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DRIVERS FOR ENERGY TRANSITION IN INDIAN CITIES

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Abstract
Cities account for about 75% of global primary energy use and 70% of energy related greenhouse gas (GHG) emissions (IRENA, 2021); a substantial increase since 2013, when the world's urban areas accounted for about 64% of global primary energy use (IEA, 2016). Indian cities, home to about 35% of the country's population, consume about 70% of the total energy consumed in the country resulting in consequent emissions (Hari Krishnan et al, 2021). Of the 50 most polluted cities in the world, 39 are in India (World Air Quality Report, 2022). Hence, Energy Transition (ET), through uptake of low carbon energy efficient (EE) and renewable energy (RE) technologies in cities in India as well as across the globe is very crucial. Although successful case studies of ET in cities worldwide are witnessed in recent years, the journey requires various enablers to push and hasten deployment of the energy efficient technologies. In this context, this paper examines the different drivers that will lead to an accelerated ET in Indian cities.

Design/methodology/approach – A survey of three hundred and twelve energy sector experts from forty relevant national and international entities (government, private sector, energy experts, NGO, media, legal professionals, think tanks and citizens) are carried out. After satisfying all the necessary reliability tests of the information collected through the survey, the data is subjected to the Principal Component Analysis (PCA) to determine the critical enablers for faster ET in Indian cities.

Findings – The results indicate that there are nine clusters of drivers to push and promote ET in Indian cities. They are: i) formulation of an ET Accelerating Cell, ii) Sectoral & Municipal Actions, iii) Financial Instruments, iv) Pilot Experimental Projects v) Awareness Building/ Environmental Consciousness, vi) Technology Innovation, vii) Service & Repair Facilities, viii) International Mandates and ix) Local Champions & Stakeholder Coordination.

Practical implications – Reducing energy consumption and consequent carbon footprints by shifting to energy efficient options is extremely urgent in Indian cities. This study offers relevant directions for the policy makers and other stakeholders for the same thereby

achieving ET.

Keywords: Energy Transition, Cities, Energy Efficiency (EE), Renewable Energy (RE)

1. Introduction

Global energy consumption recorded a 5% growth in 2021, after a 4.5% decline in 2020 (due to the global pandemic). In 2021, India was the third highest energy consuming country in the world, preceded by USA and China (Figure 1). Coal is a major source of energy in both China and India. Amongst the various continents, energy consumption in Asia has been growing at a very high rate in the last thirty years (Figure 2).

Cities consume a major share of the global energy. They are innately centers of human, economic and intellectual capital, and increasingly contributing to the growing energy demand around the world (Ram et al, 2022). In 2013, the world's urban areas accounted for about 53% of global population and 64% of global primary energy use (IEA, 2016). By 2021, share of urban population grew further to 56. 5% who accounted for about 75% of global primary energy use and 70% of energy related greenhouse gas (GHG) emissions (IRENA, 2021). World's urbanization rate is projected to be 68% by 2050 (UNCTAD, 2022). Hence, with increasing urbanization rate and subsequent expansion of urban economic activities, energy consumption by cities will continue to surge resulting in increased GHG emissions (Odugbesan et al, 2020).

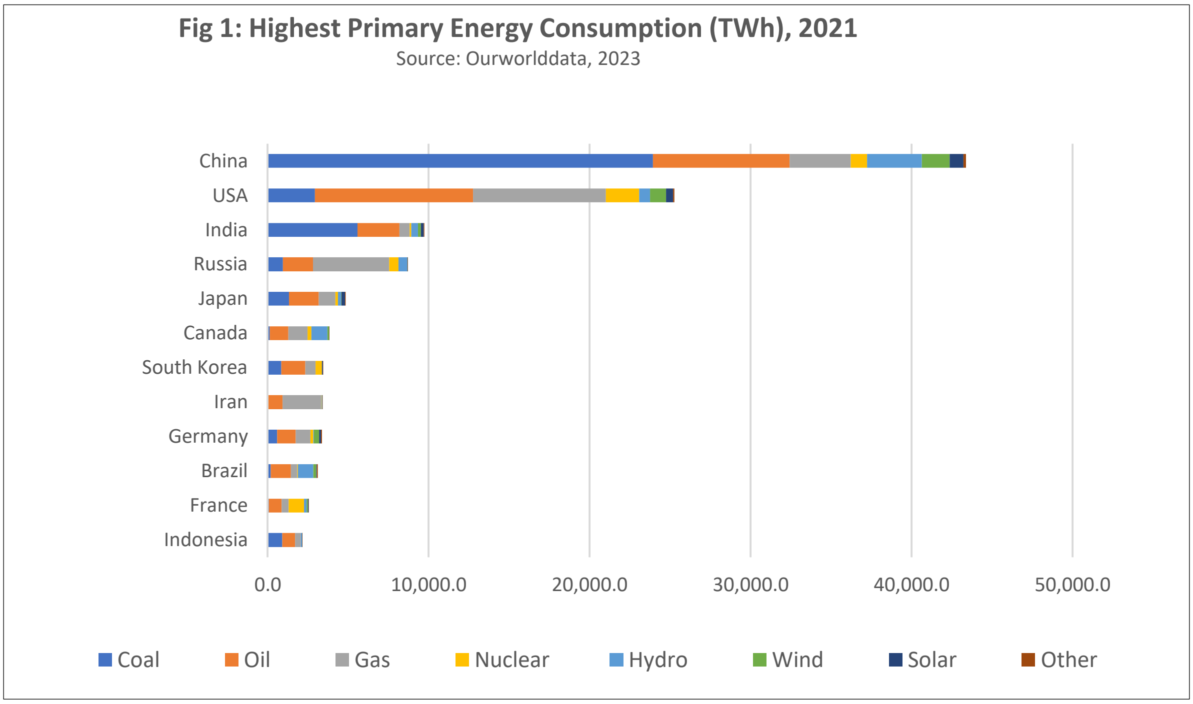
However, earth's capacity to absorb the GHG emissions is already exhausted. Under the Paris Climate Agreement (2015), countries and cities across the globe have pledged to reduce the energy and carbon intensity of their economies by 2040 – 2050 (Intended Nationally Determined Contributions (INDCs)). India intensified its 2015 INDCs further and announced during COP26 (held in Glasgow, 2021) to become net zero by 2070 (MoEFa, 2022). This will only be possible through an accelerated global energy transition (ET) away from fossil fuels to low carbon energy efficient (EE) and renewable energy (RE) technologies.

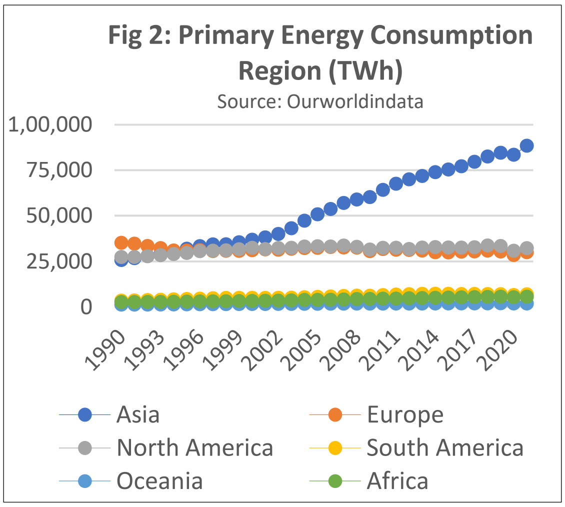
Within Asia, population and economic growth in China and India in the past fifteen years strongly pushed up their energy demand, which was met mostly by greater fossil fuel use, alongside progress in renewables deployment and energy efficiency efforts (IEA, 2019). The need for a transition from an unsustainable energy system (from social, economic, and environmental perspective), to a sustainable one is widely recognized (Grubler, 2012). This is even more compelling in urban areas, where the phenomenon of rapid urbanization poses multiple challenges (DESA, 2018).

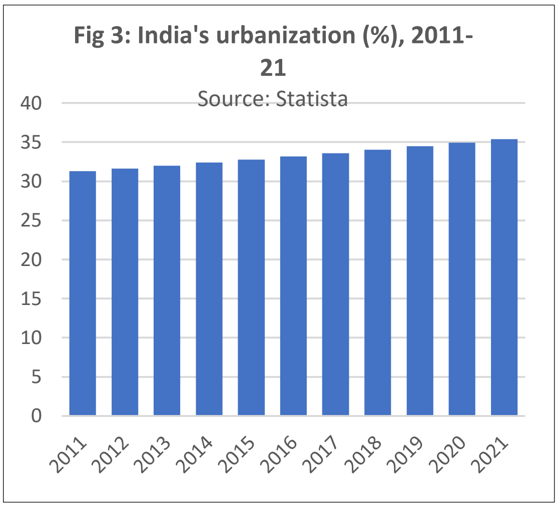
India's urbanization trend shows an increase by almost 4% in the last decade (Statista, 2023) (Figure 3). In 2021, approximately 498 million (about one third of the Indian population) (Macrotrends, 2023) lived in cities who were responsible for about 70% of the country's total energy consumption (Hari Krishnan et al, 2021). By 2035, India's urban population is estimated to stand at 675 million (UN World Cities Report, 2022). This will result in consequent increase in energy consumption and harmful emissions in its cities. Thus, ET in Indian cities is extremely crucial and urgent. Several policies and measures are being undertaken to address this concern, nonetheless, EE & RE technologies need to be deployed at a speed higher than that of the energy consumption growth.

However, achieving faster ET is not a very easy task. It encompasses various factors, enormous initiatives, and coordinated actions by all relevant stakeholders. Identifying the vital and important enablers for faster adoption of low-carbon EE & RE technologies is imperative for an accelerated and successful ET.

In the recent past, researchers have explored various drivers of EE & RE technology deployment leading to a faster ET in cities, however, very few studies have analyzed them specifically in the urban context of developing countries (Inci et al, 2022, Palit et al, 2022). Hence, this study is undertaken to identify the key drivers for a successful and more rapid ET in Indian cities. The task is carried out through a questionnaire survey and Principal Component Analysis (PCA) method. This research is expected to facilitate policymakers and relevant stakeholders undertake measures leading to an accelerated ET in Indian cities thereby achieving increased energy savings and environmental benefits in the country.







2 Literature Review

2.1 Energy Consumption Trend in India

India's energy consumption has been increasing steadily (Figure 4), 70% of which is consumed by 35% of its people living in the cities (Hari Krishnan et al, 2021). Figure 5 shows the total primary energy demand (fuel wise) in India during 2000-2020. The share of traditional biomass has reduced over time and that of coal and renewables have increased. Coal, mainly used for electricity generation, is the country's top energy source with a share of 46%.

India's installed power generation capacity is about 416 GW (Ministry of Power, 2023) of which, 57% is fossil fuel, 41% is RE and 2% is nuclear (Figure 6). However, as seen in Figure 7, the share of RE in power generation grew from 17% in FY 2014-15 to only about 21% in FY 2021-22. As seen in Figure 8, the generation capacity, grid length, per capita demand and access to electricity, all are showing a growing trend indicating higher energy generation and consumption in coming years.

With the share of urban population growing to about 57.7% by 2050, there will be further implications on urban energy consumption patterns and subsequent GHG emissions (DESA, 2018). Indian cities will continue to account for a major share of the country's increasing energy consumption. Managing this energy footprint in an efficient manner along with reducing the adverse environmental effects have become one of the most challenging goals of the country.

Fig 4: India's Energy Consumption, 1990-2021

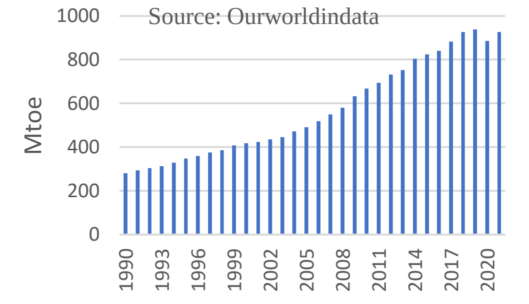


Fig 5: Primary Energy Demand, India, 2000-20 (Source: IEA, 2021)

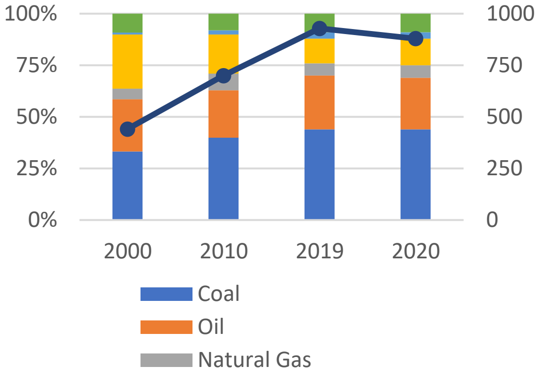


Fig 6: Installed Generation Capacity (416 GW) 31 Mar 2023 (Source: Ministry of Power)

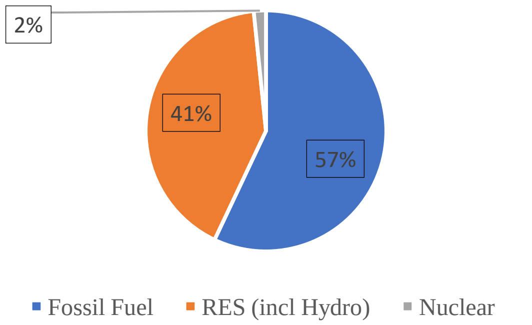


Fig 7: RE Share (%) in Power Generation (Source: Ministry of Power, 2023)

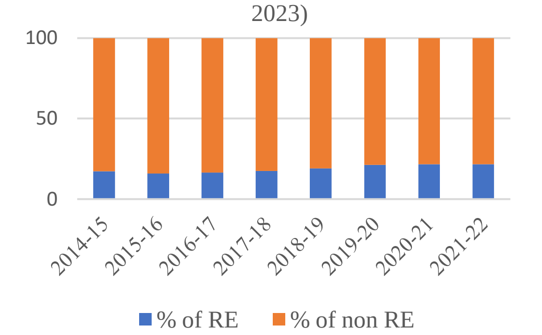
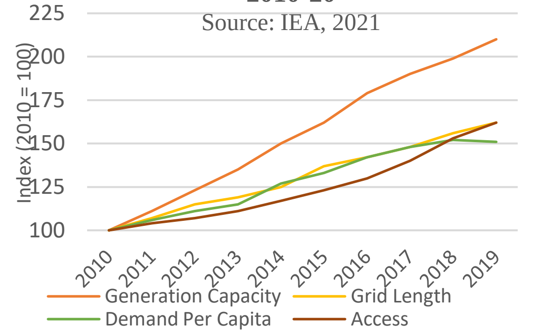


Fig 8: Electricity indicators, India, 2010-20



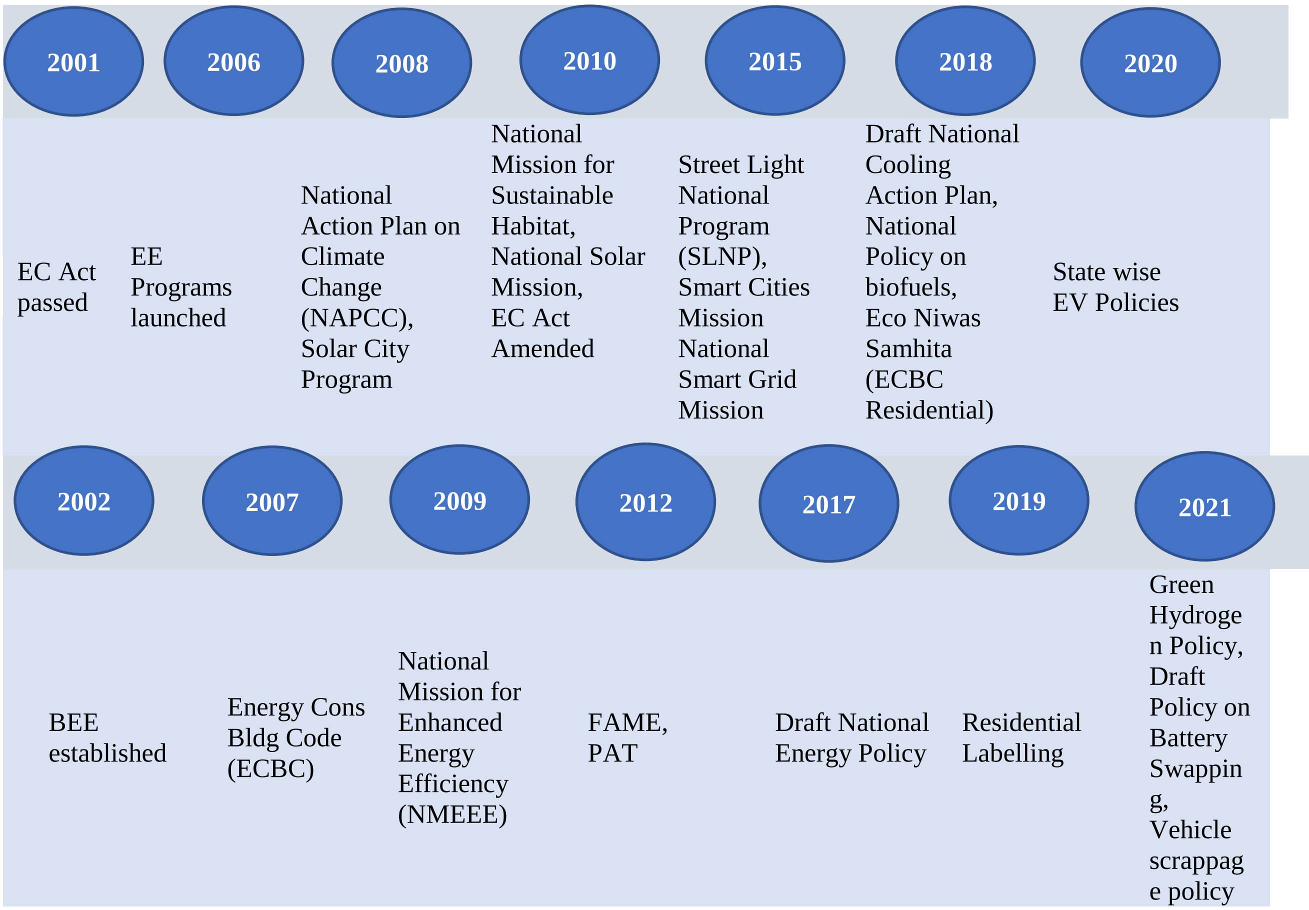
2.2 Energy Policy Landscape in India

In order to address the issues related to the growing energy demand in the country and considering that efficient use of energy and its conservation is the least-cost option to meet the increasing demand, Government of India (GoI) formulated the Energy Conservation Act, 2001 and established the Bureau of Energy Efficiency (BEE) in 2002 as a statutory body for enacting the same (BEE). The Act was revised in 2010 and under its umbrella, GoI has developed several policies and programs towards faster adoption of EE and RE technologies. On the energy demand side, a variety of innovative policy measures are introduced to improve energy efficiency. On the energy generation side, greater use of renewable energy, mainly solar and wind, is being promoted. Figure 9 presents the chronograph of key energy policies & programs, majorly those relevant for Urban India.

GoI articulated and put across the concerns of developing countries at the 26th session of the Conference of the Parties (COP26) to the United Nations Framework Convention on Climate Change (UNFCCC) held in Glasgow in 2021 (MoEFb, 2022). India presented the following five nectar elements *(Panchamrit)* of India's climate action:

- Reach 500 GW Non-fossil energy capacity by 2030
- 50% of its energy requirements from renewable energy by 2030
- Reduction of total projected carbon emissions by one billion tonnes from now to 2030
- Reduction of the carbon intensity of the economy by 45% by 2030, over 2005 levels
- Achieving the target of net zero emissions by 2070

Fig 9: Chronograph of Energy Policies in India



India's intent to meet the above have been reflected in their annual budgets too. One of the four priority areas in focus in Budget of 2022-23 was promoting technology-enabled development, energy transition and climate action. Budget 2023-24 focused on green growth. Both budgets had large financial allocations for priority investment towards energy transition and net-zero objectives (Union Budget FY 2022-2023, Union Budget 2023-2024), Ministry of Finance 2023).

However, in spite of climate friendly policies and proactive actions in the country, India is far from meeting its commitments of 500 GW of Non-fossil energy capacity and 50% of its energy requirements from renewable energy by 2030. As of March 2023, 178 GW of Non-fossil energy capacity have been set up and share of renewable energy in power generation is 21%. Hence, a hastened Energy Transition in the country is urgent and considering 70% of energy is consumed by the cities, they will have to play lead role in leapfrogging the transition.

2.3 Identification of the key drivers for successful ET in cities

A review of the literature available on various enablers for accelerating ET in urban areas indicate that it does not depend on any one factor; it is a mixed bag containing several drivers. Factors like favorable policies and actions by city authorities, experimental projects, knowledge sharing and a broad coalition of public and private actors is needed for faster ET implementation (WEFa, 2020).

Awareness building and close coordination between national and state/ local level with regard to implementing energy efficient actions in cities is key to faster ET. Policies at national level (like encouraging clean energy technologies, setting GHG emission reduction targets (like INDC), carbon pricing mechanisms, and investment in energy research) must be complemented through actions at city level (Valle et al, 2021, WEFb, 2020).

Policy regulations, city level target setting and implementation of energy efficient technologies in the energy, mobility, waste, water and built environment sectors in a city are enablers for ET. For example, towns like Aspen, Colorado, Burlington, Vermont in USA are already running entirely on renewable power. Cities like San Diego, California, aims to be 100% RE powered by 2035, and Vancouver, Canada, by 2050. Copenhagen and Denmark aim to be carbon neutral by 2025 (IEA, 2016, Bulkeley, 2019).

Technology drivers of innovation and experimentation with emerging efficient technologies (through pilot projects and documentation of findings) will address the energy challenges in cities (Loorbach et al, 2016; Mah et al, 2016). Technological maturity, it's market uptake potential, cost-effectiveness and stakeholders' responses from public, private and civil society sectors will drive its large-scale deployment (Broto et al, 2020). It will generate networks of actors, their capacity building through dissemination of learnings, its inclusion within policy and planning frameworks, and generating interventions 'at scale' will enable transitions to take place (Bulkeley, 2019).

Investment in clean energy sources (electric cars, electrolysers (to produce green hydrogen)) will ensure the most cost effective path to achieve net zero in the energy system (Ember, 2023).

Examples from China, Costa Rica, and Uganda show that despite limited access to financing and policy support, education and initiatives by city authorities have led to large-scale uptake of EE technologies. For example, in Kasese, Uganda, the municipality introduced a Sustainable Energy Strategy for promoting rooftop solar PV, which included attracting investments, training of households and small businesses, and awareness-raising activities. Subsequently, residents of Kasese embraced deployment of solar PV in their homes and the shift brought new economic opportunities as citizens saved money on electricity (IRENA, 2021).

From the available literature, various driving factors leading to ET in cities are identified and included in Table 1. It is observed that the various drivers identified for a faster ET can be broadly grouped under four categories – i) policy/ regulatory drivers, ii) technological drivers, iii) financial/ economic drivers and iv) social/ informational drivers. Active stakeholder participation is central to all the drivers.

Table 1: Drivers for faster ET in cities

Type	Divers	Author
Policy/ Regulatory drivers	Regulations for city level low-carbon energy efficient Master Plans integrated with RE. Master plans to include emissions reduction and performance targets. Strict regulations for their adherence. Relevant urban planning guidelines, policies, and bylaws.	Chong et al, 2022, IEA, 2016, Coffman et al, 2017, Guno et al, 2021, MoEF, 2022, Zaidan et al, 2022, Smith, 2017
	Policies on sector wise low carbon energy efficient strategies, RE targets, accelerated deployment of clean energy technologies, incentives	WEFb, 2020, IEA, 2016, Inci et al, 2022, Melander et al, 2022
	Multi-actor multilevel urban climate governance, close alliance and stable long-term involvement among all relevant stakeholders.	Bulkeley, 2019, WEF, 2020, Valle et al, 2021, Broto et al, 2020
	Consistent rules and policy certainty regarding enforcement of contracts to gain confidence of clean energy investors	Kumar et al, 2020
	Regulations & strategies for taking national ET goals to city level through improved Centre–State and State–City coordination, transparency, accountability, and participation	Kumar et al, 2020, Broto et al, 2020
Technological Drivers	Experiments with emerging and innovative clean & energy efficient technologies (like green hydrogen, biofuels, carbon capture and storage technologies) through pilot projects, their 3rd party survey, monitoring and necessary refinements	Bulkeley, 2019, Broto et al, 2020, Smith, 2017, Zaidan et al, 2022, Melander et al, 2022, Xiong et al, 2023, Zhang et al, 2016, Choi et al, 2022
	Determine feasibility of available energy efficient technologies through pilot projects, estimate emission reduction potential / investment required & draw action plans with targets for their deployment	IEA, 2016, Valle et al, 2021, IEA, 2019, Smith, 2017
	Improvements in existing EE & RE technologies, provision of sustainable and low emissions infrastructure	Kumar et al, 2020, Smith, 2017, Zaidan et al, 2022, Melander et al, 2022, Xiong et al, 2023, Zhang et al, 2016, Choi et al, 2022

	Undertake research, development and demonstration of smart & innovative technologies including digitization and sensor technologies	IEA, 2016
Financial Drivers	Government and private investment in clean energy & low-carbon technologies (for example: electric cars, electrolysers (to produce green hydrogen)) & sustainable green infrastructure	Ember, 2023, Smith, 2017, IRENA, 2021, Broto et al, 2020, IEA 2019
	Ensure viability of the EE & RE projects while deciding about investment priorities, resource mix, and pricing of electricity	Kumar et al, 2020, Valle et al, 2021
	Easy bank loans by both public and private sector banks for EE & RE projects at a favorable rate of interest	Kumar et al, 2020
	Favorable policies on cost of carbon-neutral products and zero-carbon transition expenses	Zaidan et al, 2022.
	Reallocation of spending from high-emissions assets (coal-fired power plants and ICE vehicles) to low-emission assets in mobility, power, and buildings sectors	McKinsey, 2022
	Creating enabling environments & financial incentives for investors and RE developers (subsidies, preferential tax policies, higher fossil fuel taxes, waivers and others) for encouraging energy efficient technologies & infrastructure	Kumar et al, 2020, Zaidan et al, 2022, Coffman et al, 2017, Melander et al, 2022, Zhang et al, 2016, Hagem et al, 2023, Choi et al, 2022, Inci et al, 2022, Costa et al, 2020, Aasness et al, 2023, Helveston et al, 2015
Social/ Informational Drivers	Knowledge, convenience, and access to clean fuel	Neto-Bradley et al, 2019
	Education, training & awareness-raising programs to reduce uncertainties regarding new EE/RE technologies on their technological, operational, and infrastructure issues	Melander et al, 2022, IEA, 2016, IRENA, 2021, McKinsey, 2022, Roemer et al, 2022, Zaidan et al, 2022, Inci et al, 2022
	Documentation & dissemination of results from pilot projects on new technologies about their cost, performance, ease of use, relative advantages, environmental benefits, and other parameters	Broto et al, 2020, Valle et al, 2021, Kumar et al, 2020, IEA, 2016, IRENA, 2021, McKinsey, 2022, Roemer et al, 2022
	Transparent planning and implementation process with participation of all relevant stakeholders to prevent fear and anxiety regarding performance of new EE & RE technologies	McKinsey, 2022, Kumar et al, 2020
	Expectations of economic development and social inclusion which include potential expansion of job market, jobs, new industries, new skills, new	Smith, 2017, Mercedes et al, 2020, McKinsey, 2022

	investment and opportunity, training of skills and others	
	Digital promotion and green consciousness	Zaidan et al, 2022, Choi et al, 2022, Almansour, 2022
	Research on psychological factors for adopting efficient technologies	Austmann, 2021

3. Research method

This study is based on a quantitative questionnaire survey on the applicable drivers for faster ET in Indian cities followed by conducting Principal Component Analysis (PCA) of the information gathered from the survey. Forty relevant entities responsible for ET in Indian cities are identified and confirmed with key government stakeholders working in the energy and environment sector (from Department of Power, Environment and Municipal Bodies). The forty entities are included in Table 2.

Table 2: Relevant entities responsible for ET in Indian cities

Policy Makers/ Project Implementors		Other key Stakeholders
City/ State Level	National Level	
Urban Local Body, Electricity Supply Corporation, Dept of Power, Transport Dept, State Environment Dept, State Electricity Regulatory Commission, State Urban Development Agency, Dept of Finance, Dept of Industries & Commerce, Traffic Police	PMO, Niti Aayog, Ministry of Environment, Forest and Climate Change, BEE, Ministry of Power, Ministry of Telecom, Ministry of Industries, Ministry of Transport, Ministry of Finance, Central CPWD, Electricity Regulatory Commission, Ministry of New and Renewable Energy, Ministry of Housing & Urban Affairs	Technology Suppliers & Manufacturers, Small scale start-ups, Industry Associations, Distributor & Retailers, Financial Institutions, Recyclers and Refurbishers, Aggregators, Technology O&M/ service providers, Bulk Consumers, Builders & Developers, Individual Consumers, Energy Consultants, NGO, Media, Academia/ Think Tanks

Following the comprehensive literature review on previous studies on drivers for an accelerated ET in cities (Table 1), relevant drivers for faster uptake of ET in Indian cities are formulated and pilot tested with twenty-five experts from the above forty entities with at least fifteen years of working experience in the subject. The aim of the pilot testing was to ascertain and refine the identified drivers. Based on the discussions and opinions from the experts, thirty-two drivers are confirmed. As presented in Table 3, they are grouped under five categories: i) Generic, ii) policy/ regulatory drivers, iii) technological drivers, iv) financial/ economic drivers and v) social/ informational drivers.

Table 3: Drivers for faster ET in Indian Cities

Generic	
ET1	International Climate Mandates
ET2	India ratifying International Policies (example - ratifying Paris Agreement has been crucial for uptake of ET in the country)
ET3	Local champions/ key players (prime initiators for uptake of an energy efficent project, for example: administrator/ NGOs/ others)
ET4	Participation, agreement, accountability, and cooperation by relevant stakeholders and other entities at various stages of ET

Policy Drivers	
RD1	Formulating a city level 'ET Accelerating Cell (ETAC)' representing primarily relevant city level entities, and also stakeholders from National level & concerned State
RD2	Sectorwise target setting for uptake of energy efficient strategies & their broad implementation framework by ETAC ((in line with directions from legislators (central/state govt))
RD3	Sectorwise detailed action plans and implementation of energy efficient strategies by respective departments as per the targets
RD4	ET focused City planning/ Master Plans/ zonal plans (consult successful international case studies)
RD5	Sectorwise regulations & amendment in bye laws - (example - concessional/ free EV slots in parking lots, compulsory EV charging facilities in residential complexes, energy-efficient Street Lights, solar rooftop in municipal & public assets/ buildings, ECBC and others)
RD6	Innovatve policy frameworks, market design, business models, financial instruments, enabling infrastructure for EE/RE technologies
RD7	Reducing bureaucratic formalities for clean energy investors for smoother uptake of new & emerging energy efficient technologies (hydrogen, carbon storage etc)
RD8	Roadmap & action plans on new & emerging EE/RE technologies based on pilot project results
RD9	Landuse policy regulations regarding new & emerging technologies (for example: allocation of land for charging infra, RE parks, hydrogen production, battery disposal etc)
RD10	Public/private collaboration for developing proficient after sales/ repair/ service centres for EE/RE technologies
Technology Drivers	
TD1	Evolution and innovation of low carbon energy efficient technologies & enabling infrastructure
TD2	Pilot projects & experimentation on EE/ RE technologies, their monitoring & necessary refinement/ modification
TD3	Standardization & certifications of new and existing RE/EE technologies
TD4	First-rate proficient after-sales / repair / service centres offering skilled expertise service for new and emerging technologies
TD5	Digitalisation and sensor technologies
TD6	Large number of EE/RE variants enabling consumers many choices
Economic/ Financial Drivers	
ED1	Government incentives for EE/RE technologies (example - grants, subsidies, lower taxes, lower tariff, reduced GST/ import duty, waivers, adequate budget allocation and others)
ED2	Cheaper public & private loans for EE/ RE technologies
ED3	Grants for research & innovation on energy efficient technologies
ED4	Restricting subsidies to conventional fuel (coal, oil) sources
ED5	Falling costs of new climate friendly EE/RE technologies
ED6	Demonstrated job & business opportunities wrt new EE/ RE technologies
Social/ Informational/ Environmental Consciousness	
SD1	Legal actions by citizens & grassroot environment movement by NGOs, citizens and media (example – Demand for ‘Right to cleaner air’)
SD2	Education/ Awareness building/ publicity (incl print & social media) on availability & benefits of EE/RE technologies
SD3	Documentation & dissemination of pilot project results to remove perceived risks like performance uncertainty & other issues
SD4	Manpower training & skill development (service, repair and other parameters) on energy efficient technologies
SD5	Environmental consciousness, green reputation and good image
SD6	Information sharing amongst different municipalities regarding both successful and unsuccessful ET related city planning measures

In the next step, to confirm the importance and significance of these thirty-two drivers for accelerated ET in Indian cities, a questionnaire was developed for taking opinion from relevant stakeholders. Four hundred national and international experts having extensive understanding of the energy and environment sector at relevant organizations were identified and the questionnaire was sent to them. The experts were requested to rank the drivers on a 5-point Likert scale (with severity between one and five). Of the four hundred stakeholders, three hundred and twelve experts (78%) provided comprehensive and usable feedback. A summary profile of the survey respondents from the eleven entities are provided in Table 4.

Table 4: Questionnaire Survey Respondents

	Profession	Share (%)
1	Academician/ Think Tanks	12
2	Central Government	10
3	Consumers	8
4	Energy Consultant	15
5	FI/Bilateral Agency/ Donor	5
6	Legal/ media	2
7	NGO	7
8	Private Sector	10
9	OEM	5
10	State Government	18
11	Urban Local Body	8
	Total	100

The information received from the three hundred and twelve questionnaires was analyzed using the statistical tool of SPSS. First, the reliability of the survey was carried out by determining the Cronbach's alpha coefficient and then the authenticity of the data was verified through the KMO and Bartlett's test. After confirming the reliability and authenticity of the survey data, PCA is carried out using the 'Dimension Reduction' feature in SPSS. PCA is the factor analysis where possibly correlated variables are grouped into a smaller number of variables called principal components.

4. Results and discussions

4.1 Reliability test

Cronbach's Alpha measures the internal consistency amongst variables in a survey. It ranges from 0 to 1 and the higher the value, the higher is the internal consistency (Cronbach, 1951). Cronbach's alpha test for this study is 0.914 which indicates high internal consistency between responses and confirms suitability of the five-point Likert scale method adopted for this analysis.

4.2 KMO and Bartlett's test

After confirming reliability of the survey, KMO and Bartlett's test was applied to verify the authenticity of the data. The value came to be 0.751 (Table 5) which is more than the recommended minimum value of 0.500 (Osei-Kyei and Chan, 2017). In addition, Bartlett's test of sphericity at 0.000 is statistically significant thereby supporting the factorability of the correlation. This result at less than 0.0 indicates that a high significant relationship among variables under study (Arokodare M A, 2021). Thus, the data gathered from the questionnaire survey is suitable for factor analysis.

Table 5: KMO and Bartlett's test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.751
Bartlett's Test of Sphericity	Approx. Chi-Square	3024.65
	df	496
	Sig.	0.000

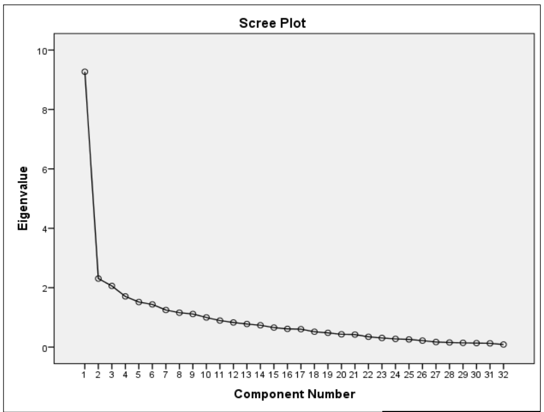


Fig 10:

4.3 Factor analysis of drivers for ET

Using the information gathered from the questionnaire survey, the PCA and Cattel scree test were carried out using SPSS tool. The scree plot indicates nine components having eigenvalues greater than one and accounting for 68% of the total variance. A varimax rotation with Kaiser Normalization method is applied to the components and the rotation is converged in 8 iterations. Figure 10 presents the scree plot and Table 6 presents the total variance.

Table 6: Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	9.269	28.967	28.967	9.269	28.967	28.967	2.999	9.373	9.373
2	2.308	7.211	36.178	2.308	7.211	36.178	2.892	9.036	18.409
3	2.060	6.436	42.614	2.060	6.436	42.614	2.566	8.017	26.426
4	1.707	5.334	47.948	1.707	5.334	47.948	2.527	7.898	34.324
5	1.518	4.743	52.691	1.518	4.743	52.691	2.456	7.675	41.999
6	1.436	4.488	57.179	1.436	4.488	57.179	2.354	7.357	49.356
7	1.249	3.902	61.081	1.249	3.902	61.081	2.251	7.035	56.391
8	1.159	3.621	64.701	1.159	3.621	64.701	2.251	7.033	63.424
9	1.114	3.481	68.182	1.114	3.481	68.182	1.523	4.758	68.182
Extraction Method: Principal Component Analysis.									

4.4 Principal components extracted from the factor analysis

The rotated component matrix (Table 7) indicates that twenty-nine of the thirty-two drivers are distributed amongst nine components having eigenvalues more than 1. Each of the nine components is found to be a distinct category/ theme related to ET in a city (included in the rightmost column of Table 8) and each theme contains mix of technological, policy, social/informational and financial drivers.

Table 7: Rotated component matrix

Drivers		Components 1	2	3	4	5	6	7	8	9	Categories/ Themes
RD1	Formulating a city level 'ET Accelerating Cell (ETAC)' representing primarily relevant city level entities, and also stakeholders from National level & concerned State	.758									**ET Accelerating Cell (ETAC)**
RD2	Sectorwise target setting for uptake of energy efficient strategies & their broad implementation framework by ETAC ((in line with directions from legislators (central/state govt))	.747									
RD6	Innovative policy frameworks, market design, business models, financial instruments, enabling infrastructure for EE/RE technologies	.645									
RD7	Reducing bureaucratic formalities for clean energy investors for smoother uptake of new & emerging energy efficient technologies (hydrogen, carbon storage etc)	.599									
RD4	ET focused City planning/ Master Plans/ zonal plans (consult successful international case studies)		.738								**Sectoral & Municipal Actions**
RD5	Sectorwise regulations & amendment in bye laws - (example - concessional/ free EV slots in parking lots, compulsory EV charging facilities in residential complexes, energy-efficient Street Lights, solar rooftop in municipal & public assets/ buildings, ECBC and others)		.642								
RD9	Landuse policy regulations regarding new & emerging technologies (for example: allocation of land for charging infra, RE parks, hydrogen production, battery disposal etc)		.636								
RD3	Sectorwise detailed action plans and implementation of energy efficient strategies by respective departments as per the targets		.593								
SD6	Information sharing amongst different municipalities regarding both successful and unsuccessful ET related city planning measures		.559								

ED1	Government incentives for EE/RE technologies (example - grants, subsidies, lower taxes, lower tariff, reduced GST/ import duty, waivers, adequate budget allocation and others)			.783							**Financial Instruments**
ED2	Cheaper public & private loans for EE/ RE technologies			.630							
ED3	Grants for research & innovation on energy efficient technologies			.555							
ED4	Restricting subsidies to conventional fuel (coal, oil) sources			.515							
TD2	Pilot projects & experimentation on EE/ RE technologies, their monitoring & necessary refinement/ modification				.823						**Pilot Experimental Projects**
SD3	Documentation & dissemination of pilot project results to remove perceived risks like performance uncertainty & other issues				.640						
RD8	Roadmap & action plans on new & emerging EE/RE technologies based on pilot project results				.603						
SD2	Education/ Awareness building/ publicity (incl print & social media) on availability & benefits of EE/RE technologies					.815					**Awareness Building/ Environmental Consciousness**
SD1	Legal actions by citizens & grassroot environment movement by NGOs, citizens and media (example – Demand for 'Right to cleaner air')					.782					
SD5	Environmental consciousness, green reputation and good image					.627					
TD1.	Evolution and innovation of low carbon energy efficient technologies & enabling infrastructure						.839				**Technology innovation**
TD5	Digitalisation and sensor technologies						.790				
TD3	Standardization & certifications of new and existing RE/EE technologies						.642				
TD4	First-rate proficient after-sales / repair / service centres offering skilled expertise service for new and emerging technologies							.816			**Service & Repair Facilities**
RD10	Public/private collaboration for developing proficient after sales/ repair/ service centres for EE/RE technologies							.695			
SD4	Manpower training & skill development (service, repair and other parameters) on energy efficient technologies							.500			
ET1	International Climate Mandates								.772		**International mandates**
ET2	India ratifying International Policies (example - ratifying Paris Agreement has been crucial for uptake of ET in the country)								.767		
ET3	Local champions/ key players (prime initiators for uptake of an energy efficient project, for example: administrator/ NGOs/ others)									.784	**Local Champions & Stakeholder coordination**
ET4	Participation, agreement, accountability, and cooperation by relevant stakeholders and other entities at various stages of ET									.539	

These nine categories account for 68% of the total variance and within the 68%, share of loading of these nine components vary between 9.3% to 4.8%. Hence, as per this analysis, these nine themes containing the twenty-nine drivers are significant for faster ET in Indian cities. The themes and the drivers included under each category are:

i.) ET Accelerating Cell (ETAC) – ET will not happen with initiatives by a single department, it is a collaborative effort from several entities in a city. Establishment of an 'ET Accelerator Cell' is a crucial overarching driver whose main focus will be strategizing and ensuring faster ET in the city. The Cell will be represented by the relevant entities working in the energy and environment sector; primarily members from the city level bodies, and also include stakeholders from National level & the concerned State. Close alliance and stable long-term involvement among all the members of ETAC is the key to a successful ET. The factor analysis included the following drivers under this theme of ETAC and its roles/ responsibilities and their respective loadings assigned by the factor analysis (PCA) are:

- sector wise target setting for uptake of energy efficient strategies & their broad implementation framework in line with directions from legislators (central/state govt) (loading - 0.747)
- innovative policy frameworks, market design, business models, financial instruments, enabling infrastructure for EE/RE technologies (0.645)
- reducing bureaucratic formalities for clean energy investors for smoother uptake of new & emerging energy efficient technologies (hydrogen, carbon storage etc) (0.599)

ii.) Sectoral & Municipal Actions – City planning department, Departments of Power, Industry, Environment, & Transport and Municipal Bodies are the key stakeholders for ET in a city. They will be responsible for implementing the strategies adopted by ETAC by developing respective sector wise detailed action plans as per the targets (loading 0.738). Role of municipal bodies like sector wise regulations & amendment in bylaws (example - concessional/ free EV slots in parking lots, compulsory EV charging facilities in residential complexes, energy-efficient street lights, solar rooftop in municipal & public assets/ buildings, ECBC and others) with loading of 0.642 and land use policy regulations regarding new & emerging RE/EE technologies like allocation of land for charging infra, RE parks, hydrogen production, battery disposal etc (loading of 0.636) are identifies as very important drivers. City planning authorities preparing ET focused Master Plans/ zonal plans (after referring to successful international case studies) are also significant drivers for ET (loading of 0.593). Lastly, Information sharing amongst different municipalities regarding both successful and unsuccessful ET related city planning strategies (loading of 0.559) is a vital driver for choosing and replicating viable measures by cities.

iii.) Financial Instruments – Finance is a very important factor for uptake of any new technology, both for energy investors and consumers (Zaidan et al, 2022, Coffman et al, 2017). Both parties need incentivizing, favorable policies. The four key drivers analyzed by the PCA and their loadings are: Government incentives for EE/RE technologies (example - grants, subsidies, lower taxes, lower tariff, reduced GST/ import duty, waivers, adequate budget allocation and others) (0.783), Cheaper public & private loans for EE/ RE technologies (0.630), Grants for research & innovation on energy efficient technologies (0.555) and Restricting subsidies to conventional fuel (coal, oil) sources (0.515).

iv.) Pilot projects – Innovative pilot projects & experimentation on EE/ RE technologies, their monitoring & necessary refinement/ modification is identified as one of the key drivers for faster ET in a city (loading of 0.823). Documentation & dissemination of pilot project results to remove perceived risks like performance uncertainty & other issues (loading of 0.640) and preparing Roadmap & action plans by ETAC on new & emerging EE/RE technologies based on pilot project results (0.603) are identified by the PCA as other important drivers with strong likelihood to enhance uptake of EVs in a city.

v.) Awareness Building & Environmental Consciousness – Continuous Education/ Awareness building/ publicity (incl print & social media) on availability & benefits of EE/RE technologies is (0.813) is identified as another key driver for faster ET in a city. Legal actions by citizens & grassroot environment movement by NGOs, citizens and media (example – Demand for ‘Right to cleaner air’) with loading of 0.782 also plays a key role and the other important enabler of ET is having environmental consciousness and striving for a green reputation and good image by both entities as well as citizens (loading of 0.627)

vi.) Technology Innovation – Evolution and innovation of energy efficient technologies & enabling infrastructure with loading of 0.839 is imperative for ET. In addition, Digitalisation and sensor technologies (0.790) and standardization & certifications of new and existing RE/EE technologies (0.642) are identified as key enablers.

vii.) Availability of skilled labor (service & repair) – Absence of such skilled technicians often deter uptake of EE/RE technologies and in this analysis availability of first-rate proficient after-sales / repair / service centres offering skilled expertise service for new and emerging technologies is identified as a key driver of faster ET (loading of 0.816). Government needs to assist EE/RE manufacturers in setting them up and public/private collaboration for developing proficient after sales/ repair/ service centres for EE/RE technologies is an important driver (loading of 0.695) too. Also, manpower training & skill development on service, repair and other parameters are important drivers with loading of 0.500.

viii.) International mandates – International mandates are vital drivers of ET in countries and cities (0.772). For example, India ratifying Paris Agreement has been crucial for uptake of ET in the country (0.767).

ix.) Local Champions & Stakeholder coordination – Participation, agreement, accountability, and cooperation by relevant stakeholders and other entities at various stages of ET is a significant driver (loading of 0.784). Often, amongst many stakeholders, an administrator or NGO become prime motivators for uptake of an energy efficient project in a city; they are the local champions and become the important initiator for an EE/ RE technology (0.539).

These are the nine categories (each having set of drivers) identified as enablers of ET in Indian cities.

This analysis indicates that the different drivers under these nine themes are required to be addressed urgently, and also concurrently. All the relevant departments and stakeholders need to collaborate for a successful and accelerated ET in the Indian cities. Pushing one or two drivers in a haphazard manner will not lead to fast deployment of the energy-efficient technologies.

5 Conclusions

Cities account for about 75% of global primary energy use and 70% of energy related greenhouse gas (GHG) emissions, making them key actors in both national and global efforts to transition to a net-zero future (IRENA, 2021). Thus, cities have a major role in the global energy transition (C40, 2022); it is rather essential that they take a leading role in energy transition (IEA, 2016). As per the IPCC 1.5 Degree Special Report, cities and urban areas are a critical global system that can accelerate and upscale climate action (Bazaz et al. 2018). Thus, cities are both part of the problem and a crucial part of the solution to emerging global challenges, most notably climate change (Bulkeley H, 2019). In this regard, cities have a key role to play in leading the way to a low carbon society (Valle et al, 2021).

Cities can catalyze the shift to a low-carbon future through ET, in turn supporting regional and national governments with the achievement of sustainable energy targets and the realization of global climate objectives. Cities can be target setters, planners and regulators (IRENA, 2021).

This study has examined the drivers for a faster ET in Indian cities. Based on the literature review and opinions from three hundred and twelve subject experts, thirty-two factors are identified through quantitative questionnaire survey and PCA. From these thirty-two drivers, PCA extracted twenty-nine and categorized them into nine components having distinct themes. The themes are i) formulation of an ET Accelerating Cell, ii) Sectoral & Municipal Actions, iii) Financial Instruments, iv) Pilot Experimental Projects v) Awareness Building/ Environmental Consciousness, vi) Technology Innovation, vii) Service & Repair Facilities, viii) International Mandates and ix) Local Champions & Stakeholder Coordination. These nine components account for 68% of the total variance and share of loading of these nine components vary between 19.3% to 4.8%. Hence, all these themes containing the twenty-nine drivers are significant for an accelerated ET in Indian cities.

The analysis indicates that pushing one or two drivers in a piecemeal manner will not lead to faster ET, rather, several initiatives need to be addressed and undertaken concurrently. For their implementation, all the relevant stakeholders need to fulfill their respective responsibilities in a coordinated and collaborative manner for a successful and accelerated ET in a city.

6 Implications and further studies

This study has various implications. It develops an approach to identify and examine the key drivers of hastened ET in Indian cities for the first time. The proposed framework will assist the policymakers, future researchers, and other stakeholders to determine key factors for successful implementation of energy efficient technologies in Indian cities.

Although numerous research studies have been conducted towards assessment of the drivers, barriers, and critical success factors of successful ET, most of the works have focused on the first-world or industrialized countries; very few papers focused on the developing nations (Inci et al, 2022, Palit et al, 2022). This research has explored the valuable insights of faster ET in Indian cities through identification of the key factors that influence the faster uptake of energy efficient technologies. This research has been designed in a way that will help policymakers effectively and efficiently.

The findings of this study offer important implications for the policymakers and other stakeholders to improve environmental sustainability in Indian cities which can eventually improve the quality of life by minimizing harmful elements of pollution.

Despite its contributions and the use of existing approaches for assessing sustainable initiatives, this study has limitations. The study formulated a broad framework for the faster ET in cities through deployment of energy efficient technologies. India's cities are quite diversified (in terms of size, geographical location, culture, applicability of technologies etc). Hence, prior to finalizing deployment of energy efficient technologies in a city, determining their applicability and feasibility will be relevant and pertinent.

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