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OVERVIEW

Assessment of energy-efficient appliances: A review of the technologies and policies in India's residential sector

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The promotion of energy efficiency has been at the forefront of the energy policy agenda. New technological inventions and increasing environmental concerns related to contemporary energy policy are the main drivers of the adoption of more energy-efficient appliances in domestic sector. Additionally, the mandatory star labeling program and incentive design mechanisms are also raising awareness and motivation for their use, thus contributing to the reduction of energy consumption and greenhouse gas emissions. Sustainable energy policies generally pursue programs aiming for energy efficiency among domestic appliances. In India there are currently nine domestic electrical appliances/end-uses certified with star labeling programs, in particular lighting sources, refrigerators, air conditioners, water heaters, televisions, computers, washing machines, ceiling fans, and water pumps. This study reviews main issues affecting selection of energy-efficient technologies in India's domestic sector highlighting the main challenges impacting design of energy efficiency policies and programs in the country.

This article is categorized under:

Energy and Climate > Economics and Policy

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KEYWORDS

appliances, energy consumption, energy efficiency, market transformation, standards and labeling

1 | INTRODUCTION

Energy performance on a global scale depends on several factors such as energy supply, energy demand, and market transformation (MT) (Jefferson, 2016). Therefore, the implementation of energy efficiency measures (EEM) in commercial and residential sectors plays a prominent role in the reduction of energy demand, further contributing to reduce global warming (Sorrell, 2015). According to an International Energy Agency (IEA) report, 71% of the world greenhouse gas (GHG) emission reduction would come from energy efficiency improvements by 2020 and 38% by 2050 (Ryan & Campbell, 2012). Energy efficiency is recognized as a key strategy to tackle three energy-related challenges—climate change, energy security, and economic development—at the least cost to society (Bukarica & Tomšić, 2017). Additionally, the policies promoting energy efficiency in the household sector are significantly and positively related to energy-efficient innovations introduced in the building sector and lighting technologies, particularly among the developing countries of the Asia-Pacific region (Girod, Stucki, & Woerter, 2017). Furthermore, developing countries face critical energy security issues due to their fast economic growth inherently supported by an increasing demand for energy (Rasul & Sharma, 2016). In fact, in 2014, India's domestic sectors consumed about 45% of primary energy (TERI, 2014). In the domestic sector, energy is primarily used for electrical equipment/appliances, lighting, and cooking, (Drysdale, Wu, & Jenkins, 2015).

The first studies aimed at estimating the potential energy savings obtainable with the use of more efficient refrigerators and air conditioning systems in India's households were published by (CMIE, 2000; Letschert, McNeil, Zhou, & Sathaye, 2009; Murthy, Sumithra, & Reddy, 2001; TERI, 2006). The Lawrence Berkeley National Laboratory (LBNL) also published a report on the assessment of the potential energy efficiency improvements of India's residential sector. However, the type of analysis therein presented accounted for the energy savings potential in the residential sector as a whole rather than per appliance or end-use. In another study conducted by the LBNL projections were issued regarding the required energy efficiency improvements in India's residential sector to cope with the residential electricity demand in the future (Mundaca, Neij, Worrell, & McNeil, 2010). The World Bank (2008) estimated the ownership rate of various electrical appliances in India's residential sector based on the projected income. In a study prepared by the LBNL, several strategies were also discussed for attaining low carbon growth in India's industry and nonresidential sectors. Since then, few publications arose in the scientific literature trying to estimate ownership rates for selected appliances, particularly addressing air conditioner systems (McNeil, Iyer, Meyers, Letschert, & McMahon, 2008), electric fans, television (TV), and refrigerators (Rathi, Chunekar, & Kadav, 2012).

More recently, the India's Low Carbon Strategy for Inclusive Growth highlights the importance of the potential energy savings achievable with the use of energy-efficient appliances (Planning Commission Government of India, 2014). According to the Standards and Labeling (S&L) scheme recognized by the Bureau of Energy Efficiency (BEE) of the Government of India there are 10 of 21 types of star-rated appliances used in households.

In an environment of rapid economic growth with high urbanization rates, the growing India's middle class pursues higher comfort levels through the purchase of a large number of appliances (Bhattacharyya, 2014). Therefore, the consequent rise in energy consumption and GHG emissions can be significantly mitigated if consumers are motivated and made aware of the different options that the market has to offer regarding the panoply of energy-efficient technologies (EET) available (Parikh & Parikh, 2016).

In this context, this study provides an updated and systematic review which aims at contributing to the discussion of the main challenges ahead regarding the design of energy efficiency policies in India. In Section 2, a brief overview of the current energy consumption patterns in India will be presented. Section 3 provides a brief overview of the technological characteristics of the appliances/end-uses typically used in India's residential sector. Section 4 describes the specific features of these appliances and end-uses. Section 5 reviews some dimensions of the energy efficiency governance framework in India. Section 6 discusses the most important cobenefits associated to the use of energy-efficient appliances. Section 7 addresses the MT overarching framework regarding energy efficiency. Section 8 is foremost dedicated to the energy efficiency market barriers. Finally, some conclusions are drawn that can contribute to the discussion and design of energy efficiency policies and programs in India.

2 | ELECTRICITY CONSUMPTION PATTERNS IN INDIA

Energy is the basic building block of economic development (Ghosh, 2002). Energy consumption plays an important role in growth and development processes as it facilitates production and improves household welfare (Karekezi, 2002). Final energy consumption is usually allocated to three main activity sectors: industry, transport, and "others"—including agriculture, services, and the residential sector (Pérez-Lombard, Ortiz, & Pout, 2008). The share of the residential sector electricity consumption in India reached about 24% in 2016–2017 (Central Electricity Authority [CEA], 2017). Therefore, after industry, which accounts for 40.1% of the total electricity consumed in India, the residential sector is the second biggest energy consumer. Figure 1 highlights the contrasting electricity consumption patterns in different sectors from 2011 to 2017 (CEA, 2017). Electricity consumption in the residential sector has been increasing 2.20% per year while in the industrial sector it has been decreasing about 2.24% over the last 5 years.

In 2014, the countries with the highest share of electricity consumption in the residential sector were the United States (36.88%), France (36.46%), and the United Kingdom (36.12%)—Table 1. In developed countries, the energy consumption shares in the residential sector reach 20–37% of the total energy use while in BRICS (Brazil, Russia, India, China, and South Africa) these values range between 15 and 25% of total electricity consumption in the residential sector (Ministry of Power, 2015).

3 | TECHNOLOGICAL CHARACTERISTICS OF APPLIANCES/END-USES

India is rapidly transforming into an urban country, but small towns and farming communities still make up the clear majority of its population. A government's survey shows that the spending patterns of India's population in cities and villages are fast converging, as rural households now pay for most goods and services usually associated with urban lifestyles (Malik, 2016).

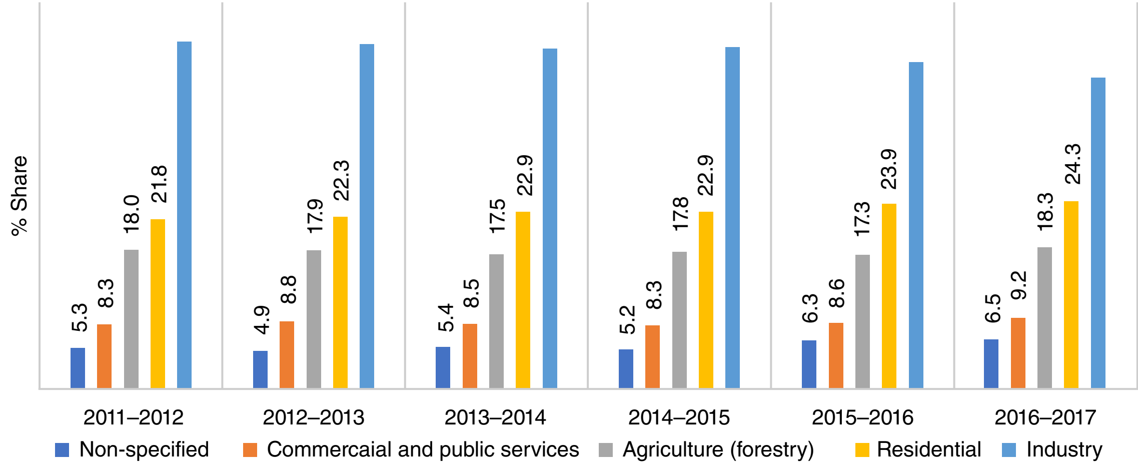

FIGURE 1 Share of electricity consumption by activity sectors from 2011 to 2017 in India

The steady increase of technological innovation has had significant repercussions on the electrical appliances available on the market. In order to promote the reduction of energy consumption of appliances in the residential sector it is necessary to foster the investment on highly efficient appliances (Goetzler, Sutherland, & Foley, 2014). In the next subsections, we present a thorough description of the main end-use appliances that may be found in India's residential sector.

3.1 | Room air conditioners

Room or window air conditioners cool limited areas rather than the complete building. If cooling is provided only where it is needed, room air conditioners (RACs) are less expensive to operate than central units, despite the fact that their efficiency is generally lower than that of central air conditioners (RAC, 2016). The businesses and residences of India use both window-mounted and split air-conditioning units. Historically, window units have conquered the market, and most of air conditioners were sold to businesses. Since 2008, the BEE presented a plan for progressively improving the efficiency of room air conditioning and promoting the MT toward better energy efficiency standards. In 2016, the S&L program has had a positive impact on the market penetration of energy-efficient air conditioners, with the sales of five star-rated systems reaching a share of 34% (Sundarmoorthy & Walia, 2017). Finally, it is worth mentioning that the BEE has also adjusted the standards for certifying the star-rating of these devices in such a way that the five star label rating obtained in 2010 became only three star label rating in 2015 and will become one star in 2018 according to the new India's Seasonal Energy Efficiency Ratio (ISEER) methodology (Ministry of Power, 2016).

TABLE 1 Electricity consumption per country in 2014

Country	Nonspecified, %	Agriculture (forestry), %	Commercial and public services, %	Residential, %	Transportation, %	Industry, %
Australia	0	1.11	29.11	29.64	1.95	38.20
Canada	0	1.82	29.49	30.49	0.84	37.36
France	0.36	1.84	32.11	36.46	2.86	26.34
Germany	0	0	28.62	26.05	2.30	43.02
Italy	0	1.96	30.42	23.41	3.63	40.55
Japan	0.75	0.10	36.10	31.14	2.02	29.90
Korea	0	1.99	31.69	13.27	0.47	52.06
United Kingdom	0	1.22	30.57	36.12	1.29	30.8
United States	3.89	0.83	35.52	36.88	0.18	22.7
South Africa	1.69	2.90	14.30	19.68	1.94	59.5
Brazil	0	4.92	25.29	24.88	0.59	44.32
Republic of China	7.63	2.45	5.92	15.06	1.26	67.68
Russian Federation	0	2.06	21.87	17.86	12.43	45.74
European Union-27	0.30	1.58	30.21	29.62	2.29	35.98
India (2014–2015)	5.20	17.81	8.26	22.92	1.71	44.11
World	4.07	2.84	22.06	26.99	1.53	42.52

3.2 | Ceiling fans

Ceiling fans (CF) are the most common electrical appliances after electric lighting in India's households and offices, and nevertheless, they have been rarely mentioned in the discussions of energy efficiency concerns (Singh, Sant, & Chunekar, 2010). In 2017, CF consumed about 20% of the electricity in India's households, and their numbers are increasing rapidly (Balasubramanian, 2017). The production of CF in India is about 40 million units per year, which, in 2010 (the most recent data known to the authors), corresponded to 28 million units in terms of annual sales just for India (Singh et al., 2010).The Bureau of Indian Standards (BIS) is responsible for specifying the minimum performance requirements for CF. Most of the chief brands also have energy saving models which consume at around 35 W (Balasubramanian, 2017). In 2016, the positive impacts of the S&L program can be seen in the sales of CF, which corresponded to nearly 100% of five star products (Sundarmoorthy & Walia, 2017).

3.3 | Lighting

In 2015, lighting was also a major energy consumer, representing roughly 20% of electricity consumption in India (IEA, 2015). There is a significant technical potential to reduce energy consumption from electric lighting with high efficient lamps, light control systems, and improved building designs (IEA, 2013). Much higher improvements are possible with gas discharge lamps, typically fluorescent lamps (FL), and with solid-state light-emitting diode (LED). FL are low-pressure gas discharge light sources, producing light mainly by fluorescent powders which get activated by ultraviolet radiation created by discharges in mercury (Halonen, Tetri, & Bhusal, 2010). The lighting appliance stock data from Electric Lamp and Component Manufacturers Association of India (ELCOMA) estimated that, in 2014, there were about 780 million incandescent bulbs (IL), 234 million FL, and 453 million compact FL (CFL) (ELCOMA, 2014).

In the building sector, both tubular fluorescent lamp (TFL) and CFL are the most commonly used lighting sources, with the latter gaining an increased popularity due to a sharp price drop in the past and to its similarity with IL (Mandil, 2006). Over the last decades, many governments have passed measures to replace conventional IL with CFL, as they only require around one-quarter to one-third of electricity to produce the same amount of visible light (IEA, 2013). Additionally, although LED lighting technology only represented 1% of the market share in 2013 it represented 70% in 2017 (ELCOMA, 2017). In fact, LED lighting technology may lead to 75% of energy savings (National Electrical Manufacturers Association (USA) [NEMA], 2014) and longer life spans than IL (Nardelli, Deuschle, de Azevedo, Pessoa, & Ghisi, 2017). Nevertheless, a major market barrier for CFL and LED is their higher initial costs in comparison to IL, although they are normally more economical on a life cycle basis, because of their lower energy consumption and longer lifetimes (Lefèvre, De T'serclaes, & Waide, 2006). Other market barriers are lack of consumer awareness and distrust of consumers in the technology, as CFL had at the beginning of its commercialization some quality and suitability issues to overcome (Letschert, Bojda, Ke, Mcneil, & Lawrence, 2012).

3.4 | Refrigeration

Refrigeration appliances can be categorized into four groups: refrigerator/freezer combinations, refrigerators only, refrigerators with freezer compartments, and freezers only (Letschert et al., 2012). The technologies across the different categories have very similar operation modes, which are typically based on an electrically driven vapor compression refrigeration cycle (BijliBachao, 2017). There are two main product groups for residential refrigerators in India: single-door direct cool (manual defrost) and two-door frost-free. Traditionally, direct cool units have taken over the market, but frost-free units are gaining importance. Several low-cost technologies for refrigeration appliances are available to improve their energy efficiency. The LBNL assessed a cost-effective approach for accomplishing the reduction of energy consumption in this type of electrical devices from 4 to 71% through the enhancement of its design just by including thicker insulation, increasing the surface area of evaporators and condensers, and incorporating higher efficiency compressors, thermostatic controls, vacuum insulation pumps (VIP), and optimized capillary tube characteristics (Letschert et al., 2012; Shah, Park, Bojda, McNeil, & Waide, 2014). In 2016, the sales of 5-star refrigeration appliances in India had a share of 25%, while the 4-star represented 10%, the 1- and 2-star corresponded to 18% and the 3-star attained 29%, respectively (Sundarmoorthy & Walia, 2017).

3.5 | Televisions

A rapid improvement of energy efficiency in TV happened in the last decade (e.g., cathode-ray tube [CRT] to liquid crystal display [LCD] and cold-cathode FL backlit LCD [CCFL-LCD] to LED backlit LCD [LED-LCD]), although simultaneously with an expected increase of penetration in households, especially in emerging economies, as well as the anticipated increase of the average screen size of the TV sets purchased (Park, Phadke, Shah, & Letschert, 2011). The market transition regards the replacement of cold CCFL backlit LCD TV with higher efficient LED backlit LCD TV. The well-known progressive shift from analogue to digital TV as well as the improvement of energy efficiency standards increased world-wide (Park et al., 2011). Plasma TV have a small portion of sales and are mainly present in the market for large screen sizes (Chunekar & Singh, 2013). Screen sizes and time of use have considerable impacts on annual electricity consumption. For instance, a growth in the diagonal's screen size of 40% leads to a 60% increase in electricity consumption (IEA, 2010a). In 2016, the share of 2-star TV sales in India was 55%, while 4- and 3-star corresponded to a share of 20% and only 5% were attained for 1-star TV sales (Sundarmoorthy & Walia, 2017).

3.6 | Water heaters

Water heaters are major energy consumers both in the residential and the commercial sectors. Conventional storage water heaters and instantaneous water heaters remain the most popular types of water heating systems for homes and buildings (Department of Energy, 2017). A storage water heater operates by releasing hot water from the top of the tank when a hot water tap is turned on. To replace that hot water, cold water enters the bottom of the tank, ensuring that the tank is always full (IEA, 2013). However, instantaneous water heaters produce hot water on demand using a gas burner or electric heating coil. Thus, instantaneous water heaters tend to have higher energy efficiencies by eliminating standby heat losses associated with a tank and often substantially reducing pipe losses (Maguire, Fang, & Wilson, 2013). Gas water heaters have normally lower rated energy efficiencies than electric ones, due to the combustion efficiency of gas and higher tank losses. However, these can represent an overall higher energy efficiency considering the energy source used, since there are no intermediary energy conversions to electricity when gas is directly burned to obtain heat. Condensing water heaters improve the energy efficiency of storage and instantaneous gas water heaters by about 10–30% capturing the latent heat of the combustion gas before it exits (Lekov, Franco, Wong-Parodi, McMahon, & Chan, 2010).

In India, the BEE labeling scheme for this sort of equipment has been in place for several years and it was voluntary until July 2015 (AEEE, 2015). Currently, however, there are mandatory labels for storage electric water heaters which consider a star rating system based on the standing (heat/energy) losses (kWh/24 hr/45°C difference) calculated according to IS 2082:1993. In this context, water heaters are categorized in 10 different rated capacities ranging from 6 to 200 L (Collaborative Labelling and Appliance Standards Program [CLASP], 2015).

3.7 | Electric water pump motors

In India, pumps are used in the domestic, industrial, and agriculture sectors. India's agriculture sector is the largest user of pumps, for several applications such as irrigation and water distribution; in the industrial and domestic sectors, pumps are used for water supply, sewage, and chemical supply.

The BEE has included the electric water pump sets in the voluntary labeling scheme. Most of the national manufacturers consider the star labeling program is an appropriate approach to save electricity (Engineerlive, 2013). A study by Shakti Foundation has shown that the market shares of pumps by end-users, are 30% for domestic, 35% for industrial, and 35% for the agriculture sector with an estimated total motor manufacturing growth of 22% between 2009 and 2014 (SSEF, 2012). India's household water pumps lie between a rated output of 0.37–2.2 kW (Padmavathi & Daniel, 2011). The star labeling rating of electric motors by the BEE is categorized in accordance with the International Electrotechnical Commission (IEC) standards. The motors lie between the ranges of IE1 and IE3 standard with an operating efficiency of 69–90% for all 2-pole, 4-, and 6-pole motors. Around one-third of the energy savings potential for electric motors is observed in motors ranging from 0.75 to 4 kW (U.S. Department of Energy, 2013). IEC has concentrated on single-speed, three-phase, 50 and 60 Hz AC squirrel-cage induction motors in the range 0.75–375 kW in its published standard IEC 60034-30:2008 and reviewed by IEC 60034-30-1:2014 (AAB, 2014).

3.8 | Computers

The Environmental Protection Agency (EPA) started a system of energy star rating in July of 2009 to classify computers, laptops, and tablets based on their yearly electricity consumption (Energy Star, 2009). The standards were set so that only 25% of the most efficient computers made the cut. This made sure that the energy star classified computers were 30% more efficient than the nonclassified ones. The Computer Specification, version 5.0 (2009), classification suggested by EPA is given below: Category A: ≤148.0 kWh; Category B: ≤175.0 kWh; Category C: ≤209.0 kWh; and Category D: ≤234.0 kWh. The BEE has extended the application of this energy star rating system to India for computers and laptops (Bijli Bachao, 2016).

3.9 | Washing machines

Although not mandatory, the BEE always recommends the purchase of 5-star-rated washing machine (WM) devices. The BEE labeling system of energy-efficient WM depends on the size and front load or top load and water efficiency (Cleaning Institute, 2010). WM in India are broadly classified into two categories: semi-automatic and fully automatic. WM with a lower capacity range from 5 to 9 kg. However, the capacity of fully automatic WM varies from 6 to 11 kg, going up to 17 kg in some brands (Aggarwal & Singh Rana, 2016).

4 | SPECIFIC FEATURES OF APPLIANCES/END-USES

Over the last two decades, the ownership rate of electrical appliances has increased substantially both in rural and urban households due to the rise of the income level (NITI Aayog, 2016; Thomas, Tholen, Rasch, & Hafiz, 2015). The market of electronic appliances in India has been growing consistently mainly due to affordable prices, constant technological innovations and intense competition.

In the next subsections, the distinct features of each appliance under consideration will be presented.

4.1 | Lifetime

The lifetime mainly depends on the operating hours (e.g., TFL usually are assumed to last 20,000 hr, under the assumption of daily use of 4 hr, which corresponds to an average lifetime of 14 years). In spite of longer lifetimes achieved by technological advancements, these are being overshadowed by fast consumption trends (Cravioto, Yasunaga, & Yamasue, 2017). The lifetime also depends on the consumption behaviors and on the socioeconomic characteristics of households (e.g., a household with many members will have a more intensive use of a WM) (Matsumoto, 2016). Table 2 presents the average lifetime of several appliances typically used in India's households.

4.2 | Operating time

India can be divided into five different climatic regions, that is, hot and dry, warm and humid, composite, temperate, and cold (BEE, 2007). Hence, the operating time of appliances differs according to each climatic region. The operating time is usually calculated based on the power of the devices (*W*), on the frequency of use, and on the average regional climatic conditions and average working days (e.g., on average, CF are used 8 hr/day and for about 200 days/year). Table 3 depicts the operating time of the main appliances typically used in India's households based on available literature (Boegle et al., 2007; TERI, 2006; World Bank, 2008). The discrepancy of data presented in Table 3 regarding the appliances' operating time can be attributed to several differences among the targets of the reported studies, namely the family size, the geographical regions as well as differences between rural and urban households.

5 | AN OVERVIEW OF ENERGY EFFICIENCY GOVERNANCE IN INDIA

According to IEA (2010b), "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." Therefore, energy efficiency governance should cover a broad set of aspects

TABLE 2 Lifetime of the main appliances typically used in India's households

Appliance/End-use	Lifetime in years	References
TFL	14[a]	ATD Homeinspection (2010)
EG	15	Department of Energy (2017)
TV	10	Kalmykova, Patrício, Rosado, and Berg (2015))
CF	15	ATD Homeinspection (2010); Franco, Shaker, Kalubi, and Hostettler (2017)
FR	15	ATD Homeinspection (2010); Cooper, Skelton, Moynihan, and Allwood (2014)
RAC	10	ATD Homeinspection (2010); Wan et al. (2011)
WM	15	ATD Homeinspection (2010); Bressanelli, Perona, and Saccani (2017)
COM	5	ATD Homeinspection (2010)
WEP	15	Haque, Islam, Islam, Haniu, and Akhter (2017)

[a] In the residential sector a use of 4 h/day is assumed.

TABLE 3 Operating time of the main appliances typically used in India's households

	TERI (2006)		McNeil, Iyer, Meyers, Letschert, and McMahon (2005)		CMIE (2000)		Murthy et al. (2001)		Boegle, Singh, and Sant (2007)		World Bank (2008)		Singh, Martins, and Henriques (2016)	
Appliance/End-use	**hr/day**	**days**	**hr/day**	**days**	**hr/day**	**days**	**hr/day**	**days**	**hr/day**	**days**	**hr/day**	**days**	**hr/day**	**days**
TFL									6	365	2.5	365	4	365
FR	24	365	24	365	24	365	24	365			24	365	24	365
TV	3	365			3	350	3.6–3.9	365	6	365	4	365	6	365
RAC	8	120	4	180	4	120	1	365	6	120	2	365	6	180
CF	10	225			6	200	4.6–6.6	365	8	200	7	365	8	200
EG	1	150		2	250	1	365	1	200	0.4	365	0.5	200	
WM	1	200		1	350	1	365	1	250	1	365	1	365	
COM		3	250	3	365	4	350							
WEP				1.5	365									

related to institutional, human, financial, and political dimensions (Pereira & Da Silva, 2017). In the next sections, a brief description will be provided regarding several dimensions of energy efficiency governance in India.

5.1 | A brief overview of the energy efficiency governance structure in India

Figure 2 depicts India's energy efficiency governance structure. In India, the BEE is the major institutional body aimed at developing, implementing, and monitoring energy efficiency policies. The National Institution for Transforming India (NITI), previously known as the Planning Commission, is also largely responsible for governing the energy policy landscape in the country. In 2010, the Government of India created the Energy Efficiency Services Limited (EESL), the world largest public energy saving company (ESCO) which also acts as the resource center for capacity building for electricity distribution companies as well as financial institutions such as the India Infrastructure Finance Company Ltd (IIFCL), the Export–Import Bank of India (EXIM Bank), the Small Industries Development Bank of India (SIDBI), and the National Housing Bank (NHB) which, in one way or the other, provide funding to energy efficiency projects.

5.2 | Energy efficiency strategies and action plans

In 2008, the National Action Plan on Climate Change (NAPCC) in India was launched and it identified a number of measures that simultaneously advanced the country's development and climate change-related objectives of adaptation and mitigation (Government of India, 2008; Kumar, 2013).

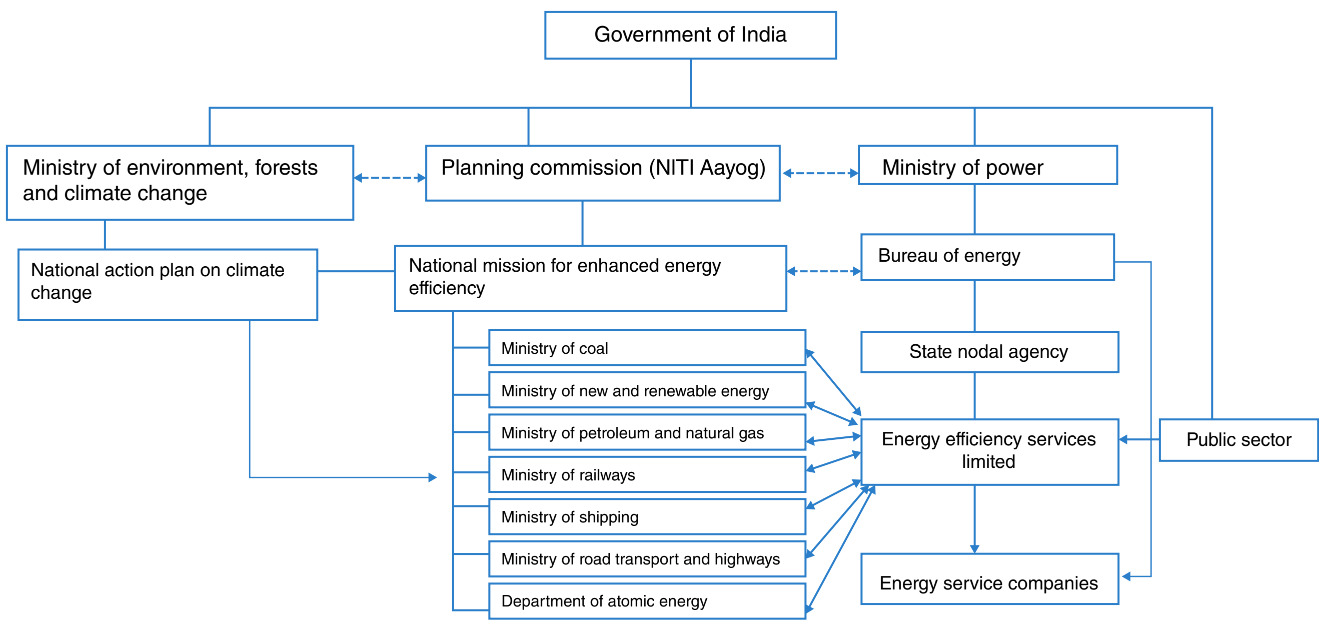

FIGURE 2 India's energy efficiency governance structure

The National Mission for Enhanced Energy Efficiency (NMEEE) is one of the eight missions under the NAPCC. The NMEEE aims to strengthen the energy efficiency market by creating regulatory and policy regimes and envisages to foster innovative and sustainable business models for the energy efficiency sector (BEE, 2012). In this framework, four initiatives were adopted to enhance energy efficiency in energy intensive industries as follows:

1. The *Perform Achieve and Trade Scheme (PAT)*, which is a market-based mechanism to enhance the cost effectiveness in improving the energy efficiency in energy intensive industries through certification of energy saving which can be traded.
2. *Market Transformation for Energy Efficiency (MTEE)*, for accelerating the shift to energy-efficient appliances in designated sectors through innovative measures to make the products more affordable.
3. An *Energy Efficiency Financing Platform (EEFP)*, for the creation of mechanisms that would help finance demand side management program in all sectors by capturing future energy savings.
4. A *Framework for Energy-Efficient Economic Development (FEEED)*, for the development of fiscal instruments to promote energy efficiency.

United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty adopted in 1992 committed to the reduction of GHG emissions toward the implementation of the Kyoto Protocol. About 192 countries participated in the UNFCCC framework and have defined national action plans. The first countries responsible for the formulation of national strategies aimed at reducing the energy consumption were the United States (1992), Australia (1998), and the United Kingdom (1999). Table 4 displays examples of some of the earliest national energy efficiency strategies and action plans adopted in various countries.

The effectiveness of the energy efficiency strategy and of the adopted action plans in India can be seen on several aspects:

- The government of India has put forward a set of intertwined legislative instruments to improve the EE of the country. One example is the 2001 Energy Conservation (EC) Act which includes instruments such as Designated Consumers, S&L of Appliances, and the Energy Conservation Building Codes. It also created the BEE, in charge of implementing the EC Act, as well as the Energy Conservation Fund, as a complete set of instruments aiming at reducing the energy intensity of India's economy.
- There has been also a specialized action toward specific activity sectors, issuing standards and guidelines, of which the Energy Conservation Building Codes is an example, as well as the cases of Demand-Side Management (DSM) in agriculture, energy efficiency improvement in municipal water pumping and in domestic lighting.
- Following the EC Act, the 2003 Electricity Act aims at efficient use of energy and energy savings through EET and DSM in various activity sectors.

TABLE 4 Examples of some energy efficiency strategies and action plans

Country	Strategy	Year	Reference
Australia	Energy Efficiency Best Practice programme	1998	CPD (2015)
Brazil	National Plan on Climate Change	2008	CPD (2015)
China	National Climate Change Programme	2007	CPD (2015)
Canada	Action Plan on Climate Change	2009	IEA (2010b)
European Union	Efficiency Action Plan	2007	IEA (2010b)
France	National Energy Efficiency Action Plan	2008	IEA (2010b)
Hungary	National Energy Efficiency Action Plan	2008	IEA (2010b)
Indonesia	Master Plan on National Energy Conservation	2010	IEA (2010b)
India	National Plan on Climate Change	2008	CPD (2015)
Italy	Climate Change Action Plan	2007	CPD (2015)
Japan	New National Energy Policy	2006	IEA (2010b)
Korea	Low Carbon Green Growth Strategy	2009	IEA (2010b)
New Zealand	Energy Efficiency and Conservation Strategy	2007	IEA (2010b)
Singapore	National Climate Change Strategy	2008	IEA (2010b)
South Africa	Energy Efficiency Strategy	2004	IEA (2010b)
Ukraine	Energy Strategy to 2030	2009	IEA (2010b)
United Kingdom	Energy-Efficiency Label (Energy Star)	1999	CPD (2015)
United States	ENERGY STAR-labeled Products	1992	CPD (2015)
Russia	Energy Efficiency Labeling Russia	2011	CPD (2015)

- An example of an awareness raising program is the national scheme designated Bachat Lamp Yojana (BLY), also known as “Save lamp schemes” for promoting energy-efficient and high-quality CFLs as a replacement for incandescent bulbs in households. The BLY scheme successfully registered under UNFCCC-Executive Board on April 29, 2010 under the Clean Development Mechanism (CDM) of the Kyoto Protocol to reduce GHGs from power plants connected to the grid.
- In 2006, India adopted an integrated energy policy which became a comprehensive National policy in 2012. This integrated policy approach will explore alternative technologies and possible synergies to increase energy systems efficiency while meeting appropriate requirement for energy services.

5.3 | Standard and labeling programs in India

Over the last decades, there has been an increasing recognition of the importance of energy efficiency in India's energy policy agenda which resulted in an Energy Conservation Act in 2001 and in an Electricity Act in 2003. One of the energy efficiency initiatives specifically targeting energy-efficient appliances in India was launched by the Minister of Power on May 18, 2006 consisting of the adoption of an S&L scheme. Later on, the BEE incorporated the USEPA's energy star rating system into India's S&L scheme, considering both mandatory and voluntary labeling. The scheme contemplated 21 types of technologies (BEE, 2006, 2009) and raised awareness regarding the energy performance of the appliances available on the market, with the least and most energy-efficient appliances being rated with 1–5 stars, respectively (Parikh & Parikh, 2016).

The star labeling scheme combines comparative star labels according to minimum energy performance standards (MEPS) (Abhyankar, Shah, Letschert, & Phadke, 2017). There are two types of labels which are depicted in Figure 3: (a) small labels which are assigned to small household appliances—that is, tube lights, computers, laptops, CF, and TV; and (b) big labels for the other type of appliances—that is, WM, refrigerators, RACs, and electric geysers. The timeline for the implementation of the S&L program in India is illustrated in Figure 4. In Table 5, it is possible to see the appliances subject to mandatory/voluntary labeling schemes and without any labeling schemes. State and central electricity regulatory commissions (ERC) are also involved in energy efficiency improvement initiatives. In this framework, ERC are only targeting lighting, RAC and CF in Maharashtra and Delhi (Singh, Sant, & Chunekar, 2012). Table 6 presents the type of labeling schemes that are being adopted in other countries.

The S&L program was introduced by the central Government to moderate energy demand growth in the residential sectors. The implementation of an S&L scheme is under the responsibility of the BEE, the Ministry of Power, the BIS, consumers associations, manufacturers associations, and the National Accreditation Board for Testing and Calibration Laboratories (NABL) (Jairaj, Agarwal, Parthasarathy, & Martin, 2016). The standard setting process is led by committees established by the BEE (Figure 5). Energy labeling usually starts with a voluntary stage requiring a minimum energy performance but in due

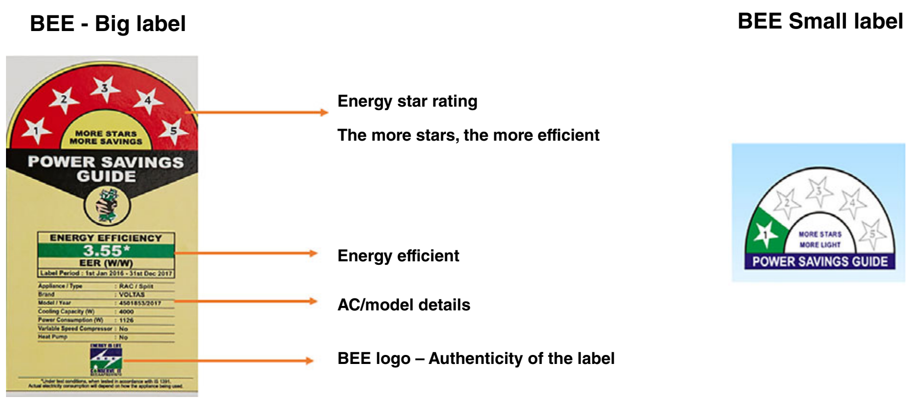

FIGURE 3 BEE label for appliances

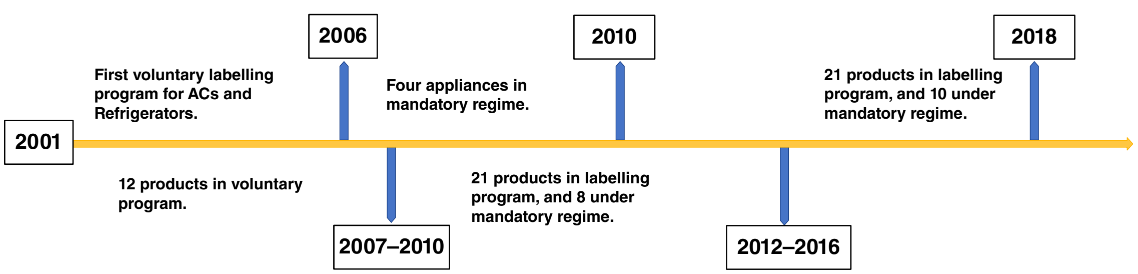

FIGURE 4 Timeline for the S&L program in India

TABLE 5 Appliances/End-use technologies with and without labeling schemes in the residential sector (India)

With energy label scheme	Without energy label scheme
Tubular fluorescent lamps (TFL)	Tape recorder, CD player
Refrigerator (FR)	Radio
Television (TV)	Air cooler
Room air conditioner (RAC)	Room heater
Ceiling fan (CF)	Set-top box
Electric water heating (EG)	DVD players
Washing machine (WM)	Electric oven
Computer (COM)	Incandescent bulb
Cooking stove LPG	Compact fluorescent lamp (CFL)
Water electric pump (WEP)	Toaster

time it is expected that these will become mandatory (BEE, 2006). Although there is lack of additional information or explanation regarding the transition of energy labels from voluntary to mandatory, the process of labeling transition is generally reviewed every 2 years. Table 7 displays the chronogram with the major energy efficiency initiatives and policies specifically addressing the appliances typically used in India's households.

6 | MARKET TRANSFORMATION AND ENERGY EFFICIENCY

Energy efficiency improvement is a rather complex phenomenon, which is affected by the decisions of different actors: manufacturers, retailers, consumers, professional consultants, and so on. Although energy efficiency is economically sustainable in that investments are repaid in a few years, the measures actually taken to improve energy efficiency in general, and electricity end-use in particular, are far less than strict economic judgment would justify: this is partly because the relevant decision making is dispersed between different actors (Bertoldi, 1999). In the context of energy efficiency, MT is a process whereby energy-efficiency innovation are stimulated and over time penetrate a large portion of the eligible market.

According to American Council for an Energy-Efficient Economy (ACEEE), “the term market transformation refers to the strategic process of intervening in a market to create lasting change in market behavior by removing identified barriers or exploiting opportunities to accelerate the adoption of all cost-effective energy efficiency as a matter of standard practice” (Vaidya, Vasudevan, & Cherail, 1996).

The technological diffusion of energy efficiency generally follows an S curve (De La Rue Du Can, Leventis, Phadke, & Gopal, 2014; Rogers, 1963). With the foregoing in mind, a double S curve is proposed in Figure 6 that illustrates the influence of the process of MT on the rate of penetration of energy-efficient appliances.

At the first early adoption stages, while innovation takes place and the maturity of the technology is not reached, the market penetration is less intense. Subsequently, the mass adoption stage of energy-efficient appliances is achieved due to incentive designed programs**.** Finally, after establishing the effective implementation of the last stage, the adoption rates start increasing in a steadier manner. Overcoming the gap between the business as usual and the best available technology options requires a process of MT.

MT depends on incentive designed programs which increase demand, and thus market penetration, of early stage highly efficient technologies. The mass increase of demand of such technologies leads to economies of scale for the manufacturers and positive learning effects, streamlining production processes and decreasing the costs of production (De La Rue Du Can et al., 2014).

Because of its inherent characteristics, in the case of India, attaining an effective MT mechanism is particularly important. Specifically, technology development can create a market demand and market demand also can accelerate the development of technology innovation processes. The first relationship is usually designated technology push and the second is usually designated demand-pull (Choi, 2017; Nemet, 2009; Peters, Schneider, Griesshaber, & Hoffmann, 2012). Technology-push favoring policies help decreasing the production cost (private cost) of innovative products—for instance, by mean of targeted R&D funding support. Demand-pull policies increase the private payoff of successful innovation through several possible mechanisms: intellectual property protection, tax credits and rebates for consumers of new technologies, government procurement, technology mandates, regulatory standards, and taxes on competing technologies (Girod et al., 2017). The Unant Jyoti by affordable LEDs for all (UJALA) program is one example of both demand-pull and technology-push policy. Under this program, 295 million LED lights were sold, bringing the price per light down from around USD $5 to less than $1 per light bulb in 2016 (CLASP, 2017).

TABLE 6 Appliances/End-use technologies with mandatory and voluntary labeling schemes in other countries (July 2016)

Appliance/End-use	Australia (Department of Environment and Energy, 2016)	Canada (Government of Canada, 2017)	Japan (Global Ecolabelling Network, 2017)	Korea (Corporation, 2017)	United Kingdom (Energy Saving Trust, 2017)	United states (Energy Star, 2017)	South Africa (Global Ecolabelling Network, 2017)	Brazil (National Electricity Conservation Program, 2017)	Peoples Republic of China (Global Ecolabelling Network, 2017)	Russian Federation[a] (Global Ecolabelling Network, 2017)	EU-27 (EU Energy Star, 2017)	India (BEE, 2015)
TFL	M	V	M	M	M	M	U	M	M	U	M	M
EG	n.a.	V	n.a.	M	M	M	U	M	V	M	M	M
TV	M	V	U	M	M	M	U	M	M	M	M	M
CF	n.a.	V	n.a.	M	M	M	n.a.	M	V	U	M	V
FR	M	M	M	M	M	M	V	M	M	M	M	M
RAC	M	M	V	M	M	M	U	M	M	n.a.	M	M
WM	M	V	V	M	M	M	U	M	V	M	M	V
COM	U	V	V	M	M	M	n.a.	M	V	n.a.	M	V
WEP	V	V	U	M	M	M	U	M	V	n.a.	M	V

M, mandatory label; V, voluntary label; U, under development
[a] Russian Federation adopted an energy label scheme in 2013–2014.

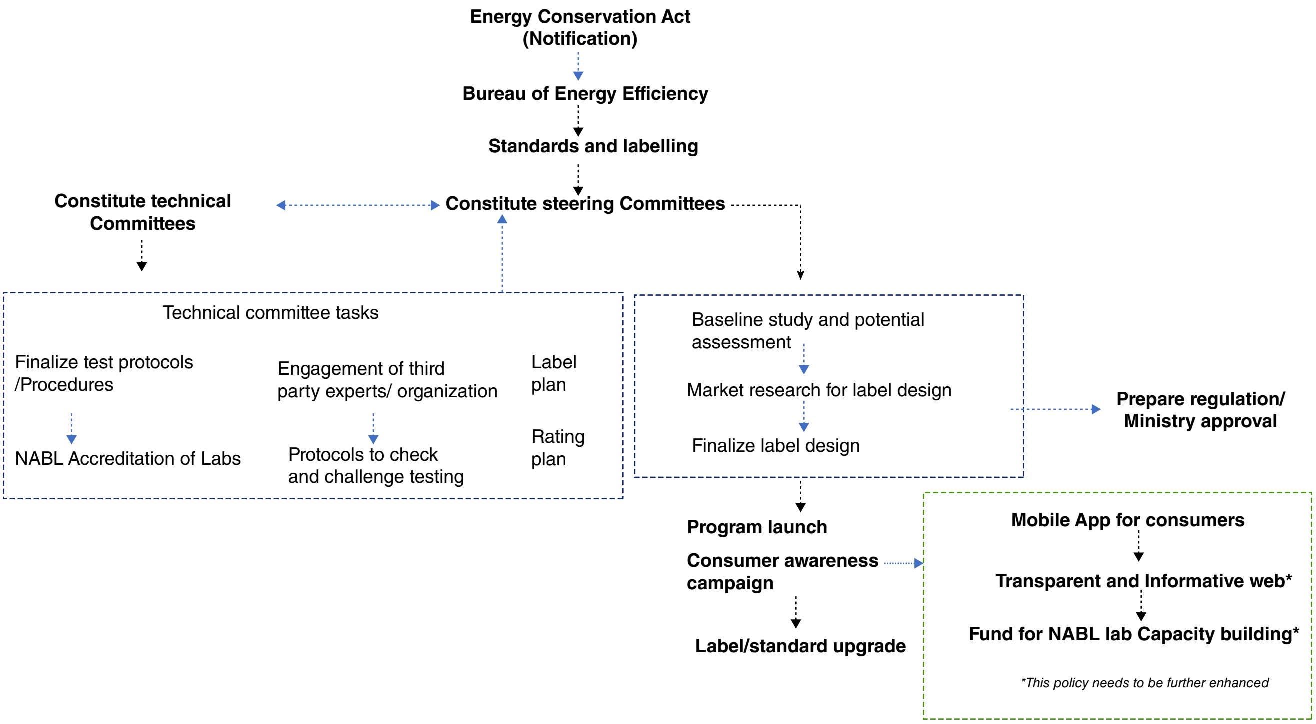

FIGURE 5 S&L program process (adapted from Jairaj et al., 2016 and Sundarmoorthy & Walia, 2017)

7 | CO-BENEFITS OBTAINED WITH THE USE OF ENERGY-EFFICIENT APPLIANCES

Energy efficiency can bring multiple benefits, such as enhancing the sustainability of the energy system, supporting strategic objectives for economic and social development, promoting environmental goals, and increasing prosperity (International Energy Agency, 2014; Ryan & Campbell, 2012). Besides being a cost-effective driver for attaining reduced energy consumption, the adoption of energy conservation measures (ECM) also allows achieving additional "cobenefits" (Thomas et al.,

TABLE 7 Energy efficiency initiatives and policies specifically addressing the appliances typically used in India's households

Program	Year	Scope	Observations
Energy Conservation Act	2001	National policy to promote energy efficiency	Launched by the government by the Ministry of Power and BEE. Information available at: https://www.beeindia.gov.in/
Electricity act	2003	National policy	Involves the participation of the private sector
Standard and Labelling Scheme (S&L)	2006	Mandatory labeling / Voluntary labeling	Is aimed at reducing the energy consumption of appliances without diminishing the services it provides to consumers
National Action Plan for Climate Change (NAPCC)	2008	Represents a long-term and integrated approach for achieving key goals in the context of climate change	National Solar Mission, National Mission for Enhanced Energy Efficiency, National Mission on Sustainable Habitat, National Water Mission, National Mission for Sustaining the Himalayan Ecosystem, National Mission for a Green India, National Mission for Sustainable Agriculture, National Mission on Strategic Knowledge for Climate Change. Information available at: http://www.moef.nic.in/ccd-napcc
Bachat Lamp Yojana (BLY)	2009	Part of the Clean Development Mechanism (CDM) program implementation	The BLY CDM Programme of Activities (PoA) registered under the auspices of the UNFCCC on the 29th of April of 2010. It involved 50 small-scale BLY projects from various parts of India but only 44 projects have been implemented. As a result, about 29 million CFLs have been distributed during the XI plan period
Super-Efficient Equipment Program (SEEP)	2013	Market Transformation for Energy Efficiency (MTEE)	Ceiling fans have been considered under this program
Energy-Efficient Lighting Programme	2014	A case study in Pondicherry	Domestic efficient lighting program
Domestic Efficient Lighting Program (DELP)	January 2015	Replacing the BLY	302 million lamps sold in the country (July 5, 2018). Information available at: http://www.ujala.gov.in/
Unant Jyoti by affordable LEDs for all (UJALA)	May 15	National program which established at target for replacing 770 million incandescent bulbs in India with LEDs by 2019	

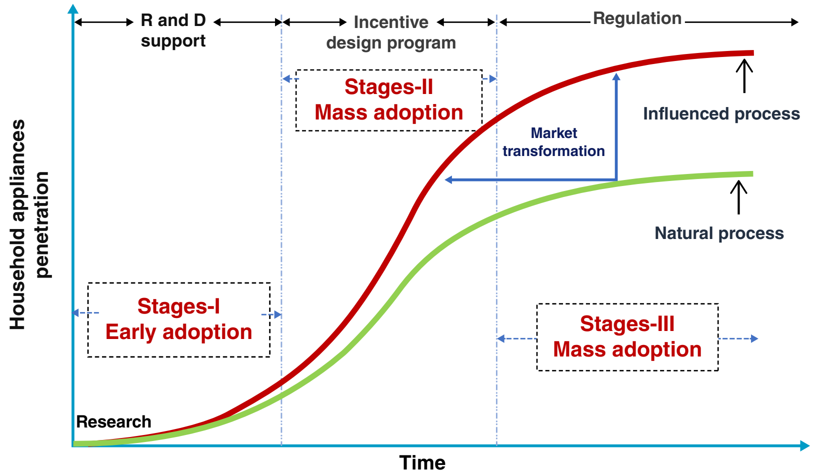

FIGURE 6 Double S curve illustrating the market transformation effect

2015). The reduction of the energy bill for households might be regarded as the main investor's direct motivation for purchasing energy-efficient appliances, but there are also other cobenefits. Figure 7 illustrates the major cobenefits obtained as a result of investing in energy-efficient appliances. In what concerns society, poverty alleviation might be expected due to the increase of disposal income with the reduction of the energy bill. However, with the rise of disposable income, private household's consumption also increases leading to a positive impact on gross domestic product and thus on national economy. The reduction of energy demand increases energy security and reduces GHG emissions during manufacturing and energy production phases contributing to positive environmental outcomes. The expected improvement of air quality and of indoor comfort levels with energy-efficient appliances reduces respiratory diseases, among other, having a positive impact on health.

8 | BARRIERS TO THE ADOPTION OF ENERGY-EFFICIENT APPLIANCES

8.1 | Global barriers

The term energy efficiency barrier refers to a mechanism that inhibits a decision or behavior that appears to be efficient both economically and from an energy point of view (Makridou, 2016). Barriers can either complicate the adoption of cost-

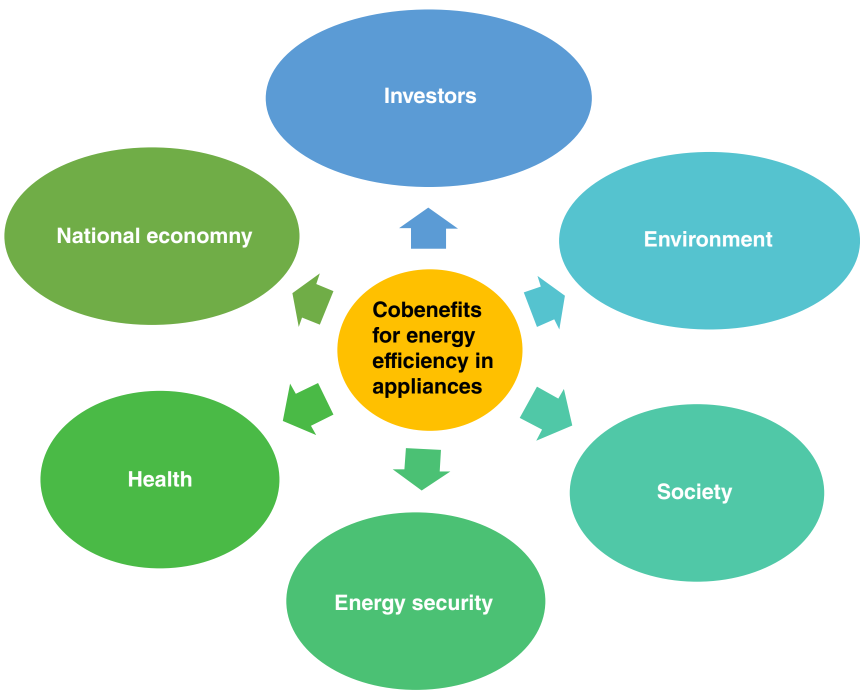

FIGURE 7 Cobenefits of the adoption of energy-efficient appliances (adapted from Thomas et al., 2015)

TABLE 8 Examples of barriers (adapted from International Energy Agency, 2010)

Barrier	Examples
Market	• Market organization and price distortions prevent customers from appraising the true value of energy efficiency • Split incentive problems created when investors cannot capture the benefits of improved efficiency
Financial	• Up-front costs and dispersed benefits discourage investors • Perception of energy efficiency investments as complicated and risky • Lack of awareness of financial benefits on the part of financial institutions
Information and awareness	• Lack of information and understanding to make rational consumption and investment decisions on the part of consumers
Regulatory and institutional	• Energy tariffs that discourage energy efficiency investment • Incentive structures encourage energy providers to sell energy rather than invest in cost-effective energy efficiency • Institutional bias toward supply-side investments
Technical	• Lack of affordable energy-efficient technologies suitable to local conditions • Insufficient capacity to identify, develop and implement and maintain EE investments

effective energy efficiency technologies or slow down their diffusion. Some examples of these barriers are high investment cost, lack of financing mechanisms in the field, lack of awareness, cost of production and risk of disruption—Table 8. There are many proposals to categorize these barriers, which can be divided in two groups (Makridou, 2016): structural (distortion in fuel prices, uncertainty about the future, or government policies) and behavioral barriers (like the perceived risk of energy efficiency investments, lack of information or lack of life-cycle thinking on the costs and savings). Other possible classifications were proposed by Eric Hirst (1990), Lohani & Azimi (1992), Reddy (1991), and Steve Nadel (1994)).

The possible categorization herein followed was proposed by Steve Nadel (1994) and identifies six market barriers (Golove & Eto, 1996).

8.1.1 | Misplaced incentives

Misplaced incentives are those incentives that do not actually benefit the person who is trying to adopt improved EEM, the majority being related to the residential sector (Rohdin & Thollander, 2006; Schleich, 2004; Schleich & Gruber, 2008). For example, if a renter decides about the energy use and pays the bills while the owner decides about the installed equipment (and chooses the cheapest alternative) the most cost-efficient combination will probably not be chosen.

8.1.2 | Lack of access to financing

This type of barrier is related with up-front costs and the corresponding lack of liquidity, namely for low-income individuals or small business owners (Hrovatin, Dol Sak, & Zori, 2016; Nagesha & Balachandra, 2006; Sorrell, 2004; Sorrell, 2015; Trianni, Cagno, Thollander, & Backlund, 2013). Moreover, there is a lack of awareness of the financial benefits associated to this type of investments on the part of financial institutions, preventing the access to capital for small investors. Finally, the perception of energy-efficient investments as complicated and risky might also subsist.

8.1.3 | Flaws in the market structure

A typical market failure is related to the fact that the existence of powerful firms might impair the arrival of other competitors supplying other EET, eventually more cost-effective (Chai & Yeo, 2012; Hrovatin et al., 2016; Schleich, 2009; Schleich & Gruber, 2008; Trianni et al., 2013).

8.1.4 | Mispricing imposed by regulation

This market barrier refers to the fact that energy regulated prices might discourage the adoption of EEM (Rohdin & Thollander, 2006; Schleich, 2004).

8.1.5 | Lack of information or misinformation

Sometimes the consumers are not well informed and do not understand how to make rational consumption and investment decisions (Schleich, 2004).

8.1.6 | Lack of standard practice

The Global Environment Facility (GEF) and the CLASP were the main drivers of MT of energy efficiency technologies in developing countries. In fact, several financed energy efficiency programs took place in India by means of the GEF through the United Nations Development Programme (UNDP) and the CLASP. However, developing countries have particular barriers for MT and energy efficiency (Birner & Martinot, 2005), namely: few experiences on fostering energy efficiency, through the use of market-based schemes and informational issues as awareness raising; absence of standard practices regarding programs for the adoption of EEM; lack of data; lack of regulation and organization with local governments and the

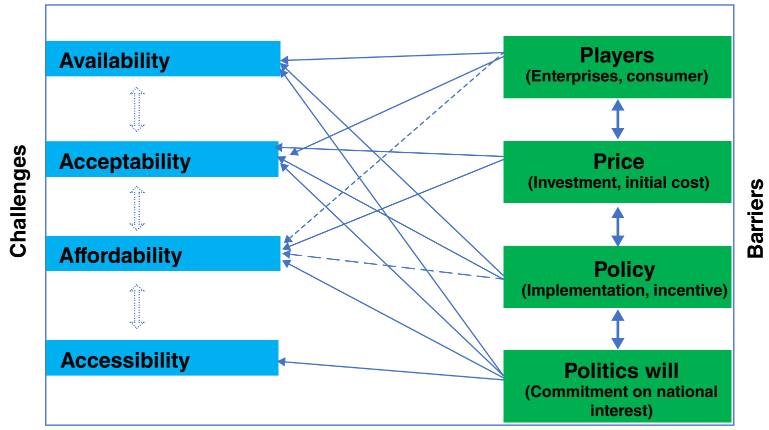

FIGURE 8 Energy-efficient technology challenges and barriers

private sector to foster energy efficiency; incipient energy efficiency markets for high EET; lack of government-based policy instruments; lack of governance capacity aiming for energy efficiency markets.

8.2 | India's national barriers

The adoption of energy-efficient appliances has faced different barriers in India's residential sector. The main barriers are the high initial cost of efficient technology and the lack of awareness or lack of interest of consumers. Heterogeneity of consumers also plays a role, since middle class families live mainly in urban areas while low income families live mainly in rural areas. The 4P's major barriers identified in this paper are: Players, Price, Policy, and Political will. They need to be addressed to create an effect of energy efficiency governance by policymakers (see Figure 8). The first of the four Ps stands for player. A player is any business oriented enterprise committed to ensure the supply of some energy-efficient product to the market to fulfill some consumers' need. The second P refers to the price barrier. Traditional, not efficient products are usually available on the market at much lower prices than efficient ones, since established manufacturers resist to make the investments needed to adapt their production lines. The third P stands for policy. India is still lacking an effective national policy plan to promote energy-efficient appliances in the residential sector. Multiple ministries related to energy issues cause a high complexity of the state government involvement, often obstructing institutional coordination for coherent central policy making.

India is a democratic country where political leaders are capable of influencing the decision making process. Political will is also important to government investment and implementation processes, which cannot occur without a strong commitment of political leaders.

9 | CONCLUSIONS

In this study, a review is presented of energy-efficient end-use appliance technologies and energy efficiency policy initiatives across national level for India's residential sector, based on literature research. Some of the main conclusions are drawn:

- India's residential sector shows higher energy consumption than in other developing countries, almost reaching the share of some developed countries like Germany and Italy (23–26% approx.)
- India's S&L scheme has been implemented during the last decades, considering both mandatory and voluntary labeling schemes, contemplating 21 types of technologies, of which only nine (only five mandatory) electrical end-use appliances in the residential sector.
- S&L, BLY, Super-Efficient Equipment Program (SEEP), Domestic Efficient Lighting Program (DELP), and UJALA energy efficiency initiatives and policies specifically address the appliances typically used in India's households. However, we found that utility program BLY and the second program DELP is expanding the Unant Jyoti program by affordable LEDs for all (UJALA). Both utility programs are based on lighting technologies. India is still lacking other large-scale policies beyond the S&L scheme.
- Energy-efficient appliances can bring multiple cobenefits, such as enhancing investment, alleviating energy poverty due to the increase of disposal income from the reduction of energy bills, causing a positive impact on the national economy. Reduction in energy demand also improves environmental impacts by reducing GHG emissions, with a positive impact on health.

- A double S curve representation is used to illustrate the effect of MT programs on the acceleration of the diffusion of efficient appliances on the market.
- Barrier types are identified that prevent the adoption of energy-efficient appliances, namely, financial, technical, related to information and awareness, or to regulatory and institutional incentives, or to market structure.
- International Agencies like UNDP, GEF, and CLASP should focus on some pilot case studies in real households.
- Since energy efficiency and energy security have a prominent role on the economic and social development of all countries, it is crucial to incorporate energy efficiency concerns in any economic program (UNFCCC, 2010).
- Therefore, developing countries like India need to promote EEM. In this context, energy self-sufficiency plays a critical role in the economic/social development and prosperity of these countries. Energy initiatives are directly associated with general political options related to tariff incentives, social cohesion, national alliances, and bilateral commercial agreements. At the same time, energy efficiency planning should include several aspects, such as energy saving targets, instruments to promote innovative technologies development and diffusion.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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