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Original research article

Role of street-level policy entrepreneurs in sustainability transition: Evidence from India's transition to LED lighting

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ABSTRACT

Recent scholarly developments emphasise integrating insights from public policy discipline within the multilevel perspective (MLP) to understand sustainability transitions better. In this context, this article incorporates the concept of street-level policy entrepreneurs, specifically government-affiliated implementation agencies, within MLP to explain technology adoption and market creation when the technology is not cost-competent. The MLP framework is applied to analyse the case of the LED transition in India and highlight how a window of opportunity emerged in India, driven by global niche developments, favourable regime conditions and relevant institutional mechanisms. However, the high upfront cost of LEDs posed a significant challenge in utilising this window for niche-regime linking. This study demonstrates the critical role and activities of a state-affiliated implementation agency—Energy Efficiency Services Limited—in utilising this window of opportunity to accelerate the transition. It examines Energy Efficiency Services Limited's innovative implementation model that helped overcome the high upfront cost of LEDs, resulting in widespread technology adoption and reorientation of firm activities towards domestic manufacturing of LEDs in India. This study contributes to MLP scholarship by exploring the role of government in the later phases of the policy process and transition.

1. Introduction

The use of the multilevel perspective (MLP) to explain sustainability transitions has increased significantly in recent years [1–3]. MLP takes a structured and holistic approach to explain transitions by including factors at the macro (landscape), *meso* (regime), and micro (niche) levels. Under the framework, radical innovations developed in niches infiltrate existing sociotechnical regimes when the latter is weakened—opening a window of opportunity for niche-regime linking. This weakening arises from actors' interactions within the regime and between the regime and niches, resulting from external shocks at the landscape level [4]. Niche-regime linking refers to the interactions and connections between niche innovations (emerging technologies or practices) and the existing sociotechnical regime (established systems and practices). This linking is crucial for adopting and scaling up niche innovations into the broader sociotechnical systems and enabling transitions. This article aims to analyse the role of state-actors (implementation agencies) in niche-regime linking within the MLP framework and contribute to the evolving scholarship on MLP.

The MLP framework has attracted some criticism. The comprehensiveness of MLP offers researchers the flexibility to include a wide range of factors to explain transitions and allows analysts interpretative freedom, threatening the validity of the analysis [5]. Such criticism on the utility of MLP as an applied framework have led to calls for focusing not only on solid theoretical foundations but also on empirical observations from different disciplines. For instance, Smith et al. [6] highlighted the need for further research on the role of public policies and political actors in unlocking regimes, creating societal support for alternative technologies in niches, and the broader inclusion of the policy processes to study sustainability transitions. Along these lines, Kern and Rogge [7] discuss five major public policy theories and their use in the sustainability transition literature. They highlight how concepts like "policy entrepreneur" have the potential to offer clarity over the individual's agency vis-à-vis that of the system [7].

Policy entrepreneurs, first proposed by Kingdon in his multiple-stream framework, utilise windows of opportunity to couple three independent streams—problem, policy, and politics—to present problems and solutions as a package to decision-makers [8]. From focusing on individual entrepreneurs in the 1970s to recognising the role of networks and organisations, the concept has adapted to encompass various

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actors and strategies in the ever-changing public policy landscape. In parallel, the concept has been extended to include street-level policy entrepreneurs as a critical component of the policy process. These policy entrepreneurs are defined in public policy scholarship as front-line workers in public service and implementation agencies in efforts to underscore the importance of policy entrepreneurs in policy implementation beyond their initial conception in agenda-setting [9].

While public policy theories focus on the active role of policy entrepreneurs in seizing the window of opportunity, the MLP traditionally views the process as more evolutionary [10]. Recent developments in MLP have started to emphasise the importance of actors like transition intermediaries and boundary spanners [11]. The concept of street-level policy entrepreneurs could offer conceptual clarity and depth to the discussion of intermediaries and boundary spanners within the MLP framework. It provides a more detailed and empirically grounded perspective on how implementation agencies or institutions at the front line can facilitate interactions, adapt policies to local contexts, and drive transitions through their strategic actions. Integrating street-level policy entrepreneurs within MLP can enhance both theoretical understanding and practical approaches to facilitate sustainability transitions. Furthermore, the current discussion on state actors in MLP focuses on their role in supporting and protecting niches, creating regulations and standards, and public procurement for market creation. Hence, it has been focusing on offering a level playing field to market-actors in niches, regimes and policies, influencing the market selection environment [10,12]. This study brings to attention the functions of implementation agencies in making the new technologically-ready innovation affordable and creating markets by assuring demand for firms.

With a focus on a government-affiliated implementation agency as a street-level policy entrepreneur, the article partially addresses the gap identified by Kivimaa et al. [11], which is "how governments can purposefully employ intermediaries to direct transitions". In this regard, the article analyses the case of UJALA (*Unnat Jyoti* by Affordable LEDs for All)[1]—a programme to promote energy efficiency by distributing affordable LED bulbs to households. Specifically, the article investigates the following research question: How did street-level policy entrepreneur facilitate the sustainability transition through niche-regime linking in the context of the UJALA programme?

Energy Efficiency Services Limited (EESL), a government-affiliated entity, implemented the UJALA programme by procuring and distributing LED lamps, ensuring their availability at a subsidised rate nationwide. This study specifically examines the role of EESL as the street-level policy entrepreneur in utilising the window of opportunity for niche-regime linking. EESL's activities included bulk procurement to lower costs and collaborating with various stakeholders to facilitate the widespread adoption of LED lighting in the country.

The UJALA case has previously been analysed using the Technological Innovation System framework by Kamat et al. [13] and Mir et al. [14]. Both articles adopt a technology-centric view to explain the impact of transitions on the innovation system. Although they attribute the success to institutional arrangements such as the implementation agency, programme design, and the Energy Conservation Bill 2001, they do not examine these details thoroughly. To better understand these dynamics, this study presents an alternative policy-centric view by employing MLP to include the historical institutional development as a part of the landscape, the industry structure as part of the regime, and integrates the role of the street-level policy entrepreneur by discussing programme implementation. By doing so, the study contributes to the scarce but growing literature on the application of MLP in the context of developing countries and highlights the importance of the active involvement of state actors as enterprising units to augment the adaptive capacities of regime actors.

[1] *Ujala*, *unnat*, and *jyoti* are Hindi words, which in English translate to 'brightness', 'progressive', and 'light', respectively.

The following section presents an overview of the discussion on actors in MLP literature and the niche-regime linking processes. This is followed by the methodology in Section 3. The empirical case study and the role of the policy entrepreneur are presented in Sections 4 and 5, respectively. This is followed by the discussion in Section 6 and the conclusion in Section 7.

2. Literature review

This section presents an overview of the evolution of actors and processes in niche-regime linking within the MLP framework. It includes a review of current scholarship on hybrid actors, intermediaries, and boundary-spanners that facilitate the diffusion of niche technologies. Furthermore, by comprehensively examining the roles and interplay of various actors, this section will also shed light on the specific role of policy entrepreneurs within the MLP framework.

2.1. Evolution of actors in MLP

The scholarship on actors within MLP has evolved from a dominant structural representation, where the discussions have focused on actors at the three levels being passively responsible for rules and structures, leading to tensions and negotiation [15], to a more fluid representation, where actors span across the three levels and actively engage in transition [16]. These concepts posit that actors passively contribute to the formation of structures and rules at various levels, but their conflicts with one another can loosen these structures, creating opportunities for transitions [10].This shift in perspective is deeply intertwined with the theoretical treatment of actors within MLP, which is grounded in evolutionary economics.

For example, in niches, governments and policymakers can assume the role of niche managers, providing support for technological advancements and innovations. They accomplish this not only by offering financial resources but also by establishing institutional arrangements that foster experimentation [17,18]. Other vital actors within niches, such as markets, firms, scientists and researchers, are deemed essential for driving innovations and technology development [19]. Market actors, in particular, straddle both regimes and niches, and their actions are influenced by how they perceive the risks associated with transitions and the impact of policymakers, consumers and social movements. While incumbent actors are commonly associated with resisting transitions and clashing with proponents of new regimes, they may also collaborate to introduce favourable reforms. They play a crucial role in effecting changes and bridging the gap between niches and regimes. This is achieved by comprehending the prevailing context and creating opportunities within the regime [20]. Successful transitions are more likely when incumbent regime actors have vested interests in them, although external actors may be necessary to initiate the transition process. Such external actors are detached from the system's established rules and structures and play a pivotal role by providing the essential financial and managerial resources for the diffusion and commercialisation of niche technologies [21].

The evolution in MLP scholarship towards recognising actors' dynamic and active roles has significantly expanded the discourse on actors' involvement in linking niches and regimes beyond the traditional focus on the three levels within the MLP framework.

2.2. Current discussions on actors in Niche-Regime linking

In recent years, the processes of creating niche-regime linkages have focused on understanding the role of intermediaries and boundary spanners [11,22–25]. Intermediaries serve as actors connecting regimes and niches by explaining niche innovations within the regime context through market creation (demand assurance and generation) and adoption (overcoming the challenge of upfront cost). Boundary spanners operate in both regimes and niches and use their presence to establish

links between them.

Köhler et al. [16], while acknowledging the recent increase in scholarly interest in such actors, highlight the need for greater research on intermediaries' roles and functions in the later phases of transitions. These functions include market creation, which can involve various actions primarily related to policy implementation for technology adoption, with a focus on suppliers and consumers [29]. These intermediaries' actions are dynamic and influenced by the windows of opportunity leading to transitions [24,30]. It is worth noting that the intermediation activities are primarily determined by historical institutionalism rather than solely based on market selection among competitive goods. This is mainly due to inertia resulting from factors such as sunken costs, investments, rules and institutions prevalent in markets [25].

Similarly, boundary spanners play a crucial role in the adoption process as they capitalise on regime tensions and facilitate niche-regime interactions [22]. For instance, Smink et al. [23] emphasise that transitions necessitate the co-ordination of activities among previously unrelated actors. However, achieving such co-ordination poses challenges due to institutional and cultural practices. In this regard, boundary spanners can be crucial in overcoming such challenges. They highlight the need for further research to identify boundary spanners' specific skills and activities. These considerations determine the focus of this article—actors facilitating the process of linking niches and regimes in the later phases of transitions.

The initial attempts at explaining niche-regime linking have discussed economic drivers of price and performance, patterns of niche accumulation, technological complementarity and co-evolution, and actor-related patterns. Within actor-related patterns, the discussion has focused on regime actors and policy-related patterns that provide financial assistance to augment technology adoption or resist change because of political lobbying from existing regime actors, resulting in unfavourable policies [28].

However, empirical evidence, initially, in MLP has primarily been from historical cases spanning a long timeframe and ignored "…messy dynamics that occur within and between projects and networks of actors that are involved in innovation processes" [27]. Hence, the earlier attempts offered a crude understanding of links between niches and regimes. This lack of clear understanding has led to a call for a theory linking niches and regimes to analyse such dynamics better. In the context of this article, it is essential to understand these patterns and the processes of linking to highlight their insufficiency in facilitating niche-regime linking and understand the crucial role played by EESL in it.

One of the analytical lenses to elucidate the interaction between niches and regimes is "… *sociotechnical translations*" [26]. Translation processes are essential to establish niche solutions as widespread regime products. One example of such translations is the use of regulations and standards to promote niche technologies; however, such translations are weak. Regulations only work where the niche innovation is a ready fit to the mainstream context, and standards are not a comprehensive solution to encourage more profound changes in the regime [26].

Another way of explaining the interaction between niches and regimes is anchoring: the process by which radical innovations are linked to niches or regimes in a novel and/or more robust way. As these links grow, the chances of forming durable links between niches and regimes strengthen. The anchoring lens also paves the way for hybrid actors and forums that are neither inside nor outside existing regimes and play an important role in anchoring. One way of anchoring is through institutions—institutional anchoring—which means "…that developments within a niche are translated into new or adapted (interpretative, normative or economic) rules that play a role, at least temporarily, in orienting the activities of both niche and regime actors" [27].

While the discussions on interaction have focused on a nuanced analysis of niche-regime linking, two significant issues emerge from them. Firstly, most of these case studies are from developed countries where the challenge of diffusion and upscaling differs from that of developing and least-developed countries. For example, focus on practices and culture from the end-user's perspective when translating or anchoring niche innovations results from stable regime characteristics [20,31]. Secondly, the construct of concepts—translations and anchoring—offers a foundational understanding but further requires specifics, especially in the context of developing and least-developed countries where these alone might not reorient activities in regimes [32] and hence, may necessitate active government intervention in the adoption process.

State actors have a crucial role in ensuring technology adoption [33], particularly in the case of low-income countries where they play the role of "steward" between end users and technology [34]. The challenges related to capacity and governance, technology transfer and innovation systems, and absorption capacity in the case of developing countries assume importance in niche-regime linking [32]. They are not just specific to sustainability transitions. In developing countries, the lack of capabilities at the firm level has been a barrier to facilitating technological catch-up, thus shifting focus on policy design and the government's role in technology diffusion [35].

These developments underscore the evolution from an implicit structural view, where researchers have explored the complex, strategic and multifaceted roles that state actors could play in fostering, managing and accelerating sustainability transitions. It has led to a richer and more detailed understanding of how state actors can effectively contribute to sociotechnical change and calls for studying state actors as "a key focal point" [12].

2.3. *Policy entrepreneur in sustainability transitions*

In the case of sustainability transition studies and MLP, the discussion on policy entrepreneurs has focused on their role in different policy stages. Policy entrepreneurs may set the agenda in the early stages of the policy process by advocating niches [36] and utilising normative pressure on the landscape [37] and, in later stages, by formulating strategy and implementation [38]. They are key to ensuring the success or failure of sustainability transitions. For instance, the failure of Norwegian offshore wind development in the policy formulation stage has been attributed to the absence of a policy entrepreneur who could have provided sustained political momentum for the technology as an alternative [39].

When scaling up niche activities, niche-regime linking and related intermediary activities, the function of policy entrepreneurs (discussed either explicitly or implicitly) entails communication and implementation strategies [40–42]. For example, Kivimaa [41] discusses government-affiliated agencies as intermediaries and identifies policy implementation as one of their functions. The existing scholarship on actors in niche-regime linking, intermediation for market formation and the role of state actors within MLP has focused on policy entrepreneurs and their activities, seldom invoking them explicitly.

Traditionally, policy entrepreneurs have been observed as actors with knowledge and self-interest who exploit windows of opportunity to advance their policies and agendas [43]. This initial conceptualisation has evolved in three directions. First, Zahariadis and Exadaktylos [44] extend the idea from individuals to groups (or organisations) by defining policy entrepreneurs as groups rather than just individuals. Second, their role has extended beyond agenda-setting to encompass other stages in the policy process. For example, Arnold [9] distinguishes between elite policy entrepreneurs involved in agenda-setting and initial policy formulation and street-level bureaucrats functioning as policy entrepreneurs who implement policies. Third, the widespread importance of policy entrepreneurs in policy change, including implementation, has led to calls for further analysis of their strategies and capacities [45]. For example, Cairney [46] interprets John's [47] treatment of policy entrepreneurs as actors who engage in trial-and-error activities. The idea of EESL as a street-level policy entrepreneur in this article is based on the above considerations, where their role as an implementation agency in

the case of UJALA is examined. This includes a discussion of EESL's skills and entrepreneurial activities that led to the innovative implementation of UJALA. Moreover, it must be noted that although other policy entrepreneurs might have also played crucial roles in the agenda-setting and other stages of the policy cycle, the scope of this study is limited to the implementation stage of the policy cycle to focus on street-level policy entrepreneurs. Table 1 presents a summary of the literature review and its relevance to the article.

3. Methodology

This section outlines the methodology employed to examine the role of an implementation agency as a street-level policy entrepreneur in linking niches and regimes within the MLP framework. It consists of two key aspects: the operationalisation of MLP specifically tailored to the context of India's energy conservation and efficiency efforts, and the detailed methods used for data collection and analysis. The operationalisation focuses on defining the policy landscape and regime, while the methods section describes the within-case analysis of the UJALA programme, including data sources, data extraction techniques and the analytical approach used to understand the sociotechnical transition.

3.1. Operationalisation

The landscape is operationalised as a policy landscape rather than the traditional sociotechnical landscape. This is because the user-related patterns (cultural meaning of incandescent lamps) in this case are not prominent, and the sociotechnical household lighting system is not deeply entrenched in India. This operationalisation is based on two considerations: the slowness of change and the exogenous shocks that characterise the landscape.

Firstly, though five-year plans[2] in India had a short period, their recommendations (setting up institutions and institutional reorganisation) took place rather slowly, indicating slower changes more akin to landscapes than regimes. For example, recommendations related to regulatory bodies and energy conservation were made in the late 1980s and early 1990s, but the Bureau of Energy Efficiency (BEE) and EESL were only established in 2002 and 2009 respectively. Secondly, these plans and other policy documents used as sources for landscape also reflect the impact of different exogenous factors, such as the oil shock, dependence on oil imports and formulation of climate change action plans resulting from India's participation in global efforts directing national planning for climate change. Hence, the data for the landscape is obtained from sources such as India's five-year plans and policy planning documents. Since the operationalisation of the landscape, in this case, focuses on energy efficiency policymaking, the exogenous development (to India) of technology is not included as a part of the landscape.

The operationalisation of the regime is more challenging as the niche is missing in the case, and it raises questions as to whether institutional activities meant for supporting niche activities should be treated as regime or niche. For example, the standardisation of LED lights and related testing and benchmarking activities can be treated as niche activities, but they affect the regime in this case. Avelino and Wittmayer [48] propose a 'third space' where new institutions and structures for niche resources take shape, as opposed to the regime where existing institutions and structures are reinforced, which might be more suitable for this case. However, the new institutional developments are treated as part of the regime because they follow related global developments where the niche is already linked to the regime, resulting from transition activities in Europe and other developed countries. The data on the electric lighting manufacturing sector in the regime is included to highlight the favourable conditions within the industry structure and the benefits that accrued to the sector as a result of the transition. Finally, the niche is viewed as the international development of LEDs as a lighting solution.

Table 1
Summarising the literature review.

Section	Purpose	Contribution to the article
Evolution of Actors in MLP	Discusses the historical and theoretical evolution of actors' roles within the MLP framework.	Establishes the theoretical foundation and historical context, showing the shift from passive to active roles of state actors.
Current Discussion on Niche-Regime Linking	Examines recent research on the roles of intermediaries and boundary spanners in niche-regime linkages.	Explores contemporary mechanisms and processes, highlighting the complex roles of intermediaries and boundary spanners. Sets the context for understanding the specific functions and strategies of policy entrepreneurs, allowing for the identification of patterns and processes in the empirical case.
Policy Entrepreneurs in Niche-Regime Linking	Focuses on the role of policy entrepreneurs in facilitating niche-regime interactions and transitions.	Highlights the unique contributions of policy entrepreneurs, linking theoretical insights to practical examples. Helps identify the existing gap and the value of reconceptualising different actors as street-level policy entrepreneurs.

3.2. Within-case analysis

The study employs a within-case analysis, which allows for gaining deep insights into the UJALA case to explore the intricacies and dynamics contributing to a broader theoretical and practical understanding of the transitions. Based on the operationalisation of the MLP, information about the transition has been collected. The literature review section determined the choice of the actors, patterns, and processes of niche-regime linking that contributed to the emergence of the window of opportunity.

The data on the policy landscape—tracing emphasis on energy conservation and efficiency in long-term economic planning in India—is collected from five-year plans and other relevant policy documents. The operationalisation of the regime is in terms of institutional development and industry structure. The data on institutional development following the five-year plans is collected from secondary sources—documents and annual reports of different ministries and EESL, departments and governmental organisations.

The Annual Survey of Industries (ASI),[3] a yearly survey of factories in India conducted by the Ministry of Statistics and Programme Implementation, is used for industry data. The *National Industry Classification Codes 2008* is used for identifying relevant factories manufacturing electric lighting equipment—different types of lamps and related accessories—and the *National Product Classification for Manufacturing Sector* for identifying specific products—incandescent lamps and LEDs—within the factories (Table 2). The first set of codes is used to

[2] Like other planned economies, India previously formulated its economic and development planning in the form of five-year plans. The last year five-year plan was published in 2012, after which they were discontinued.

[3] The Annual Survey of Industries (ASI) in India is a comprehensive statistical survey that collects and analyses data on various aspects of the industrial sector. It covers key metrics such as production, employment, investments and financial performance of industrial units across the country.

Table 2
Details of data extracted from the ASI survey.

Data source	National industry code	Sector detail	Product codes	Product details	Blocks in ASI	Data
Annual Survey of Industries	27,400	Manufacture of electric lighting equipment	Till the year 2011: 77448	Incandescent lamp	Block A	Factory details
			After 2011: 4651004	Incandescent lamp	Block C	Information on capital investments
			After 2015: 4654110	LED lamps	Block E	Information on jobs
					Block J	Gross output of factories

Note: The table outlines data extracted from the Annual Survey of Industries (ASI) for the electric lighting equipment manufacturing sector in India, identified by the National Industry Code 27400. The product codes change over time: incandescent lamps are represented by code 77448 until 2011 and by code 4651004 after 2011, while LED lamps are introduced under code 4654110 starting in 2015. The ASI data is segmented into different blocks, each providing specific types of information. Block A details general factory information, Block C covers capital investments, Block E focuses on employment data, and Block J reports the gross output of the factories. This structured data collection highlights the industry's transition from incandescent lamps to LED lamps, offering insights into factory operations, investment patterns, job creation and output, which are critical for analysing the impact of policy initiatives like the UJALA programme.

identify the factories in the electric lighting equipment manufacturing sector, and then these are filtered by the second set of codes to identify the factories that produce incandescent lamps and LEDs. The ASI data includes LED lamps as a separate product class from 2015; hence, the data pertaining to factories specifically producing LEDs has only been classifiable since 2015. However, industrial activity in the sector before the UJALA programme were negligible [13].

The data for ten years from 2009–10 to 2018–19—five years before and after the programme launch in 2015—is extracted. The descriptive statistics at the national level are computed using the weights provided in the survey. The statistics included in the study focus on firm characteristics like the number of people employed, final products produced, capital investments and gross output. These statistics help understand the regime structure—favourable or resisting—and indicate the capacity and impact of transition. Data about niche developments is collected from secondary sources—research articles, reports and news media articles discussing the global development of LEDs and solid-state lighting.

In the case narrative, the role of EESL within the MLP is contextualised, focusing on interactions across different levels in MLP. EESL's evolution as an implementation agency is outlined, highlighting its crucial role in niche-regime linking. The narrative explains how the existing literature supports the case, putting the role of EESL within the broader theoretical framework of MLP and demonstrating its active engagement in the transition process.

4. Case study – explaining UJALA using multi-level perspective

In 2015, the Government of India launched the UJALA programme to promote LED lighting solutions for domestic lighting purposes. By 2018, the sale of LEDs had surpassed the sales of traditional incandescent light bulbs and compact fluorescent lamps as illustrated in Fig. 1. The programme has been successful in improving energy efficiency without offering any direct subsidies. It has been hailed as one of the most successful zero-subsidy programmes by the International Energy Agency (IEA) [49].

Appendix A provides a detailed description of the case-specific overview of the energy efficiency policy landscape, descriptive statistics of industry structure and institutional development (regime), and global developments related to LEDs (niche) to provide an overall context. The next section focuses on niche-regime interaction and challenges in utilising the window of opportunity emanating from global niche developments.

4.1. Niche-regime interaction and window of opportunity

Fig. 2 shows the different developments at the three levels of MLP (for detailed description, refer to Appendix A), specifically in the context of changes in landscape resulting in changes in the regime regarding regulatory and institutional arrangements and parallel global niche developments. These include the establishment of BEE and EESL as well as the formulation of technical standards by the Bureau of Indian Standards in the regime. Further, the niche is viewed as the global development of LEDs for household lighting and further mass-scale production in China and Taiwan, which resulted in reductions in retail prices from approximately USD 50 in 2011 to less than USD 30 in 2015 in the niche (see Section 3 in Appendix A).

The existing industry structure in the regime did not offer any resistance to the transition; instead, the industry welcomed the state intervention [52,53]. Data on capital investments and jobs reflects that the sector had less to lose and more to gain from the transition (see Figs. A.3 to A.7 in Appendix A). It is primarily because incandescent lamps were not the primary product of firms in the electric lighting manufacturing sector. Most of the firms in the sector produced a diverse range of products (see Fig. A.4 in Appendix A), which meant that other lines of products could have absorbed the risk of shifting to LED production.

The industry structure in the system was favourable for niche technologies to infiltrate the supply side since the manufacturing of LEDs could have helped them to grow, as evidenced by the data after 2015 (see Section 2 in Appendix A). However, the shifting of domestic manufacturing activities relied on assurance of demand in the domestic market for LEDs. Additionally, though niche activities leading to low global prices of LEDs contributed to the opportunity to shift from traditional lamps to LED lamps, the upfront cost of LEDs to end-users in India, as compared to incandescent lamps, remained too high, acting as a barrier to demand creation.

Before the launch of the UJALA programme, the retail price of LEDs in India was approximately INR 400 per unit, while compact fluorescent lamps cost INR 120 per unit and incandescent lamps approximately INR 10. However, for 50,000 h, the total expenditure on incandescent lamps and LEDs was INR 18330 and INR 2200 respectively. Hence, while LEDs cost 40 times more upfront, they resulted in more savings in the long run [54]. Thus, the biggest challenge was to make the retail price of LEDs comparable to incandescent lamps. In the following sub-sections, the patterns and processes of linking, based on the earlier discussion in Section 2.2, are presented to contextualise the transition within the existing literature.

4.2. Patterns and processes in niche-regime linking

An interesting point in this case is that the niche is not in the same geographical area as the regime. Analysing LED transition in India using the Technological Innovation System framework, Kamat et al. [13] showed how India was not a part of the global value chain of the semiconductor industry, including LEDs, and most of the developments in the country occurred after the launch of UJALA. In other countries, niche accumulation occurred in the form of LED-based applications as indicator lights for electrical appliances and as decorative lighting (see

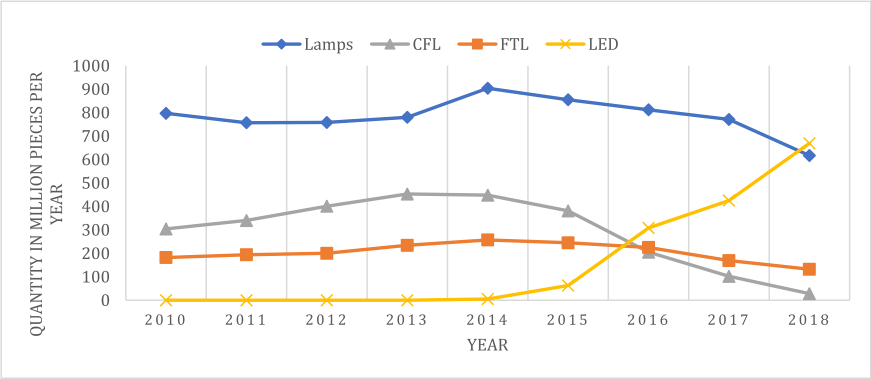

Fig. 1. Sales of different lighting solutions in India (latest data is unavailable). Legends: lamp – incandescent lamps, CFL - compact fluorescent lamps, and FTL – fluorescent tube lights.
Source: [50].

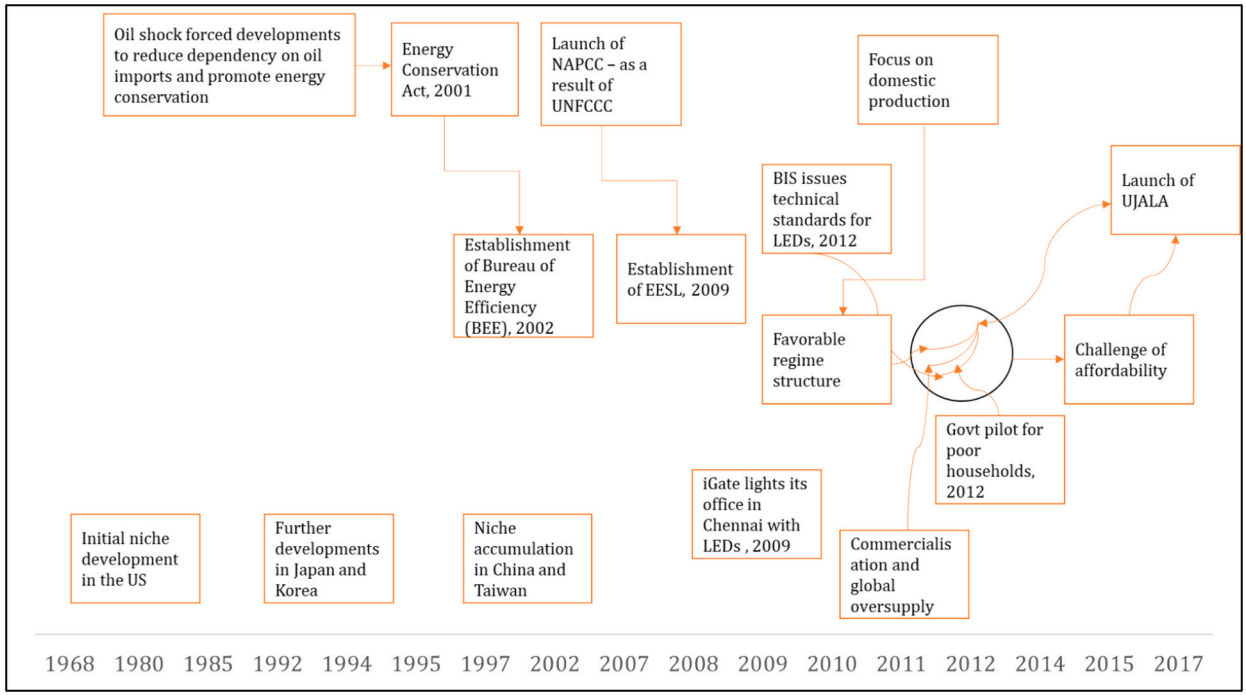

Fig. 2. A broad overview of transition using MLP; Author's presentation.
Note: The bottom layer denotes niche developments globally, leading to commercialisation, oversupply and reduction in retail prices. It also includes a private demonstration project in India and a pilot project by the government. The landscape factors reflected in the five-year plans are represented in the top layer, and how these factors lead to institutional developments seen as regime changes are presented between the two layers. The circle represents the window of opportunity, the challenge of affordability and the launch of the UJALA programme. The lack of arrows and links in the figure does not imply that developments in the niche were independent of each other. Any directionality is avoided because of complex transnational interactions of niches and niche actors and India's non-participation (through global value and supply chains) in the global niche of LEDs.

Section 3 in Appendix A). These developments helped commercialise and develop technology for general-purpose lighting on a global scale. LED lamps are highly compatible with user practices, and changes in other aspects of sociotechnical systems are not required. Hence, policy patterns are more important in this case than firm-related patterns [28].

4.3. Translation and anchoring in UJALA

Regulation-driven translations of niche innovation can be sufficient for niche-regime linkages if the niche innovation is highly compatible with the existing system. However, although LED lamps are highly compatible, niche-regime linking did not materialise in this case despite regulations and standards being in place due to the high upfront cost of the new technology.

Economic institutional anchoring in the form of a lack of cost competence emerged as the critical barrier that prevented technology adoption and transition. Explicit efforts such as policies to promote local production, conditions for local value addition on finished products and creating a market using public procurement could not overcome the upfront cost barrier to end users and failed to reorient the activities in the regime.

Both anchoring and translation, in this case, overlooked the role of actors in the fundamental issue of high upfront cost in market creation where a technology is well-defined and has high compatibility with an existing system (Table 3).

To summarise, the window of opportunity for transitions emerged in

Table 3
Summary of patterns, processes, and actors in the niche-regime linking in LED transition.

Patterns and process	Prevalence in case	Actors
Niche-accumulation	Niche accumulation occurs globally as the niche is global, with developments in China resulting in global oversupply and price reductions.	Non-existent in the context of India
Actor-related pattern	While the regime actors remained favourable towards transition, they required the assurance of market demand more than financial incentives to manufacture LEDs as their participation in the global value and supply chain was limited, and LEDs were significantly costlier than incandescent lamps. Support for local production takes place after UJALA was launched.	Electric lighting manufacturing factories, Ministry of Electronics and Information Technology, and Department of Scientific and Industrial Research
Translation	Regulations, labelling, and standards for LEDs	Bureau of Energy Efficiency and Bureau of Indian Standards
Anchoring	Public procurement and demand aggregation reduced prices through competitive price bidding. However, LEDs still remained five times costlier than incandescent lamps, inhibiting their wider diffusion.	The partial role of EESL in UJALA can be explained using economic anchoring as it undertakes public procurement activities.

this case due to low global prices of LEDs, translation in the form of regulation and standards at the regime level, and a favourable incumbent industry desiring the transition. The challenge in utilising this window existed in terms of making LEDs affordable (cost-competent), and assuring demand to incumbent firms in the regime for furthering manufacturing activities. EESL, as explained in the next section, emerged as the street-level policy entrepreneur that recognised and utilised this window of opportunity and accelerated the transition to LEDs.

5. Evolution of EESL and its role in UJALA

EESL, as the implementation organisation, was responsible for market creation and linking the niche and regime by making LEDs affordable. It is challenging to place EESL as an actor at any of the three levels. Although it is a regime actor, it also plays a significant role in market creation and, hence, can also be defined as a hybrid actor in a hybrid forum, following Elzen, Van Mierlo, and Leeuwis [27]. Its role in market creation through public procurement, demand aggregation, and policy implementation by co-ordinating activities and linking unrelated actors could also be defined as intermediatory [25] and boundary-spanning [22,23].

Hence, EESL and its activities could have multiple definitions within the MLP framework, resulting in various interpretations. However, defining EESL as a street-level policy entrepreneur in the later stages of the policy cycle [9] not only offers conceptual clarity by consolidating different conceptualisations in transition literature but also allows for the inclusion of implementation as a critical strategic component in the MLP framework and the transition process.

The initial conception of EESL[4] was as an implementing, co-ordinating and capacity-building entity for the Bureau of Energy Efficiency and other energy efficiency programmes initiated by the central and state governments [55]. The bureau was established as a result of the Energy Conservation Act of 2001, which also outlined the roles of central and state governments in promoting energy efficiency. The Energy Conservation Act delineated its several functions, including research, training, consultancy services, benchmarking and standardisation, as well as the implementation of pilot and demonstration projects [56]. Despite these comprehensive mandates, the pace of implementation of energy efficiency programmes remained slow. To address this challenge and accelerate the implementation process, EESL was formed to share the Bureau of Energy Efficiency's responsibilities and serve as its co-ordination and implementation agency [57].

EESL started by helping the Bureau of Energy Efficiency with several tasks and implemented energy efficiency activities on a smaller scale, which helped it gain financial autonomy for demand aggregation and public procurements on a larger scale. EESL started with a meagre share capital of INR 25 million in 2009–10, and its financial resources improved (Fig. 3) as it undertook the implementation of energy efficiency programmes, co-ordinating with different actors—municipalities, state electricity distribution companies (utility companies), state governments and other private entities. The initial share capital provided by the four public sector companies[4] ensured financial autonomy and prudence in the early activities of the organisation and set the stage for its later entrepreneurial activities.

Over time, EESL has evolved beyond its initial mandate. Riding on the success of the UJALA programme, it has transformed itself into a full-fledged energy services company, demonstrating its capacity to drive large-scale energy efficiency initiatives [58]. In the following subsections, EESL's initial pilot and demonstration projects are analysed as their entrepreneurial activities that improved its institutional capacity to implement the UJALA programme at the national level.

5.1. Entrepreneurial activities

In its first year of inception, EESL undertook an energy audit exercise for a municipality (the city of Ludhiana in Punjab) to retrofit street lights with LED lamps. Its other activities focused on implementing standards and labelling energy-efficient products, conducting energy audits for different entities and preparing annual energy-saving plans for four states in the country [55].

EESL was also involved in the implementation of a programme launched by the central government to replace incandescent lamps with compact fluorescent lamps in households—*Bachat Lamp Yojana* ("Saving Lamp Scheme"). The objective of the programme was to reduce the price of compact fluorescent lamps to make them comparable to that of incandescent lamps, as the former cost 7–8 times the latter. It was also an attempt to utilise the Clean Development Mechanism of the Kyoto Protocol to finance the difference in prices [59].

The policy implementation involved three main actors in a public-private partnership—the Bureau of Energy Efficiency, private suppliers and traders of compact fluorescent lamps and utility companies. EESL signed memorandums of understanding with different utility companies in 2010–11 to implement the programme. The programme's economic viability depended on certified emission reduction trading and, as the global carbon market plunged, it became unviable [60]. Meanwhile, EESL also expanded its partnership with different states and municipalities to conduct energy audits and act as the implementation agency for activities under the state energy conservation funds in different states [61,62].

EESL later continued working with utility companies to develop the DSM (demand-side management)-based efficient lighting programme to promote the use of LEDs. EESL piloted the programme in Puducherry (a union territory in southern India) in April 2014 to replace incandescent lamps with LED lamps. The objective was to utilise the successful features of the discontinued *Bachat Lamp Yojana* programme—co-

[4] EESL was formed in 2009 by the Ministry of Power as a 100 % government-owned joint venture between four public sector companies—National Thermal Power Corporation Limited, Power Finance Corporation Limited, Rural Electrification Corporation Limited, and POWERGRID Corporation.

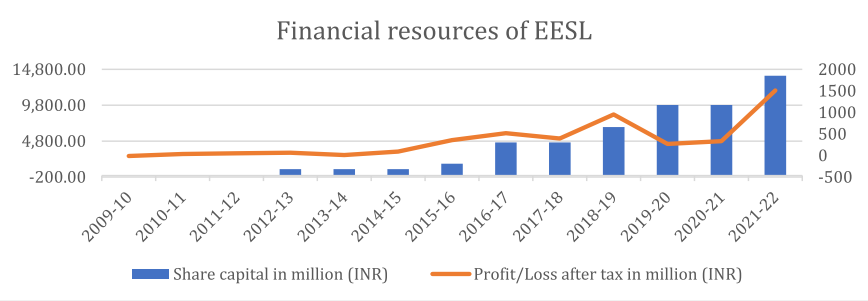

Fig. 3. Financial resources of EESL extracted from EESL's Annual Reports from 2009 to 10 to 2021–22.
(Source: https://eeslindia.org/en/investors-zone/#annual_reports accessed on August 16, 2023).

ordination with different actors and its experience with municipalities across the country—and avoid weaknesses, for example, linking the programme finance with volatile global carbon prices [63].

These experiences significantly enhanced EESL's capacity to manage large-scale energy efficiency projects and helped EESL develop expertise in co-ordinating with multiple stakeholders, designing innovative financial mechanisms and adapting to changing market conditions. By expanding partnerships with state and municipal entities and piloting new programmes like the DSM-based efficient lighting programme, EESL strengthened its role as a key implementation agency capable of driving and managing extensive energy efficiency initiatives across India.

5.2. EESL's implementation strategy

EESL's efforts to create a market for LEDs had two major strategies: reducing price through public procurement by aggregating demand and creating a zero-subsidy financing model to further reduce the upfront costs to end users.

Demand aggregation at the national level and competitive bidding, coupled with a global reduction in LED prices, helped the agency reduce the cost of LEDs to end-users. One of the earliest procurements, based on aggregated demand by EESL, was for retrofitting streetlights with LED lamps, followed by procurement for the pilot project in Puducherry. These procurements reduced the retail price in India from INR 400 to INR 310. Next, EESL signed a memorandum of understanding with Andhra Pradesh, a state in southern India, to aggregate the demand for LED lamps for households in that state. As a result of competitive bidding, the lowest bid received was INR 204 per lamp.

The utility companies provided further discounts to end-users. These discounts, clubbed with the reduction of prices driven by competitive bidding, resulted in further cost reductions to INR 50 per LED lamp from INR 400. Consumers were also offered the option to buy LEDs by paying a nominal amount upfront (INR 10 instead of INR 50) and the rest in instalments (INR 10 per month), which were added to their electricity bills [49]. The rationale was that since LEDs would reduce energy consumption and hence the electricity bill, the difference in the actual price paid by the consumer and the market price could be recovered from the savings from reduced electricity expenses.

Although the utility companies had to offer steep discounts to make the price of LED lamps comparable to that of incandescent lamps, they recovered the costs from the revenue generated by not having to buy excess power to meet peak load during evenings as the demand was primarily from the lighting needs of households. They could also supply the excess power (saved by energy-efficient lighting) to commercial consumers [54]. Utility companies are not traditionally part of the market as retailers of LEDs. However, they played a crucial part by offering steep discounts on LEDs and recovering them in instalments, and effectively acting as retailers by distributing LEDs through their utility centres (electricity billing counters), making them essential market actors. Utilities, thus, played a crucial role in market formation and created an assured demand for LEDs for firms in the regime.

5.3. Co-ordination with other actors

In addition to its resources and entrepreneurial activities, EESL's ability to co-ordinate with different actors and foster partnerships also played a vital role in the transition. As discussed in the previous section, in its initial years, it partnered with utility companies, municipalities, private entities, and state and local governments to implement different programmes and conduct energy audits. These partnerships, in part, resulted from its inception as an implementing organisation for all energy efficiency programmes, whether from the Bureau of Energy Efficiency, the central government, or state governments, and the indirect agency it received from the Energy Conservation Act of 2001 through the Bureau of Energy Efficiency.

Given the standard and uniform implementation model at the national level and short-term engagement, EESL successfully brought utility companies and state electricity authorities on board [63]. Their strategy followed the emerging global practice of offering energy efficiency as a resource to utility companies based on the standard offer programme (monetising energy savings using energy efficiency purchase agreements). The monetisation of energy savings is also expected to reduce state governments' subsidies for assisting utility companies in compensating for their aggregated technical and commercial losses. Including such underlying benefits to other stakeholders within the programme helped EESL co-ordinate with state governments, state electricity regulatory authorities and utility companies [64]. These efforts were also bolstered by the transparency in the procurement bidding process and its successful pilot at the municipal level for street lights, which added legitimacy to its innovative programme design [63].

EESL was able to provide LEDs to consumers at almost the retail price of incandescent lamps. This price reduction did not entail any subsidies or costs to the stakeholders involved but was driven by market-based mechanisms [65]. While the initial cost reductions resulted from low global prices, public procurement, demand aggregation and the involvement of utility companies in the implementation model helped make LEDs affordable, facilitating niche-regime linking.

6. Discussion

With LEDs being a ready-fit artefact that does not necessitate significant transformations, one could question whether the case presented in this study is about substitution rather than transition. It is essential to consider the overall transition context in this regard.

EESL's efforts to create a market for LEDs had two major components—public procurement through demand aggregation and a zero-subsidy financing model to reduce upfront costs to end users. However, the success of both these strategies depends on the transition context, the locus of adaptive resources, and the co-ordination of the selection

process [66].

In this case, adaptive capacity lies both within the regime and outside it. It is within the regime in terms of firms' diversified outputs, which allow them to absorb the shock of declining production of ILBs as they shift their resources to meet the increasing demand for LEDs. The capacity is also outside the regime, as the market creation initiative introduces new actors—utility companies and EESL. These actors span the boundary between niche and regime. The involvement of utility companies in LED distribution, where they assume the role of retailers and play a crucial part in offering the initial discount and recover it as instalments, make them essential market actors. They play a crucial role in market formation and creating assured demand for new products for firms in the regime. Thus, by lending their resources, they contribute to the adaptive capacity of the regime.

In terms of co-ordination of selection pressure, the selection is articulated in terms of public procurements for creating markets for niche products. The large-scale distribution of LEDs through a well-defined programme indicates a co-ordinated approach. Support to regime actors is created through institutional and financial arrangements—regulations, standards, conditions of local value addition in public procurement tenders and high import duties on finished LEDs. These factors favour the case of regime transformation vis-à-vis substitution and put the case between endogenous renewal and purposive transition [66].

This study further highlights how favourable conditions in regime, landscape and global niche developments may result in a window of opportunity for regime shifts. However, recognising and utilising such windows of opportunity require the active involvement of street-level policy entrepreneurs—EESL in this case—to enable transitions through innovative implementation models for market creation.

EESL recognised the opportunity emanating from global niche developments and used its entrepreneurial experience to make LEDs cost competent by aggregating demand for public procurement and designing a zero-subsidy programme. In the process, it also created domestic demand for LEDs for firms in the country. It was able to do so by co-ordinating with other actors like utility companies to offer zero-subsidy discounts and for LED distribution, and state governments and local urban bodies to aggregate demand. These partnerships were developed over a period of time because of EESL's entrepreneurial activities. Hence, EESL, as a street-level policy entrepreneur, performed the intermediary and boundary-spanning functions of market creation by co-ordinating with different actors.

The EESL agency results from legislative developments that respond to the need for energy efficiency and conservation in India, which manifested in the form of the Energy Conservation Act of 2001. Additionally, the existing institutional mechanisms for regulations, labelling and LED standards that form the overall environment conducive for niche-regime linking result from the long-term emphasis on energy efficiency in the landscape. Suppose landscapes are actor-less [67] and state actors' involvement in niches is more about resource diversification than picking winners. In that case, regimes become an arena of intervention for state actors. Thus, the discussion of actors in a regime must not remain limited to firms and supply-side policy interventions.

This case can be viewed as an intervention point in a larger system transition to energy-efficient lifestyles. With a successful and possibly durable link between niches and regimes, the reproducibility of the process may allow it to spill over to cover other appliances that can conserve energy. As a matter of fact, EESL is now using the demand aggregation model for the National Motor Replacement Programme in India. This programme aims to replace inefficient motors with more efficient IE3 models in different industries, improving the embodied energy efficiency of many products [68].

Moreover, the UJALA programme is also expected to improve the financial health of state utility companies, which, in turn, could improve their ability to increase renewable electricity in their energy mix [65]. These impacts in the regime beyond just manufacturers and retailers show how LEDs are nested in a more extensive sociotechnical system of energy consumption. Hence, while the LED transition may appear simplistic, its impact could prove transformational.

These findings directly affect domestic lighting transitions in the Global South, where efforts to promote LED lamps have primarily focused on anchoring and translation. For example, countries like Bangladesh, South Africa, and Nigeria have focused on creating stringent efficiency standards to promote the use of LEDs [69–71]. In contrast, Pakistan has banned the manufacturing and the use of incandescent bulbs [72]. While these initiatives contribute to creating a window of opportunity for LED transition, the lack of a street-level policy entrepreneur to make LEDs available and affordable may hinder the pace of transition.

7. Conclusion

The reproducibility of the UJALA model has direct implications for policymaking as this case offers a nuanced view of the green entrepreneurial state discussed by Mazzucato [73]. As the availability of and access to technology and finance for transitions improve, the focus should be on enhancing institutional capacities. Institutions responsible for implementing policies become crucial as they can augment adaptive capabilities, foster rapid market creation and create durable links using innovative financial mechanisms. Such institutions and their capacity might be more relevant in the case of developing countries, where the innovation systems are weak, sociotechnical systems are unstable and markets are immature.

In immature markets, mass-scale production depends on active government involvement because of inadequate innovation systems and the risk-averse nature of firms. The traditional role of governments and policy actors in innovation systems primarily entails R&D expenditure, protection of and support to niches through regulation, and market creation initiatives. However, explaining transitions in developing countries will require revisiting assumptions such as regime stability, institutional capacity and cost-competence of technology, on which existing scholarship on policy actors relies. Berkhout, Wieczorek and Raven [74] discussed the challenges of explaining the sociotechnical change in developing countries where regimes are relatively fluid compared to those in industrialised countries. While this dynamism in the regime is a result of late industrialisation characterised by the concurrent transformation of society and industry in a high-growth-rate environment, the lack of general capacity—institutional and governance—in these countries also presents an institutional barrier to technology adoption.

In this study, the street-level policy entrepreneur is incorporated within MLP to explain its role in augmenting regime capacity and co-ordinating with different actors to enhance the overall implementation of policies for transitions. Understanding historical landscape developments and focusing on implementation agencies within MLP could lead the way for designing a capacity development agenda and reforms for government-affiliated institutions. Such an agenda could focus on empowering institutions like EESL and ensuring their freedom through legislative actions. As a result, these institutions can emerge as street-level policy entrepreneurs, which can recognise the appropriate windows of opportunities and intervention points in large sociotechnical systems and pave the way for accelerating sustainability transitions.

CRediT authorship contribution statement

Shubham Sharma: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Overview of landscape, local regime, and global niche of LED transition in India

In the following sub-sections, a brief overview of developments in the landscape, local regime, and global niche is presented. It follows the operationalisation discussed in Section 3. The regime discussion includes an overview of the industry structure and institutional developments resulting from the landscape. Finally, the niche discussion presents the overall global development of LEDs as a household lighting solution.

A.1. Energy efficiency policy landscape in India

India's early post-independence energy planning aimed to meet growing demand, neglecting energy conservation. Reports from 1965 to 1985, including energy surveys, committee reports and Planning Commission analysis, overlooked energy-saving options, according to Sengupta's assessment [75]. In the 1980s, India's energy planning shifted to consider conservation due to global oil concerns. The sixth five-year plan targeted electrification and reduced oil use, while the seventh plan quantified conservation potential in key sectors and proposed establishing an energy efficiency fund [76,77].

In the subsequent five-year plan, household lighting and cooking were integrated into energy demand considerations, marking a notable shift. The plan emphasised creating institutional frameworks, such as a National Energy Conservation Organisation, and it proposed an Energy Management Centre within the Department of Power, which fell under the Ministry of Power, Coal, and Non-conventional Energy until 1992 [78]. In 1992, the ministry was split into three ministries—Ministry of Power, Ministry of Coal, and Ministry of Non-Conventional Energy (Ministry of New and Renewable Energy after 2006).

The Rio Earth Summit of 1992 redirected global focus towards environmental concerns and advocated a transition from fossil fuels. This event led to the creation of the United Nations Framework Convention on Climate Change, eventually leading to agreements such as the Kyoto Protocol in 1997 and the Paris Agreement in 2016. India actively engaged in these developments, shaping policies and initiatives aligned with its treaty commitments [79]. One such development was the National Mission on Enhanced Energy Efficiency in 2008, which led to the formation of EESL in 2009.

Taking a cue from the previous plan, the ninth five-year plan compared technologies like filament lamps and compact fluorescent lamps in household lighting on the basis of their energy efficiency—the first specific comparison of technology in household lighting [80]. The tenth plan emphasised international benchmarking of energy efficiency and proposed a long-term technological vision for energy efficiency [81]. Subsequent plans (eleventh and twelfth) suggested energy efficiency labels for home appliances, incentives for super-efficient products like LEDs, and discussed promoting chip fabrication in India due to a lagging semiconductor industry [82,83].

A.2. Regime

In 2001, the Government of India passed the Energy Conservation Act,[5] which paved the way for establishing the Bureau of Energy Efficiency, succeeding the Energy Management Centre mentioned in the previous section. Its objective was to formulate recommendations to the central government on a variety of issues concerning energy efficiency and to develop codes, standards and labelling mechanisms while promoting research and development, implementing pilots and demonstration projects, and offering financial assistance to institutions to achieve higher energy efficiency [56].

The eleventh five-year plan explicitly focused on the fabrication and packaging of LEDs and their R&D; this was also reflected in the working group report from the Council of Scientific and Industrial Research published by the Department of Scientific and Industrial Research.[6] The report envisioned exponential growth in LED markets and focused on domestic fabrication of LEDs using gallium nitride in government laboratories. This signified a push for basic science and R&D activities in the niche [13,84].

In 2009, EESL was established by four public sector undertakings working on different aspects of energy generation and distribution. The primary objective of EESL is to promote energy-efficient technologies and products using innovative business models under the aegis of the National Mission on Enhanced Energy Efficiency (NMEEE) [85]. The NMEEE was one of the eight action plans under the national action plan on climate change launched in 2008.

As EESL took shape as an agency, a programme—*Bachat Lamp Yojana* (*BLY*)—was launched by the Bureau of Energy Efficiency in 2010 as a market transformation scheme to replace incandescent lamps with compact fluorescent lamps [59].

Meanwhile, following global developments, the Bureau of Indian Standards, which is responsible for creating standards for products in India, issued technical standards for LED lamps in 2012 [86]. The Ministry of Communication, and Information Technology's Department of Electronics, Information and Technology, announced a scheme to subsidise capital, R&D expenditure and import duties for electronic manufacturers in 2012 [87].

[5] The Energy Conservation Act, 2001 was formulated to enact measures pertaining to energy efficiency and conservation in the country. Through this act, the government incorporated the Bureau of Energy Efficiency as an autonomous government body under the Ministry of Power, extending the scope and powers of an earlier departmental body—the Energy Management Centre.

[6] CSIR and its labs are the largest research and development organisations in India. The Ministry of Science and Technology is its parent organisation.

In efforts to promote the use of LEDs, EESL conducted a pilot in a union territory of India, Puducherry, resulting in its first public procurement of LEDs in the country [88]. One of the prime concerns was balancing imports and domestic manufacturing to create jobs and investments in the system; hence, a mandatory requirement of domestic value addition for LEDs in government procurements was issued in 2014. Additionally, prior to the formal nationwide launch of the UJALA programme in 2015, the government announced skilling programmes in the sector and, in later years, the focus shifted to manipulating customs duties to foster local production [13].

While the developments discussed above signify the changes for assisting the uptake of new technology, the analysis of the existing industry structure reflects changes in the electric lighting manufacturing sector before and after the UJALA programme. The data from the ASI from 2009 to 2019 is used to present an overview of the sector.

From 2009 to 2019, 630 firms in the electric lighting manufacturing sector were surveyed on average every year, with over 800 firms surveyed in 2009 (Fig. A.1), representing the overall state of the sector. Out of the factories surveyed in the ASI, factories in the electric manufacturing sector account for approximately 1 %. The low percentage signifies the overall impact (lack of) of the sector on India's GDP and labour market.

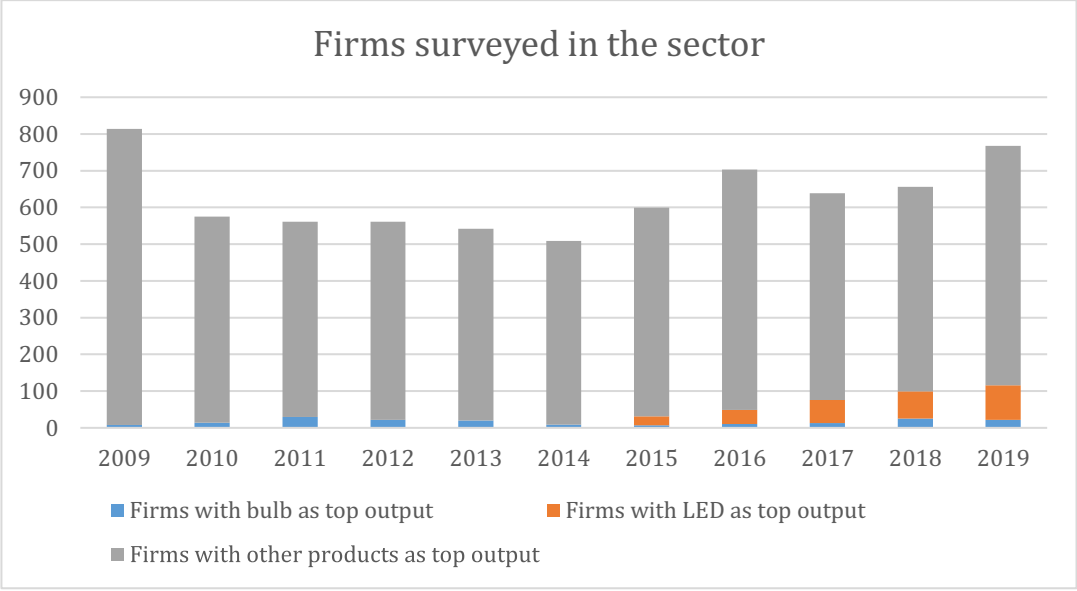

Fig. A.1. Total firms surveyed in ASI in the electric lighting manufacturing sector (Author's calculation).

At the firm level, the impact of the programme depended on whether incandescent lamps were the primary product of the majority of firms or not. Very few of these firms listed incandescent lamps as their primary product. If incandescent lamps were not the primary products of factories in the sector, then what were they producing? To assess this, the frequency of products reported by factories in the survey as their top three outputs is plotted (Fig. A.2).

From 2009 to 2011, the major products were light-fitting accessories, while compact fluorescent lamps were also in the top three products for the years 2009 and 2010. Compact fluorescent lamps were part of the *Bachat Lamp Yojana* scheme discussed earlier, which was launched in 2009, and, hence, the prominence of compact fluorescent lamps in these years is likely a consequence of *Bachat Lamp Yojana*.

Since 2011, the major products have been other electric lamps and lighting fittings, including those used for public open spaces and thoroughfares. From 2017 to 2019, the survey shows that factories had LED lamps among their top three products. Fig. A.2 shows that the impact of transition as a result of UJALA was more likely to be absorbed by the diversified output of the firms, and the government's push for LED lamps created a new opportunity for regime actors.

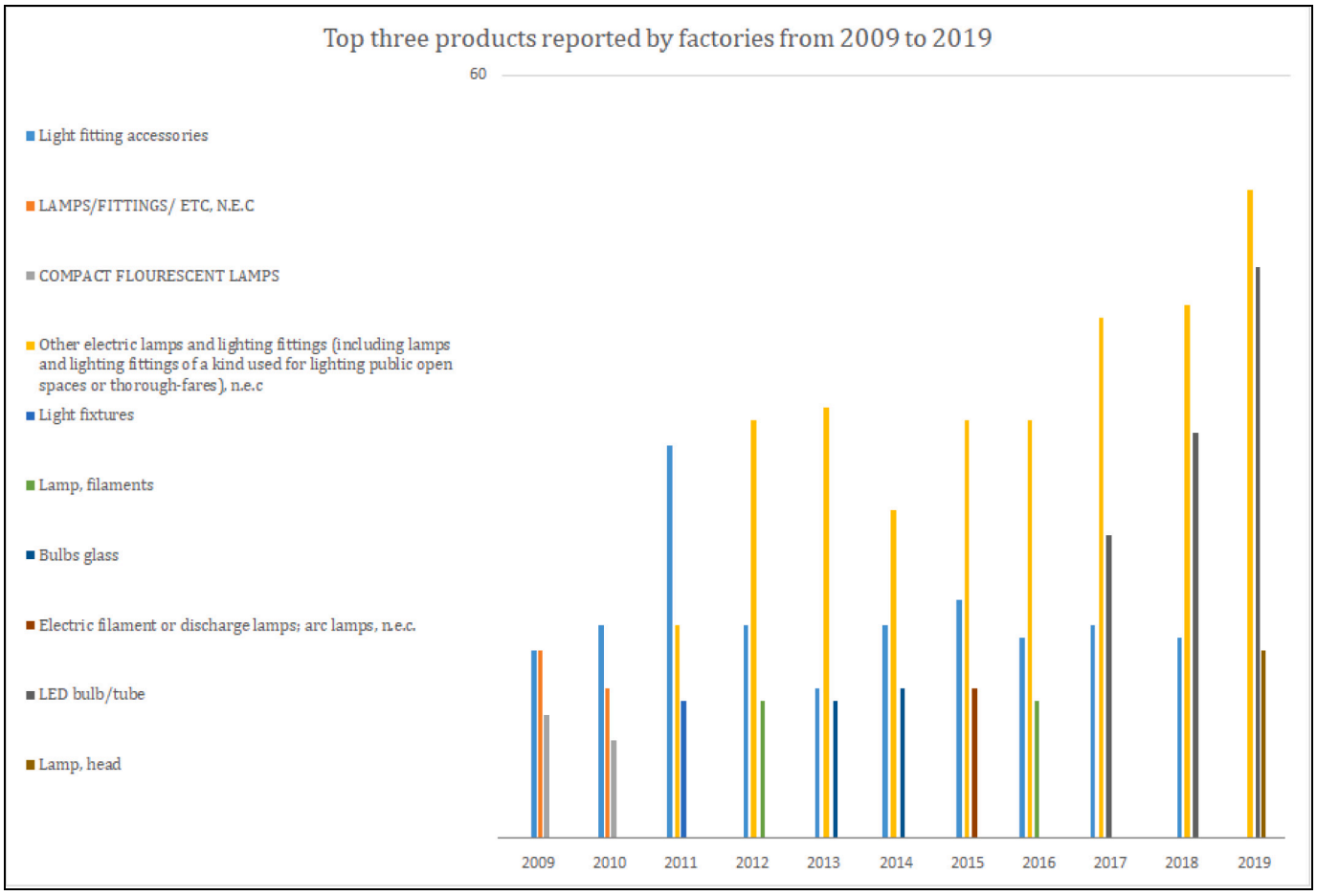

Fig. A.2. Top products by year (Author's calculation).

The survey also records financial details, and the capital in progress and total capital by product category from 2009 to 2019 is presented to gauge the financial impact of the UJALA programme. The total capital denotes the existing fixed capital, and the capital in progress denotes investments in fixed assets that are still a work in progress but for which expenses have been incurred.

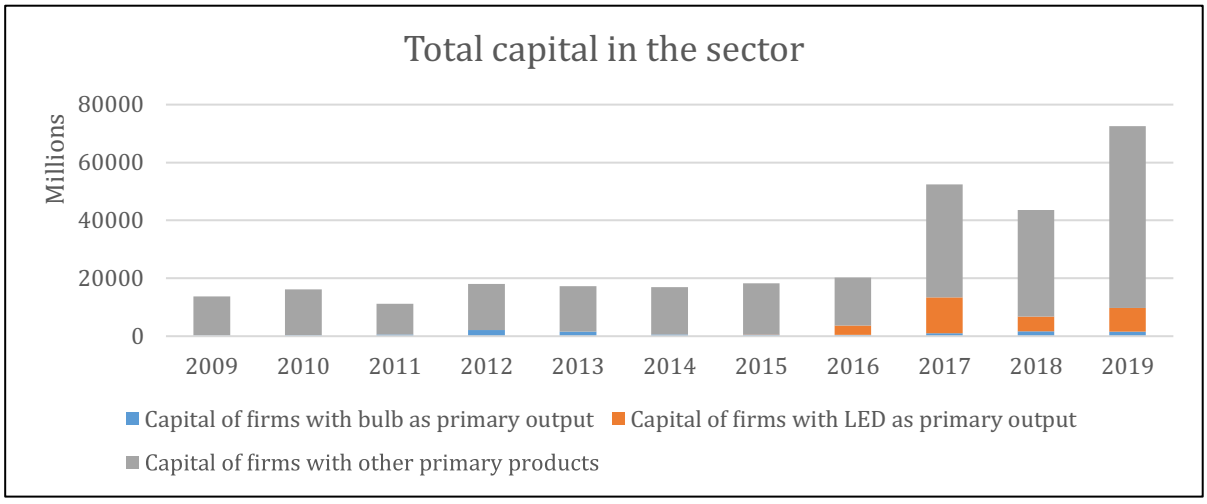

Fig. A.3. Total capital in the sector in Indian rupees (INR) (Author's calculation).

Fig. A.3 shows the total capital in the sector. Most of the assets are in the factories whose primary output was not incandescent lamps before 2016. However, since then, capital investments in factories whose major product is LED lamps have shown a significant increase. This increase is more substantial in the case of capital in progress, where, especially in 2017, the work-in-progress fixed assets of factories producing LED lamps is almost comparable to those of factories whose primary products were neither incandescent nor LED lamps (Fig. A.4).

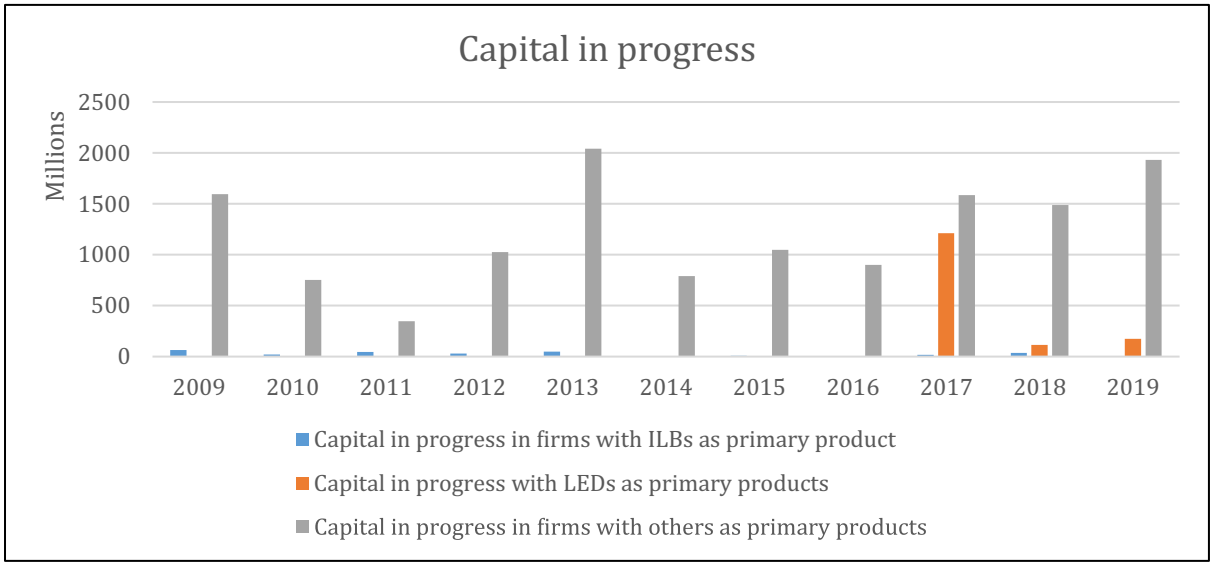

Fig. A.4. Capital in progress for different products in INR (Author's calculation).

Fig. A.5 shows the output of factories—ex-factory value (i.e., exclusive of taxes, duties on sale, and inclusive of subsidies, if any) of products and by-products manufactured and other income. The factories that produce LED lamps have a significantly higher output than those producing incandescent lamps, though the output is lower than in factories producing all other products (Fig. A.5). Hence, it can be concluded that LED lamps were generating more value for factories than incandescent lamps after the launch of UJALA.

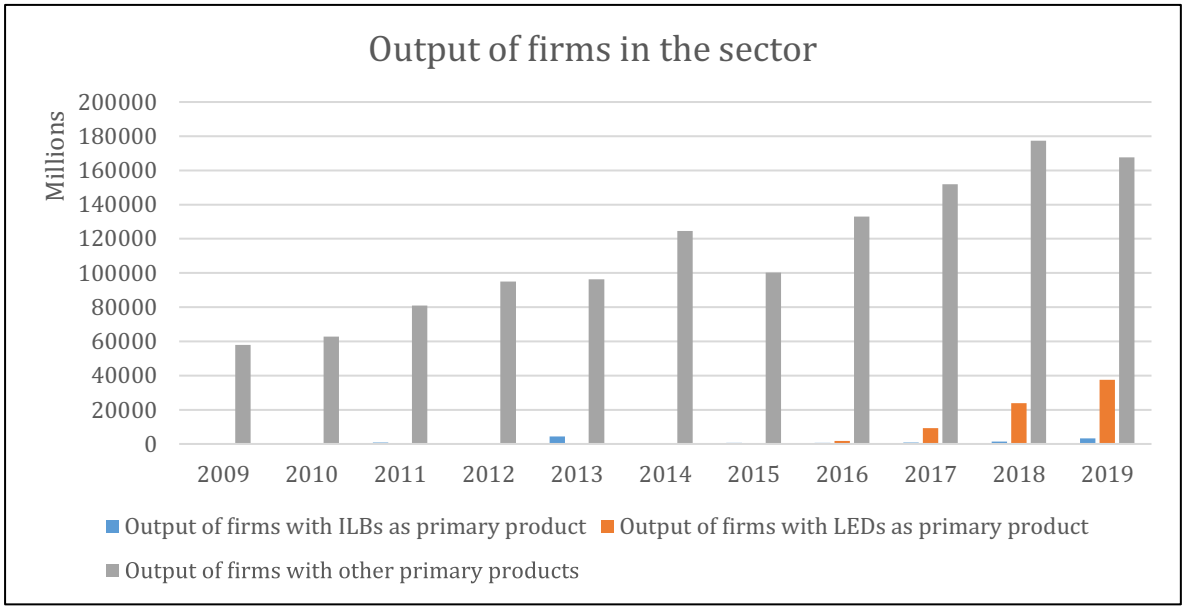

Fig. A.5. Comparing incandescent lamps (ILBs) with LEDs in terms of industry output (Author's calculation).

The impact of the transition on the number of jobs is also an important consideration. The total number of jobs offered by the sector showed constant growth after 2015 (Fig. A.6). The comparison of the average number of jobs per factory shows that the factories producing LED lamps had an increasing share of jobs created in recent years over factories producing incandescent lamps and other accessories (Fig. A.7).

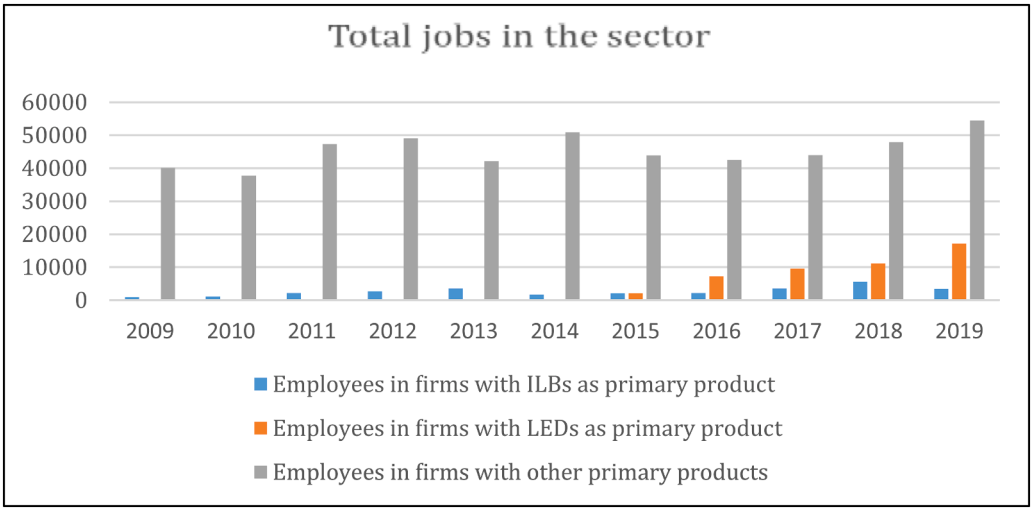

Fig. A.6. Total number of jobs in the sector (Author's calculation).

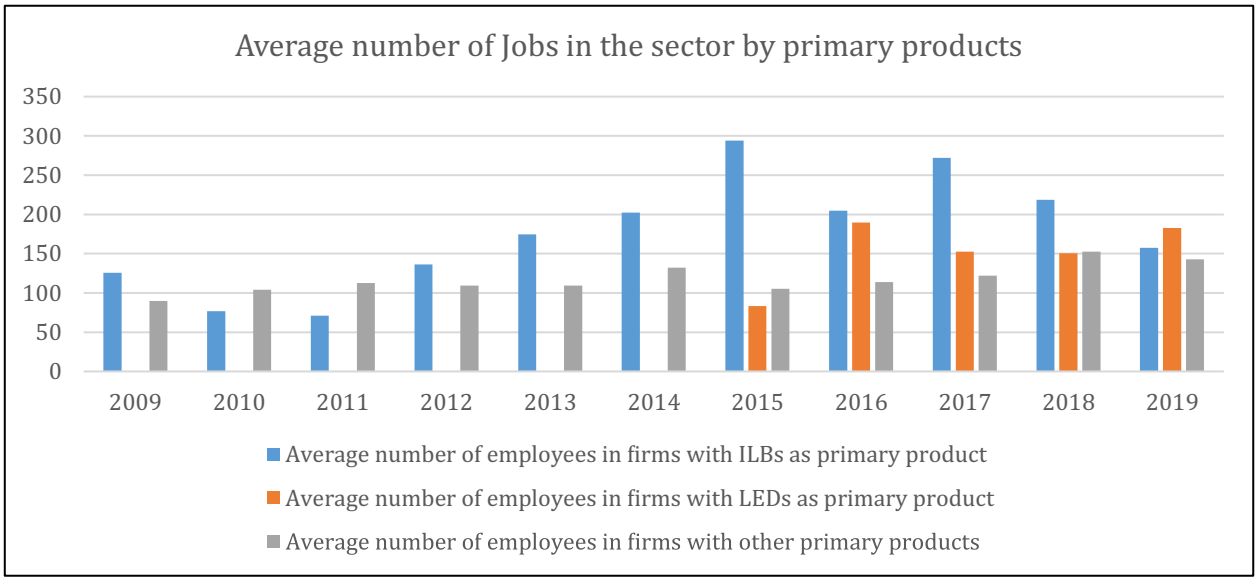

Fig. A.7. Average number of jobs per factory as per their primary products (Author's calculation).

The key argument here is that incandescent lamps were not the primary product of firms in the electric lighting manufacturing sector. The data on capital investments and jobs also reflects that the sector had less to lose and more to gain from the transition. Hence, there were weaknesses in the system that could have made it easy for niche technologies to infiltrate the supply side, as the manufacturing of LEDs could have helped them grow, as evident from the data after 2015.

A.3. Niche

The history of LED lamps traces back to the early discovery of electroluminescence in 1907 [89], but the focus here is on recent visible LED developments. Texas Instruments patented and commercially sold LED lights to IBM in 1962, followed by red LEDs for indicators in 1968 at Hewlett-Packard and Monsanto in the US [90]. Nichia Corporation supported Shuji Nakamura, who invented high-brightness blue LEDs in 1993 [91].

Early LEDs lacked the brightness required for lighting but found utility as indicator lights, decorations, traffic signals and displays due to their colour options and efficiency. Later, during the late 1990s, companies in the USA and Japan and, in the early 2000s, South Korea and China shifted focus towards developing LED replacements for conventional light bulbs [92]. The US government, notably through the Department of Energy (DOE), actively promoted innovation by introducing the Bright Tomorrow Lighting Prize (L Prize) competition in 2008. This aimed to encourage manufacturers to create more efficient and effective LED lamps compared to existing products, offering both cash and non-cash incentives. The National Institute of Standards and Technology in the US also contributed by issuing LED product standards and testing methods in the same year [93].

Philips Lighting diverted its resources and R&D efforts from compact fluorescent lamps to LEDs (solid-state lighting) in 2008 [94]. In the same year, Ushio, a Japanese firm, launched the first LED filament lamp, which resembled the classic Edison light bulb but had shortcomings related to thermal dissipation and faulty flux geometry [95].

In pursuit of LED alternatives to traditional lamps, early demonstration projects emerged. Sentry Equipment, with the support of CREE (a LED manufacturer based out of the US), illuminated its outdoor spaces using LEDs in 2008 [96]. Likewise, in India, iGATE, an IT company, adopted LEDs

for office lighting in 2009 [97]. The US Department of Energy promoted LED adoption based on outdoor public lighting pilot projects, enhancing awareness of LED applications [92,98].

Competing in the L-prize, Philips Lighting submitted its LED lamp as a replacement to the standard traditional Edison incandescent lamp in 2009 and went on to win the L-prize for its lamp in 2011 [99]. The competition advanced technology by 3 to 5 years, and the developments led to mass-scale production in countries like China and Taiwan, bringing down the cost of LEDs [100]. The average price of LED lamps fell from approximately USD 50 in 2011 to less than USD 30 in 2015 [51].

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