energy Dashboard - Demography. Demography.

Parikh, K. S. and J. K. Parikh (2016). "Realizing potential savings of energy and emissions from efficient household appliances in India." Energy Policy **97**: 102-111.

Pelz, S., et al. (2021). "Energy access for marginalized communities: Evidence from rural North India, 2015–2018." World Development **137**.

Psacharopoulos, G. and H. A. Patrinos (2018). "Returns to investment in education: a decennial review of the global literature." Education Economics **26**(5): 445-458.

Reddy, B. S. (2003). "Overcoming the energy efficiency gap in India's household sector." Energy Policy **31**(11): 1117-1127.

Reed, M. S., et al. (2009). "Who's in and why? A typology of stakeholder analysis methods for natural resource management." Journal of environmental management **90**(5): 1933-1949.

Revinova, S. and K. Gomonov (2023). "A Comparative Analysis of Government Policies to Promote Energy Efficiency in the US, China, and India." International Journal of Energy Economics and Policy **13**(1): 291-306.

Richmond, J., et al. (2020). "Drivers of household appliance usage: Evidence from rural India." Energy for Sustainable Development **57**: 69-80.

Safarzadeh, S., et al. (2020). "A review of optimal energy policy instruments on industrial energy efficiency programs, rebound effects, and government policies." Energy Policy **139**.

Santos, A. H. C. D., et al. (2013). "The risks of an energy efficiency policy for buildings based solely on the consumption evaluation of final energy." International Journal of Electrical Power and Energy Systems **44**(1): 70-77.

Sarangi, G. K., et al. (2019). "Indian electricity sector, energy security and sustainability: An empirical assessment." Energy Policy **135**.

Schleich, J. (2019). "Energy efficient technology adoption in low-income households in the European Union – What is the evidence?" Energy Policy **125**: 196-206.

Shodhan, A. (2015). "The Sidi Badshah of Western India: The Politics of Naming." Journal of African Diaspora Archaeology and Heritage **4**(1): 34-49.

Shrivastava, S. (2017). "Measurement units of length, mass and time in india through the ages." International Journal of Multidisciplinary academy **7**.

Singh, J., et al. (2018). "Analysis of technical and economic electricity saving potential in the urban Indian households." Sustainable Cities and Society **43**: 432-442.

Singh, J., et al. (2018). "Characterizing domestic electricity consumption in the Indian urban household sector." Energy and Buildings **170**: 74-82.

Singh, K. (2020). "Are energy efficiency policies efficient? Evidence from India." European Journal of Research **5**(6): 3-10.

Singh, V. K., et al. (2018). "Fostering investment on energy efficient appliances in India–A multi-perspective economic input-output lifecycle assessment." Energy **149**: 1022-1035.

Singh, V. K., et al. (2019). "Assessment of energy-efficient appliances: A review of the technologies and policies in India's residential sector." Wiley Interdisciplinary Reviews: Energy and Environment **8**(3).

Singh, V. K., et al. (2019). "A multiobjective optimization approach to support end-use energy efficiency policy design–the case-study of India." International Journal of Sustainable Energy Planning and Management **23**.

Solà, M. d. M., et al. (2020). "Promoting energy efficiency at household level: a literature review." Energy Efficiency **14**(1).

Stavytskyy, A. V., et al. (2018). "Estimating the interrelation between energy security and macroeconomic factors in European countries." Journal of International Studies: 217-238.

Teddlie, C. and A. Tashakkori (2003). "Major issues and controversies in the use of mixed methods in the social and behavioral sciences." Handbook of mixed methods in social and behavioral research **1**(1): 13-50.

Teddlie, C. and A. Tashakkori (2009). Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioral sciences, Sage.

TERI (2021). India Transforming to a net-zero emissions energy system, TERI, Shell.

TERI (2023). An economy-wide quantified goal on EE in India. Delhi, India.

Thapar, S. (2020). "Energy consumption behavior: A data-based analysis of urban Indian households." Energy Policy **143**.

The Energy and Resources Institute (2014). "Regional Report on the Transition to Efficient Lighting in South-Asia."

Thomas, S., et al. (2018). "Energy sufficiency policy for residential electricity use and per-capita dwelling size." Energy Efficiency **12**(5): 1123-1149.

Winter, J. (2004). "Response bias in survey−based measures of household consumption " Economics Bulletin **3**(9): 1-12.

Yu, S., et al. (2018). "Implementing nationally determined contributions: Building energy policies in India's mitigation strategy." Environmental Research Letters **13**(3).

Yu, S., et al. (2017). "Improving building energy efficiency in India: State-level analysis of building energy efficiency policies." Energy Policy **110**: 331-341.

Appendix A – Variable Name Transformations

Table 13: Variable name transformations

State_abbv	State Abbreviation
q103_survey_type	Rural – Urban
q205_priminc_earner_age	Age Primary Income Earner
q208_priminc_earner_educationlevel	Education Level Primary Income Earner
Q211_caste_type	Caste Type
q213_no_members_household	#members in household
q216_housetype_pucca_kachha	Housing structure type
q217_house_apartment_type	House – Apartment
q220_ownership_house_yn	Ownership of House
q227_a_plot_area	Plot Area
q234_monthly_expenditure	Monthly Expenditure
q235_income_type	Job type
Q236_income_category	Monthly Income
q301_electricitygrid_yn	Electricity grid connection
q312_grid_electricity_meter_yn	Electricity Meter
q401_bee_star_label_awareness_yn	Star Label Awareness
q403_bee_benefits_env_friendly	Environmental Friendliness Awareness
Density (/km2	Population Density
Smart meter AEEE 2021	Smart Meter
Policy & regulation score	Policy & regulation score
Institutional capacity	Institutional capacity
Adoption of EE measures	Adoption of EE measures
Financing mechanisms	Financing mechanisms
EE programs for residential buildings	EE programs for residential buildings
Q610_b_billed_units	Monthly Electricity Consumption
Average_electricity_prices	Average Electricity Price
Appliance_nr	Number of Lights Owned
q410_ceiling_fan_number	Number of Ceiling Fans Owned

Appendix B – Interview Questionnaire

Vincent Loon – Delft University of Technology

What are the socio-economic, geographic, energy and policy drivers and barriers behind state-level adoption patterns of energy-efficient appliances in the residential sector in India?

1. *What socio-economic, geographic and energy variables determine the adoption patterns of energy efficient appliances in the residential sector in India? (Literature review & desk research)*
2. *What are key energy efficiency policies for the residential sector in India, and how is responsibility for implementing these policies allocated across institutions and states? (Literature review & desk research)*
3. *How do socio-economic, geographic, energy and policy variables influence differences in the adoption patterns of energy-efficient appliances across states in India? (Quantitative analysis)*
4. ***What contextual factors further influence the drivers and barriers behind adoption patterns of energy-efficient appliances in the residential sector in India? (Qualitative analysis)***

Section 1: State-level differences in Adoption of energy efficient appliances (RQ3 & RQ4)

- What are, in your opinion, the most significant barriers to energy efficient appliance adoption in Indian states?
  - And specifically for LED lighting and ceiling fan?
- What are differences across Indian states in the adoption of energy efficiency policies?
- There's a very strong contrast between adoption rates of LED lights (80%) and energy-efficient ceiling fans (~7%). Why do you think this is?
  - What are your expectations for other energy efficient appliances?
  - How could they close this gap?
- We've observed that certain states outperform others in terms of energy-efficient appliance adoption. What factors do you think contribute to such differences?
  - What are the adoption drivers?
- The main pattern we've observed in the regression and descriptives is the relationship between education levels, income levels and grid connections on improvement of adoption rates for both LED lights and ceiling fans.
  - What's your view on this pattern?
  - Would there be other hidden variables that can explain these relationships? (e.g. on the policy side?)
- The regression shows several more relationships that I would like your view on:
  - Clear relationship between awareness of environmental benefits and adoption rate across appliances. What do you think of this relationship?
    - What is the effect of awareness campaigns in influencing the adoption of energy-efficient appliances?
  - The relationship between cast and adoption rate seems to be strong for fans, but not for LED lights. Why would that be?'
  - The relationship between state-level policy score and adoption rates is more clear for ceiling fans than for LED lighting, why would this be?

Section 2: Model performance Analysis (RQ3 & RQ4)

- States like *Chhattisgarh, Jharkhand and Madya Prades*h show a notably low adoption - What underlying factors might cause this?
  - Why could this correlate with their high energy expenditure.
- *Delhi, Himachal Pradesh, Maharashtra, Odisha, and Uttarakhand* outperform in LED adoption. Can you shed light on the potential reasons behind this?
  - Why would Odisha perform well despite being relatively poor?
- *Explanation of operationalization of policy variables* – What do you think of this approach and would you have recommendations for improvement?
- The contrast between performance of energy efficiency policy (rated by AEEE), and their adoption rates for energy efficient appliances in states like *Delhi and Maharashtra* is intriguing. How do you interpret this?
- Are you surprised by the performance of certain states – based on your expert opinion?
  - Implementation mechanisms

- What is the influence of electricity tariffs on consumer decisions to adopt energy-efficient appliances?

Section 3: Policy recommendations (RQ2 & RQ4)

- Considering the observed state-wise differences, what targeted measures would you recommend for states lagging in adoption?
    - Are there policy elements currently often overlooked? (institutional or financial capacity/ regulatory/ enforcement?)
    - At which government level should this be done?
- Are there specific state-level policies or regulations that, in your opinion, have been particularly influential in driving energy efficiency improvements in households?
    - Are you aware of any local or community-driven initiatives in specific states that enhance energy efficiency adoption?
    - Financial incentives for consumer adoption? (green loans, fiscal benefits, donations)
    - How do implementation mechanisms differ among states?
- Are there any collaboration programs that have led to successful energy efficiency campaigns or initiatives?
    - Multilateral, public-private-partnership or between states?
    - In relation to India's ambition as international leader for global south?

Appendix C – Informed Consent Form

Welcome,

You are being invited to participate in a research study titled *Drivers and Barriers behind the Adoption of Energy Efficient Appliances in Indian Households*. This study is being done by *Vincent Loon* from the TU Delft.

The purpose of this research study is to shed lights on the influences behind the adoption of energy efficient appliances in India and will take you approximately *30* minutes to complete. The data will be used for *my master thesis*. We will be asking you to give insights into what you believe are drivers and barriers behind adoption of energy efficient appliances and the influence different policies have here. Furthermore, this interview aims to capture contextualization of state-level policy and adoption differences.

As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by remaining confidential on the given answers and de-identifying them for usage in the results of this research. I will take detailed interview notes.

The interview will be recorded. The recording will be considered confidential, for data storage I will use only secured systems such as the TU Delft OneDrive and my own laptop.

All personal data collected (audio recording and this form) during this project will be deleted at the latest 1 month after the end of the project.

I will produce an anonymous summary of the discussion, based on the notes and recording. The summary will be made publicly accessible at the end of the project, as supplementary material to the thesis.

The summary will be sent to you for review a few days after the meeting where you can request for me to delete or adapt it if you disapprove of the content.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions. If after the interview is finished, you would still like to remove your data, this is also possible within the first 7 days.

My name is Vincent Loon, and my thesis supervisor is Dr. Nihit Goyal

Thank you very much for your cooperation!

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information above, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason. I understand that taking part in the study involves: taking written, detailed meeting notes, audio recording, anonymizing the responses and incorporation of insights into the Master Thesis project, which will end in November 2023.	☐	☐
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
3. I understand that taking part in the study involves the following risks re-identification through the expertise shown in the answers. I understand that these will be mitigated by anonymizing the responses by the researcher before incorporating them in the project. The anonymous summary will be sent to the participant for review, where they can request deletion or adaptation if they disapprove of the content.	☐	☐
4. I understand that taking part in the study also involves collecting personal for administrative purposes. Further identifiable information such as the insights given in the answers can have a potential risk of my identity being revealed. This risk is mitigated by the researcher by anonymizing the responses and only incorporating the anonymous summary in the master thesis.	☐	☐
5. I understand that the following steps will be taken to minimise the threat of a data breach and protect my identity in the event of such a breach such as anonymisation of responses, secured data storage with access only for the researcher where only an audio recording and written notes will be stored. I understand that personal information collected about me that can identify me, such as my name and profession, will not be shared beyond the study team. The (identifiable) personal data I provide, such as the notes, audio recording and this form will be destroyed upon completion of the research project.	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
12. I understand that after the research study the anonymised summary based on our discussion may be used for possible publication of the research by the researcher. It will publicly be accessible at the end of the project.	☐	☐
D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE		
16. I give permission for the de-identified answers that I provide to be archived in the TU Delft repository so it can be used for future research and learning.	☐	☐

Signatures

____________________________ ___________________________ _________

Name of participant [printed] Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

__________________________ ____________________ _________

Researcher name [printed] Signature Date

Study contact details for further information: Vincent Loon

Appendix D – Interview Summaries

Government Entity

Several factors influence the adoption of energy efficient appliances. On an individual level**:** income and socioeconomic properties of the households. A lot of people cannot afford to take energy efficiency into account as they are on tight budget constraints. While government are aware of the problem and have created a national and political narratives. The general consumer lives in a completely different world in which maybe they have not even heard of climate change or energy efficiency. And of course, we have a country with here with eight hundred million people that are living in almost poverty.

Furthermore, India's policy landscape is challenging. Even with national guidelines in place, implementation can be slow. The translation of these guidelines varies among states; while some lead the way, others lag significantly and haven't implemented measures to promote or subsidize energy efficiency. A broader, macro approach is needed. There are clear disparities between states in terms of wealth, both at the individual and governmental levels. This disparity also extends to policy ambitions. Much of this difference stems from the leadership within individual states. Notably, southern states often exhibit a more robust commitment to climate objectives.

The contrast between LED and energy efficient ceiling fans might be explained by differences of their characteristics. Households or companies using energy-efficient products likely take other environmental measures. To know how to close this gap, you could try to set up discussion with producers to see whether you can help incentivizing energy efficiency choices. I think awareness will come often at a very late stage for consumers if it comes at all. So, I think the awareness campaigns would also be a good policy to implement.

Higher education correlates with increased consumption of energy-efficient devices, and those with this education often have more awareness of them. But if one does not have a strong grid connection, alternative solutions might be chosen. While some might go for less costly appliances in the short run without thinking of the long-term energy expenses, those with greater education and income can make more well-informed decisions, leaning towards long-term gains. Factors like social status, caste, religion, and regional influences, where one might be influenced by the choices of their peers or neighbors, also play a role. This points towards the idea of intersectionality, where one should not just consider singular identity markers. It is a category where you see things like caste intersecting with socioeconomic status, ethnicity, region, and religion. So, there is a variety of factors at play.

Chhattisgarh, Jharkhand and Madya Pradesh are states with low socioeconomics and consumers with limited finances and lower educational levels compared to other states. These factors might deter them from focusing on energy policies, leading them to use more energy-intensive appliances. This due to an inability to invest in long-term energy-efficient alternatives. The upfront cost of adopting newer appliances serves as a barrier for these individuals. Moreover, it is essential to consider the broader context. Rapid adoption of these technologies might also have environmental implications, including material and transportation impacts beyond just CO2 savings.

State think tanks should make benchmarks to provide more data and insights. This will facilitate discussions at the policy level about effective strategies. Given the strength of individual states, rivalry and competition can be leveraged. Encouraging more dialogue between states would also be beneficial.

Think Tank

Private organizations are now providing LED lights, and their costs have substantially decreased, removing most purchasing barriers. There could be a difference in the business model between LEDs and ceiling fans. LED lighting costs were previously deducted from energy bills and ceiling fans are just expensive without such an incentive in place.

An existing sentiment is that energy efficiency equals revenue loss for electricity distribution companies. This perspective is reinforced by the fact that many states can't recover the full cost of energy. If higher paying consumers would use less energy, it means even lesser income for these distribution companies as they are the dominant income stream.

The main regression trend indicates that affordability and awareness are indeed key factors in energy-efficient decisions, insights that I would agree with. Environmental awareness currently doesn't significantly influence appliance purchases as people tend to base their choice on other factors such as cost. The higher cost of energy-efficient fans and their lower adoption can be seen as an example of this trend. The situation in Mathra Pradesh remains unclear for me. Delhi and Maharashtra stand out in India for their high income and education levels and thus is makes a lot of sense that they have high adoption levels across appliances. It's also relatively straightforward that when electricity tariffs are high, consumers tend to lean towards energy-efficient choices to save money.

A necessary step forward is increasing public awareness about the benefits of energy-efficient appliances, especially at the government level, distribution companies, and urban local bodies or municipalities. A national campaign that promotes energy efficient choices and that is transferred through mass media would be beneficial.

It must be further emphasized that energy efficiency is the foremost short-term achievable solution, and focusing on it can prevent wasteful losses.

Think Tank

Energy-efficient appliances are significantly more expensive upfront than non-efficient ones. The public has not yet grasped the long-term benefits of such choices, and there's a need to highlight the payback period or payback calculation. Payback is not just a function of the appliance itself but also depends on consumer behaviour. For instance, if an LED is utilized in a suboptimal lighting point, its true savings potential isn't achieved. It's noteworthy that adoption rates and patterns that have been observed can differ partly due to the different lifespans of appliances: LEDs typically last 3-4 years, whereas ceiling fans go for a minimum of 10 years.

Government policy plays a big role in this diverse landscape, so a national narrative is essential. The awareness of the benefits and environmental impacts of energy efficient appliances is a more direct indicator of a consumer's choice than their education levels, especially after considering income levels.

Another important thing to note is that the income earner of the family might not be the one who buys and operates the appliances. This could have implications for the usability of income as a proxy for consumer behaviour. For example, a wife or housekeeper might be the one who manages such things, and they can have a very different awareness level than the prime income earner.

Besides the observed performances: Certain states like Bihar, Rajat, and UP are lagging in various metrics, indicating potential weak performance. In contrast, states like West-Bengal, Punjab, and Kerala have more proactive governments. However, even when regulations are in place, the implementation can face challenges in these states. Furthermore, important to note is that consumer dynamics have shown to be very different in hilly regions in comparison to the rest of the country.

Facilitating easy access, such as offering payment in installments or discounts, can help in adoption rates. The LED program, for instance, initially had dual objectives: reducing consumer energy bills and decreasing the need for power production. But the first iteration of this program faced hurdles. The LEDs were priced significantly higher than fluorescent lights, making it a costly program for the government. The prevalent outages at the time harmed the LEDs, shortening their lifespan. As a result, when these lights broke, consumers often reverted back to non-LEDs. Yet, a shift occurred a few years later when India could produce LEDs domestically. This made prices drop by nearly 70%. This move transformed the program, marking it a national success across different regions and social classes.

Industry Player

India has a population of over 1.4 billion people, with over 300 million belonging to the middle class. This middle-class segment is growing both in terms of numbers and income levels. Although India's per capita electricity consumption is low compared to the world average, the country is one of the highest energy-consuming nations due to its large population. Energy consumption is growing rapidly, with a 10% annual increase.

India has taken a comprehensive approach to improving energy efficiency, led by the Bureau of Energy Efficiency. Initiatives like the distribution of LED lamps to reduce lighting energy consumption and India Cooling Action Plan are in place. The India Cooling Action Plan addresses cooling technology, refrigerants, and energy consumption reduction.

Per capita income has the most significant effect on influencing the adoption of energy-efficient appliances. States with higher per capita income tend to have a more favorable environment for such adoption.

Education levels too have a strong influence on appliance choice and energy-efficient adoption. Higher education not only contributes to understanding the importance of efficiency but also fosters awareness and commitment to environmental sustainability.

Price sensitivity remains a barrier. Higher-star-rated appliances may come at a premium cost. People often calculate the payback period based on their own usage patterns, which can result in a preference for lower-star-rated appliances as their payback period may be longer than advertised.

There is an importance of government policies and initiatives in driving energy-efficient appliance adoption. Policies like the Standards & Labeling Program and ECBC play a pivotal role in shaping consumer choices.

Cost of capital in India is a crucial factor, especially for large commercial projects. High-interest rates and limited capital availability can impact the decision-making process for adopting energy-efficient technologies.

There's often a conflict between long-term environmental goals set by governments and the short-term profit motives of manufacturers. Balancing these interests is challenging.

Awareness about global environmental issues has grown among the educated population of India, driving them to make more energy-efficient choices in their households.

Changing consumer behaviour remains a critical aspect of energy efficiency. Encouraging individuals to minimize waste and make energy-conscious choices, such as not leaving refrigerator doors open, is essential.

The technology needed for energy-efficient appliances is by now available. The challenge lies in accelerating implementation through policies and awareness campaigns.

The Kigali Amendment and its effect on refrigerators can be seen as an example of international agreements driving energy efficiency. Harmonizing global agreements and local policies is crucial so agreements like that need to be developed more.

Government Entity

Energy efficiency should be the primary strategy to curtail energy consumption. At the state level, the responsibility mainly centers around implementation of policies. While states have the opportunity formulate new policies, there's often not enough expertise required for real initiatives at the state-level. A recent interesting development is the declaration in the upcoming G20 meeting to double the target for energy efficiency, showing the growing importance!

A trend is the rising demand for cooling, now even in rural areas, where exponential growth is seen. A prime example of successful energy efficiency measures is the LED bulb distribution, managed by EESL. This initiative found success across both urban and rural areas. Across the building sector, many policies exist under the Ministry of Urban Development and Housing: the ECBC and the Green Building program for example.

Energy efficiency is divided into a supply and demand side. While the central government primarily drives the supply of energy-efficient appliances, the demand is shaped mainly by individual states. Progressive states in terms of development have higher adoption rates. On the other hand, states deriving a larger portion of their income from agriculture show a trend of lower adoption rates. A crucial factor influencing appliance purchasing decisions remains socioeconomic status. Those with limited means often face barriers to purchasing costlier, efficient appliances, showing a need for awareness and financial accessibility.

The shifting peaks in demand are putting pressure on the electricity distribution companies. This added pressure is caused by changing behaviour like electrical cooling, making energy efficiency measures a priority for them. An exemplary project has been the "free of cost distribution of LEDs project". Instead of an upfront investment, the financial burden is shifted to consumers through a slight increase in their electricity bills. The difference in adoption between LEDs and ceiling fans can be attributed to the big price differences between the two appliances, with the ceiling fan having a significantly higher price and longer life cycle. In contrast, the commercial sector, given its shorter life cycles, might already be having higher adoption rates. It would be very interesting for future research to investigate. Impact studies are also essential to understand effects of not adopting energy-efficient measures.

India's electricity distribution, which functions as a monopoly, struggles with a complex income system. They provide free or nearly free power to low-income individuals. Higher-income groups then paying a bigger portion of the costs, thereby reducing the incentive for the distribution companies to want consumers to transition to more energy-efficient methods. For the poorer population, there's limited motivation to adopt energy-efficient appliances as it does not reflect on the energy bill. It's an inversed matrix where high consumers pay more, while the low consumers pay far less.

Odisha has privatized the distribution of their LED lights, leading to a significant rise in energy efficiency adoption in that state. Similar privatization exists in places like Delhi and Maharashtra. However, there remains an absence of a mandatory push towards energy-efficient appliances. While the industrial and commercial sectors are under mandatory regulations, no such measures exist yet for individual consumers. The current policies focus more on promoting adoption rather than genuinely incentivizing consumers to make the shift towards energy efficient appliances. There's a need to not only reduce costs but also give consumers tools to change their purchasing decisions. Determining the beneficiaries of particular policies becomes crucial. For instance, while expensive appliances might benefit manufacturers, distribution companies (discoms) will then possibly lose money. This raises the question: Is there a genuine incentive for government to act?

Industry Player

India has made progress in certifications of appliances. However, consumer knowledge remains a challenge. Larger appliances in mainstream shops have clear energy efficiency labels, smaller items like LED bulbs are often bought at small retailers. Here, shopkeepers tend to promote products that offer them better commissions or are from specific distributors. Although the government is enhancing consumer awareness through advertising campaigns, the real push seems to be in not allowing uncertified products to be sold. A good project was the large-scale LED adoption program by the government. However, when consumers visit smaller shops, they often encounter limited choices, making them settle for products with lower energy efficiency ratings. This problem is less present in bigger cities where consumers have multiple options. As India's e-commerce sector grows, with platforms like Amazon, there will likely be more choice and increasing consumer awareness. Consumer awareness can increase through advertising and various marketing efforts.

Historically, most of India's distribution companies are state-owned. There's a trend to privatize discoms. Some states already having done so, and others are in the process. The government now rates these distribution companies since last year. Those with better ratings benefit from lower debt costs, making expansion easier. This setup has made distribution companies motivated to support energy efficiency. Southern states are ahead in these initiatives, though certain Northern states are catching up. The BEE and the EESL are driving forces behind this push for energy efficiency.

Electricity tariffs in India vary strongly. The agricultural sector has the lowest tariffs (₹1 to ₹2), residential tariffs range from ₹5 to ₹8-9. Commercial and industrial sectors see by far the highest tariffs, starting from (₹8-15). This is up to double the residential rates. Commercial and industrial consumers thus subsidize residential and farmers. With inflation and related escalations, it is politically challenging to hike rates for residential and agricultural sectors. Discoms face financial challenges as industries increasingly turn to renewable sources and implementing energy efficiencies. Discoms have thus reduced incentives to focus on making residents more energy efficient. The central government is putting pressure on both the state-level government and the discoms. They must improve operations and improve financial management or face lending restrictions. Cleaning up the balance sheet has become imperative for distribution companies. If they don't manage their finances well, they risk not procuring the necessary electricity to meet demands. The rating of distribution companies is a good move in this.

Most distribution companies are almost bankrupt, with a few exceptions like Gujarat. Decades of mismanagement have left many in a difficult state. The demand for electricity is rapidly growing in India, especially in states like Uttar Pradesh. Distribution companies are in the middle of unprecedented growth and limited funds for investments. After COVID, there's been a shift of population to tier-two cities and increased industrial activities, leading to more demand. An essential initiative to address this issue is the implementation of smart metering and prepaid metering, especially for agricultural consumers. This combats the mindset where farmers consume electricity for free. Government has assisted distribution companies by providing loans to improve their financial health. However, these loans, come with agreements. Distribution companies are required to show progress and meet specific key parameters for improvement. This shows the government focus on improvements in the sector.

Lobby Organization

In regions like Himachal and Uttarakhand, government schemes exist focused on energy efficiency, especially advocating the switch to LED bulbs. These efforts spotlighted the importance of local policies in propelling energy efficiency measures across varying terrains and demographics.

In Tamil Nadu, state-sponsored initiatives have driven awareness and adoption of energy-efficient products, especially LED bulbs. Distribution companies, like Tangedco, played a role in promoting LED bulbs by offering them at subsidized rates, making them more accessible to the public. In 2018, the government of Tamil Nadu, in collaboration with Tangedco, conducted a campaign where LED bulbs were sold at a significantly reduced price. This initiative triggered widespread interest and prompted numerous queries from consumers about the benefits of LEDs, their cost-effectiveness, and their role in energy conservation. Post-campaign feedback showed an increase in awareness and adoption of LED bulbs.

However, the promotion and adoption of energy-efficient ceiling fans didn't gain the same momentum as LED bulbs due to Brand Loyalty. Many consumers in areas like Chennai were loyal to well-known fan brands. making it challenging for energy-efficient fans to enter. Cost: Energy-efficient ceiling fans were significantly more expensive than regular fans. Lack of Awareness: The general public was less informed about energy-efficient fans compared to LEDs. While people could easily compare the functionality and output between traditional and LED bulbs, it was more complicated with fans. Consumers were familiar with components like motors and capacitors in standard fans and were unsure about the benefits of switching to energy-efficient models.

The usage and preference for appliances, especially fans, varies significantly across regions, largely due to differing climatic conditions. In the southern region, fans are not just a luxury but a necessity. Here, the fan is an integral part of daily life, with its usage spanning longer durations throughout the day. The adoption and acceptance of energy-efficient fans will likely vary across the country. It can be seen that in states like Tamil Nadu and other southern regions, where fans are highly essential, the uptake of energy-efficient fans might be higher.

The government should propose a universal scheme. This scheme should be equitable, serving all economic backgrounds. On the governance level, while electricity is a consolidated subject, both central and state bodies should collaboratively work. A centralized policy should be formed at the national level, which states should adopt and execute. This demands a balance of funding, monitoring, and feedback mechanisms between the center and the states.

In Tamil Nadu, compared to other states, the electricity tariff has historically been low. However, there was a tariff increase recently after five years, leading to public agitation. This change in tariffs could influence people to consider energy-efficient appliances as a cost-saving measure.

Think Tank

The public is aware of energy efficiency labels on high-cost items like air conditioners and refrigerators. However, for other appliances, the awareness is limited, partly because some appliances don't yet have a labelling scheme. For items like ceiling fans, the initial cost difference between a regular and energy-efficient fan often overshadows the potential operational savings. Large organizations, however, are actively pursuing net-zero targets and see the value in every energy-saving opportunity. To foster broader adoption of energy-efficient appliances, initiatives that aggregate demand and lower costs for the consumer, like programs run by EESL, are essential. There's an ongoing effort to bridge the cost gap, ensuring energy-efficient options are as affordable as conventional ones.

The adoption of LED lights in India experienced a significant boost due to EESL's UJALA scheme. This public procurement initiative effectively used demand aggregation, prompting many manufacturers to produce LEDs domestically. The resulting economies of scale from bulk production drastically reduced the cost of LEDs, making them an affordable choice for consumers. This success mirrored that of the air conditioning industry, where super-efficient air conditioners, initially quite pricey, became affordable due to similar demand aggregation. Such models, leveraging bulk procurements and aggregation, are key drivers for energy-efficient equipment. The LED light sector exemplifies a successful shift. Ceiling fans, for example, still face a dilemma in consumer choice, primarily due to the significant price difference between standard and energy-efficient models.

In the future, the focus might not just be on energy efficiency alone. Appliances may need to communicate with the grid, enabling demand response capabilities. This is a futuristic concept, aiming for real-time cost and consumption adjustments. Implementation of energy efficiency measures at the state level in India faces challenges, even when policies are notified. For more adoption of energy-efficient appliances a robust framework is crucial. Urban local bodies (ULBs) or municipal corporations play a pivotal role in enforcing such policies. States where energy efficiency is given priority might exhibit higher adoption of efficient appliances.

The current approach to policy implementation is fragmented, lacking the necessary integration. Measurement and verification are highly important for assessing the real-world impact of policies and proving the usefulness of measures. The current system falls short in tracking and reporting these effects. Without top-down direction, there's a tendency to shirk responsibility, resulting in a blame game.

The true cost of electricity generation is not yet entirely accounted for. There is a sentiment that the 2070 target for energy efficiency lacks ambition; a more immediate target is essential. While renewable energies receive more attention, there are some glimpses of energy efficiency measures taking center stage. The challenge remains in the tangible measurement and robust implementation of energy efficiency strategies. It's easier to quantify and discuss the achievements in renewable energies than in energy efficiency.

On the topic of distribution companies (discoms); they face challenges, especially in larger cities, dealing with peak demand. The inability to improve infrastructure to handle this demand results in penalties. Even though their focus is on meeting demand, energy efficiency can be a viable solution to reduce peak demand pressures.

Lobby Organization

non-energy efficient appliances have better upfront cost, often being cheaper. If you buy an energy-efficient air conditioner, pay roughly 30 to 40% more than for a standard one. The production and demand for LED bulbs have seen a significant surge recently. Thanks to economies of scale, as production has ramped up, prices have come down. The incandescent bulb now finds itself almost completely phased out. This isn't merely a matter of energy savings. Local retailers mostly stock LEDs, steering the consumer choices. But LEDs still come at a premium. This leaves a question mark for lower-income households. The challenge is navigating the initial cost and understanding the long-term benefits.

Many consumers are pivoting towards energy-efficient appliances, driven primarily by the aim to save on costs. The UJALA scheme was the government's initiative to improve the LED market, and it appears to have worked. On the flip side, the push for energy-efficient fans, like the BCLD fans, hasn't seen a similar governmental push. Its adoption is primarily private sector-driven, with companies striving to generate demand through advertisements and marketing campaigns. When cost-conscious decisions are the norm, creating awareness is key. Political dynamics are the main reason for state-level differences. Situations different than state's socio-economic progress can be partially attributed to political parties' social agendas. Differences in adoption rates between LED bulbs and energy-efficient fans are obvious. LEDs are easily accessible, while fans are long-term investments, often lasting decades. Additionally, the average consumer isn't familiar with the technicalities of products like fans, including blade width, speed, and air delivery.

If the government incentivizes retrofitting, adoption rates might increase. However, research into this specific domain seems limited. Consumers focus on the immediate cost and needs rather than the long-term return on investment (ROI). Energy efficiency isn't a main consideration, especially since domestic energy tariffs in places like Tamil Nadu are subsidized, lowering household energy costs. Recent tariff revisions might change this dynamic where time-of-day pricing has been introduced. There is a lot of push to prevent price increases for consumers. By keeping tariffs lower for the general mass, the costs are passed onto industries through cross-subsidization. Often the infrastructure is owned by state government. This led to utilities lacking capital for these investments. Instead, they focus on short-term operational costs, such as staff salaries, and aim for modest returns on equity. The tariffs set by utilities are thus focused on covering these operational expenses rather than infrastructure investments.

Education levels might not necessarily be the most direct relationship with adoption as I know many very wealthy businesspeople with limited education who only have expensive smart appliances, so the socioeconomic status is something captured in the income pattern. Sociocultural aspects also define certain patterns. It is never a conscious decision to pay for a product just to help environment. Young people now have been educated with environmental knowledge, older not so much.

We conducted an initiative that encourages households to conserve energy by comparing their consumption with similar homes. After gathering baseline data, households received reports on their energy usage against their neighbors. Three months later, an updated report measured improvement. Only this measuring led to significant energy reductions. This emphasizes community's role in reducing energy consumption as India's demand rises. While transitioning to renewable sources like solar is vital, grassroots energy efficiency is equally important.

Government Entity

The gradual development of energy efficiency measures in India has seen significant improvement and expansion over the years. The standards and labeling scheme have expanded from voluntary labels to mandatory ones when sufficient market transformation has been observed. There are many challenges in a developing country like ours. We have a rising energy demand and rising per capita income, leading to a strong increase in purchase of appliances. The challenge lies in facilitating this growth affordably and at the same time improve energy efficiency.

The ceiling fans market is very disorganized. More than 50% of ceiling fans are driven by small and medium sized industries. While the manufacturers of other appliances like LED bulbs or air conditioners or refrigerators have already adopted efficiency measures, this subsector has seen way less penetration of this. This was a problem because the appliance is so essential to Indian households. However, right now a switch has been made. Very recently the labeling scheme has been made mandatory and this will lead to a significant pick-up rate in the next few years. The difference in adoption rate across India will be driven mostly by the per capita income, the purchasing power of households in the states. If you look at the richer west of India, there will be a higher penetration of energy efficient appliances. We do believe that the market has matured by now and that the penetration rate of the lower income regions will improve now as people prefer efficient appliances.

In richer states there is more awareness around the benefits of energy efficient appliances, both for their own finances and to contribute to the climate goals. We now need to engage more with the masses to educate them on the benefits, as they will now reach the point where they start adopting appliances. The problem with this is that when you want to reach everyone, you must translate information into 26 or so languages instead of just Hindi and English. This makes it way less cost-efficient. The LED program was a massive success as it combined the government subsidy program with the private market. This was really a project for the masses and there are probably not really many differences across states visible anymore. They tried to develop a similar program for ceiling fans, but this proved to be a logistical nightmare. You can just procure a bulb, and anyone can put it in their point. In the case of a ceiling fan, this is not true because you need a technician for every home.

States have their own policy mechanisms in place. For example, the approval mechanism for energy efficiency. The division of responsibilities for energy efficiency varies. Some states the renewable energy department has responsibility and in others the ministry of Power. Two states, Kerala, and Andhra Pradesh, have standalone SDAs. A reason why there is the option for states to differentiate is that there is not yet a state-level energy efficiency target to which they must adhere to. The Bureau of Energy Efficiency is currently developing such a target. The primary objective of the energy efficiency scheme is to promote market-driven approaches. This shows that there's not always a need for state policies, given that energy efficiency pays for itself. It's crucial to make individuals recognize the benefits and then they can make their own decisions to invest.

Discoms recognize that improving efficiency reduces the overall electricity bill. From the consumer's perspective, discoms have been set specific targets for loss reduction, unlike energy efficiency measures. The shift from fossil fuel power to renewables further incentivizes discoms. By implementing energy-efficient appliances, a discom might only need to set up a 9 MW solar plant instead of 10 MW. This leads to reduced capital costs, and fewer investments. If supply isn't used efficiently or if demand isn't managed through energy efficiency measures, there's a mismatch, potentially leading to greater losses. Such considerations have become better for convincing discoms today, compared to five years ago.

Appendix E – Descriptive Statistics Figures

	state_abbv	q205_priminc_earner_age	q208_priminc_earner_educationlevel	q213_no_members_household	q227_a_plot_area	q234_month_expenditure_99_ifdontknow	q235_income_type	q236_income_category	q312_grid_electricity_meter_yn	q403_bee_benefits_env_friendly	Population	Density (/km2
1	AP	2.134538	3.716867	3.716867	109.24431	6099.398	4.588353	2.676596	0.997992	0.044176707	49577103	303
2	AS	14.082707	5.007519	4.573935	149.57619	5645.589	4.719298	2.449315	0.9824561	0.067669173	31205576	397
3	BR	8.907132	3.804606	6.27266	115.36012	5961.738	3.632244	2.43083	0.8818722	0.019316493	104099452	1102
4	CH	9.432642	4.101036	5.380829	52.88039	2784.974	2.839378	2.002667	0.8626943	0	25545198	189
5	**DL**	**18.146835**	**5.589873**	**5.351899**	**69.97172**	**12687.595**	**6.888608**	**4.143266**	**0.9696203**	**0.30126582**	**16787941**	**11297**
6	GJ	14.903509	4.067669	5.008772	29.01417	6709.649	4.071429	2.659091	0.9611529	0.062656642	60439692	308
7	**HP**	**17.580729**	**5.052083**	**4.760417**	**121.85644**	**8248.698**	**3.679688**	**3.082192**	**0.9921875**	**0.125**	**6864602**	**123**
8	HR	10.78329	3.344648	4.394256	76.01432	8149.739	5.172324	2.745714	0.8590078	0.015665796	25351462	573
9	JH	10.626943	4.277202	5.494819	149.59375	6034.456	4.42487	2.572917	0.6554404	0.015544041	32988134	414
10	KA	17.794416	4.738579	4.475888	73.81589	7096.827	4.044416	3.118622	0.930203	0.096446701	61095297	319
11	**KL**	**32.225974**	**5.044156**	**4.353247**	**131.66985**	**3380.519**	**4.963636**	**2.6**	**0.9974026**	**0.05194805**	**33406061**	**859**
12	MH	22.207239	5.251952	4.97516	89.31859	9261.533	4.701916	3.305714	0.9829666	0.125621008	112374333	365
13	MP	8.963693	3.488589	5.822614	72.99186	4667.842	3.171162	1.891089	0.7852697	0.006224066	72626809	236
14	OR	22.880546	4.295222	4.943686	230.80326	6619.454	4.472696	2.674061	0.943686	0.051194539	41974218	269
15	PB	17.425693	4.224181	5.020151	132.68988	7506.297	4.672544	3.381074	0.9697733	0.010075567	27743338	550
16	RJ	3.367934	3.779034	5.516958	147.15209	9226.31	3.857143	2.772487	0.9373073	0.124357657	68548437	201
17	TN	33.196078	4.901961	4.152735	45.96048	7405.366	5.048504	3.070321	0.9349845	0.083591331	72147030	555
18	TS	5.06288	4.217039	3.776876	136.01392	6275.862	4.334686	2.85	0.9959432	0.119675456	35003674	312
19	**UK**	**18.476562**	**4.583333**	**4.963542**	**59.19445**	**8110.677**	**5.151042**	**3.042373**	**0.953125**	**0.08854167**	**10086292**	**189**
20	UP	20.072997	4.2823	5.652455	107.66084	5054.07	4.167313	2.653153	0.8527132	0.054909561	199812341	828
21	WB	17.984694	4.32551	4.460204	274.61893	7102.041	4.52449	2.367865	0.9622449	0.07244898	91276115	1029
	Overall	**15.943371**	**4.352973**	**5.045855**	**105.76621**	**6856.167**	**4.317958**	**2.755966**	**0.9196014**	**0.07191435**	**77336282**	**804.6543**

	state_abbv	renewable grid CAP (2020)	Smart meter AEEE 2021	Policy & regulation score	Institutional capacity	Adoption of EE measures	Financing mechanisms	Res. Elec. Cons. 20 (kWh/p/y)	EE programs for residential buildings	q405_non_led	q405_ledlighting	Electricity_tariffs	Cli
1	AP	8365	1	8.5	1	3.5	2	301	1	1.5240964	2.485944	3.49	
2	AS	75	0	5.5	0.5	1.5	0	108	1	0.8220551	3.641604	4.26	
3	BR	343	1	2	0.5	1.5	0	125	0	0.7711738	3.606984	3.35	
4	CH	552	1	3.5	0	2.5	0	208	0	2.1787565	1.906736	1.25	
5	**DL**	**217**	**0**	**2**	**0.5**	**3**	**1**	**699**	**0**	**1.1594937**	**4.868354**	**3.93**	
6	GJ	10636	0	3	0.5	2	0	247	0	1.1817043	2.75188	5.46	
7	**HP**	**952**	**1**	**4.5**	**1**	**2.5**	**0**	**301**	**0**	**1.0989583**	**4.981771**	**2.9**	
8	HR	531	0	8.5	2.5	6	4	384	1	0.9451697	2.958225	4.35	
9	JH	47	1	2.5	0	1.5	1	170	0	2.0699482	2.393782	2.62	
10	KA	15232	0	10	0.5	6	2	216	1	2.4492386	2.992386	6.4	
11	**KL**	**427**	**1**	**8**	**2**	**1.5**	**2**	**329**	**1**	**3.4779221**	**4.436364**	**4.47**	
12	MH	9710	0	9.5	0.5	3	2	238	1	2.1220724	2.618169	7.42	
13	MP	4995	1	3.5	1	1.5	0	183	1	1.0207469	2.038382	3.33	
14	OR	522	0	7	1	1.5	1	172	0	0.2542662	3.348123	3.77	
15	PB	1449	0	8.5	2	5.5	3.5	453	1	1.8992443	3.191436	4.95	
16	RJ	9583	0	8.5	2.5	1.5	2	166	1	2.0020555	2.974306	5.98	
17	TN	14247	0	6	1	2	0	413	0	2.755418	2.392157	2.26	
18	TS	4025	0	4	1	3	0	325	1	1.4685598	2.383367	4.36	
19	**UK**	**661**	**1**	**3.5**	**1**	**1**	**0**	**281**	**0**	**1.0026042**	**3.929688**	**4.17**	
20	UP	3236	0	4	1	3.5	1	184	0	0.8940568	3.248062	5.23	
21	WB	533	0	3	1	1.5	0	177	0	1.0336735	3.42449	5.61	
	Overall	**5149.493**	**0.3186991**	**5.4765**	**0.9647498**	**2.567706**	**0.9388257**	**243.7823**	**0.4504074**	**1.4961955**	**3.0705**	**4.584625**	

Figure 12: Descriptive statistics of LED lighting dataset

	state_abbv	q205_priminc_earner_age	q208_priminc_earner_educationlevel	q213_no_members_household	q227_a_plot_area	q234_month_expenditure_99_ifdontknow	q235_income_type	q236_income_category	q312_grid_electricity_meter_yn	q403_bee_benefits_env_friendly	Population
1	AP	2.134538	3.716867	3.716867	3.57E+03	6099.398	4.588353	2.676596	0.997992	0.044176707	49577103
2	AS	14.082707	5.007519	4.573935	3.58E+04	5645.589	4.719298	2.449315	0.9824561	0.067669173	31205576
3	BR	8.907132	3.804606	6.27266	9.43E+03	5961.738	3.632244	2.43083	0.8818722	0.019316493	104099452
4	CH	9.432642	4.101036	5.380829	2.36E+02	2784.974	2.839378	2.002667	0.8626943	0	25545198
5	**DL**	**18.146835**	**5.589873**	**5.351899**	**5.71E+01**	**12687.595**	**6.888608**	**4.143266**	**0.9696203**	**0.30126582**	**16787941**
6	GJ	14.903509	4.067669	5.008772	4.22E+00	6709.649	4.071429	2.659091	0.9611529	0.062656642	60439692
7	HP	17.580729	5.052083	4.760417	1.04E+05	8248.698	3.679688	3.082192	0.9921875	0.125	6864602
8	HR	10.78329	3.344648	4.394256	2.02E+04	8149.739	5.172324	2.745714	0.8590078	0.015665796	25351462
9	JH	10.626943	4.277202	5.494819	1.34E+04	6034.456	4.42487	2.572917	0.6554404	0.015544041	32988134
10	KA	17.794416	4.738579	4.475888	2.07E+02	7096.827	4.044416	3.118622	0.930203	0.096446701	61095297
11	KL	32.225974	5.044156	4.353247	1.80E+03	3380.519	4.963636	2.6	0.9974026	0.051948052	33406061
12	MH	22.207239	5.251952	4.97516	1.22E+03	9261.533	4.701916	3.305714	0.9829666	0.125621008	112374333
13	MP	8.963693	3.488589	5.822614	3.79E+04	4667.842	3.171162	1.891089	0.7852697	0.006224066	72626809
14	OR	22.880546	4.295222	4.943686	8.43E+04	6619.454	4.472696	2.674061	0.943686	0.051194539	41974218
15	**PB**	**17.425693**	**4.224181**	**5.020151**	**2.24E+03**	**7506.297**	**4.672544**	**3.381074**	**0.9697733**	**0.01007557**	**27743338**
16	RJ	3.367934	3.779034	5.516958	1.79E+04	9226.31	3.857143	2.772487	0.9373073	0.124357657	68548437
17	TN	33.196078	4.901961	4.152735	1.61E+01	7405.366	5.048504	3.070321	0.9349845	0.083591331	72147030
18	TS	5.06288	4.217039	3.776876	8.89E+03	6275.862	4.334686	2.85	0.9959432	0.119675456	35003674
19	UK	18.476562	4.583333	4.963542	8.55E+03	8110.677	5.151042	3.042373	0.953125	0.088541667	10086292
20	UP	20.072997	4.2823	5.652455	6.54E+04	5054.07	4.167313	2.653153	0.8527132	0.054909561	199812341
21	WB	17.984694	4.32551	4.460204	5.00E+04	7102.041	4.52449	2.367865	0.9622449	0.07244898	91276115
22	**Overall**	**15.943371**	**4.352973**	**5.045855**	**2.22E+04**	**6856.167**	**4.317958**	**2.755966**	**0.9196014**	**0.07191435**	**77336282**

	state_abbv	Density (/km2	renewable grid CAP (2020)	Smart meter AEEE 2021	Policy & regulation score	Institutional capacity	Adoption of EE measres	Financing mechanisms	Res. Elec. Cons. 20 (kWh/p/y)	EE programs for residential buildings	Electricity_tariffs	Climate Zone	q410_ceiling_fan_number	q414_b_beerated_ceiling_fans_number
1	AP	303	8365	1	8.5	1	3.5	2	301	1	3.49	1	1.845382	0.02811245
2	AS	397	75	0	5.5	0.5	1.5	0	108	1	4.26	5	2.080201	0.15037594
3	BR	1102	343	1	2	0.5	1.5	0	125	0	3.35	4	1.611441	0.01485884
4	CH	189	552	1	3.5	0	2.5	0	208	0	1.25	3	1.414508	0.01813472
5	**DL**	**11297**	**217**	**0**	**2**	**0.5**	**3**	**1**	**699**	**0**	**3.93**	**4**	**2.364557**	**0.27594937**
6	GJ	308	10636	0	3	0.5	2	0	247	0	5.46	3	1.857143	0.10776942
7	HP	123	952	1	4.5	1	2.5	0	301	0	2.9	6	1.554688	0.05729167
8	HR	573	531	0	8.5	2.5	6	4	384	1	4.35	3	1.394256	0.02610966
9	JH	414	47	1	2.5	0	1.5	1	170	0	2.62	4	1.484456	0.03108808
10	KA	319	15232	0	10	0.5	6	2	216	1	6.4	1	1.205584	0.03299492
11	KL	859	427	1	8	2	1.5	2	329	1	4.47	1	2.535065	0.04675325
12	MH	365	9710	0	9.5	0.5	3	2	238	1	7.42	2	1.748048	0.08445706
13	MP	236	4995	1	3.5	1	1.5	0	183	1	3.33	2	1.205394	0.01763485
14	OR	269	522	0	7	1	1.5	1	172	0	3.77	4	1.513652	0.01365188
15	**PB**	**550**	**1449**	**0**	**8.5**	**2**	**5.5**	**3.5**	**453**	**1**	**4.95**	**3**	**2.367758**	**0.15617128**
16	RJ	201	9583	0	8.5	2.5	1.5	2	166	1	5.98	3	1.653649	0.0688592
17	TN	555	14247	0	6	1	2	0	413	0	2.26	1	1.673891	0.01960784
18	TS	312	4025	0	4	1	3	0	325	1	4.36	1	1.805274	0.11156187
19	UK	189	661	1	3.5	1	1	0	281	0	4.17	6	1.377604	0.08072917
20	UP	828	3236	0	4	1	3.5	1	184	0	5.23	4	1.709948	0.04844961
21	WB	1029	533	0	3	1	1.5	0	177	0	5.61	5	1.846939	0.09591837
22	**Overall**	**804.6543**	**5149.493**	**0.3186991**	**5.4765**	**0.9647498**	**2.567706**	**0.9388257**	**243.7823**	**0.4504074**	**4.584625**	**3.046058**	**1.688034**	**0.06268938**

Figure 13: Descriptive statistics of ceiling fans dataset

Appendix F – State Fixed Effects in Regression

Table 14: State Fixed Effects in the Regressions

	LED Lighting			EE Ceiling Fans		
Model with State Fixed Effects	**Estimate**	**Std. Error**		**Estimate**	**Std. Error**	
state_abbvAS	16.79	421.7		2.146	0.5942	***
state_abbvBR	2.898	0.9521	**	-0.3183	0.7348	
state_abbvCH	0.1529	0.9192		1.348	0.8019	.
state_abbvDL	0.7603	1.046		1.635	0.5742	**
state_abbvGJ	1.101	0.8819		2.137	0.5584	***
state_abbvHP	1.089	0.9979		0.1986	0.7388	
state_abbvHR	2.692	1.321	*	1.475	0.7389	*
state_abbvJH	0.3654	0.9402		1.69	0.6918	*
state_abbvKA	-0.1556	0.8738		1.124	0.6079	.
state_abbvKL	1.269	1.131		-0.5409	0.8929	
state_abbvMH	-0.1303	0.8482		1.541	0.5428	**
state_abbvMP	0.602	0.8822		0.6952	0.7117	
state_abbvOR	3.375	1.026	***	-0.1256	0.739	
state_abbvPB	0.3165	0.9126		2.451	0.5807	***
state_abbvRJ	0.1735	0.9403		1.654	0.5636	**
state_abbvTN	-0.1876	0.8535		0.3092	0.6399	
state_abbvTS	1.651	1.113		1.828	0.5619	**
state_abbvUK	2.831	1.279	*	1.31	0.6335	*
state_abbvUP	0.8949	0.8592		1.126	0.5698	*
state_abbvWB	1.396	0.8889		1.848	0.5623	**