


POLICY BRIEF

MAKING INDIAN CITIES ENERGY SMART

UNSW SYDNEY

THE ENERGY AND RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future

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ABOUT THIS POLICY BRIEF

Abstract

India, being the second most populated country in the world, contributes to 6% of the world's primary energy consumption. Due to rapid urbanisation and the burgeoning urban population, there will be serious implications on energy consumption and subsequent carbon emissions. Cities face a series of complex interconnected challenges across different sectors (built environment, mobility, water & waste management, and public services) and it is critical to re-look at these challenges by integrating the principles of smart energy management for achieving sustainable and low-carbon urban development. Managing the energy footprint of cities is one of the most challenging goals, and with the evolution and transformation of existing cities into smart cities, smart energy management thus becomes an integral component of this urban transformation.

To this end, The Energy and Resources Institute (TERI), India, in partnership with the University of New South Wales (UNSW) Sydney, Australia, organised a Knowledge Exchange Workshop to understand the potential of mainstreaming smart energy management in different sectors and identifying strategies to interlink sectors for achieving integrated smart energy management in Indian cities. With sector experts from mobility, buildings, public services, water and waste management participating and contributing, the Workshop identified key challenges and enablers for mainstreaming smart energy management for sustainable cities. This Policy Brief is an outcome of the Workshop and presents the challenges, enablers and recommendations for making cities energy smart with a view to contribute to urban policies that manage the energy footprint and influence future carbon emissions.

Background

India is currently undergoing rapid urbanisation which is one of the key drivers for the increase in energy demand and consumption. The country accounts for 18% of the world's population and 6% of the global primary energy consumption (IEA, 2015). Globally, urban areas emit between 50%-60% of the world's total greenhouse gas (GHGs) emissions (UN Habitat, 2017). With India's urban population growing from 31.6% to 57.7 % by 2050, there will be further implications on energy consumption patterns and subsequent GHGs emissions (United Nations, Department of Economic and Social Affairs , 2018). Thus, the task of managing and reducing energy-related carbon emissions is often challenging for urban planners and needs to be addressed simultaneously in different sectors to ensure an integrated approach to energy management.

Against this background, it is imperative that urban challenges, such as mobility, access to reliable and clean energy, the provision of green and resilient infrastructure and waste management, are addressed through the principles of smart energy management (SEM). It is important to develop policies that can manage urban energy demand, influence future carbon emissions, and achieve the sustainable development goals (SDGs).

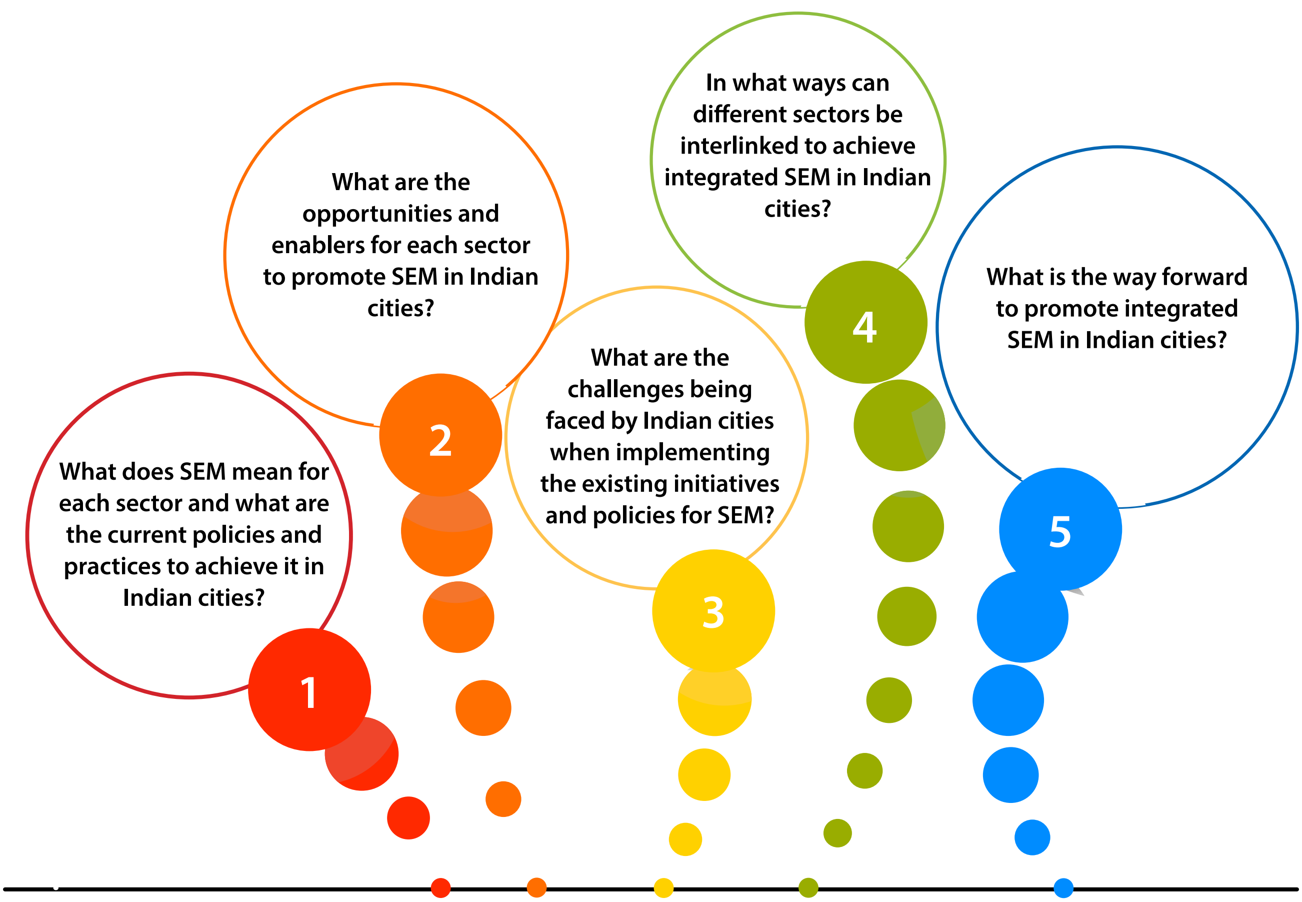
Indian cities are also facing a series of complex interconnected challenges related to energy management due to the inadequate existing infrastructure to meet the growing energy demand. The increasing pressure on non-renewable energy sources to meet the energy needs of cities adds a greater burden on the environment. Moreover, the depletion of energy resources has had a negative impact on climatic conditions, and the high levels of urban energy-led GHGs emissions have further exacerbated climate change and global warming. Therefore, energy management needs to be closely linked to environmental management and socio-economic development (WRI, 2017).

In the current policy landscape, the impetus for reimagining energy supply and demand management for the country through technological advancements is already in place. Further, under the Intended Nationally Determined Contributions (INDCs), strategies are in place to reduce the emissions intensity of GDP by 33%–35% below 2005 levels and build 40% of fossil-free power generation capacity by 2030 (MoEFCC, 2015). A detailed discussion on the policies, programs, and missions relevant for integrating SEM for sustainable cities have been included in the section 'Existing Policy Landscape'.

In order to address the above-discussed urban energy issues and improve the quality of public life, the integration of innovations in physical infrastructure with intelligent information and communications technology (ICT) has recently been one of the key priorities for city governments across India. However, there needs to be a greater momentum towards scrutinising the potentials of energy management and applying it in the urban planning policies and frameworks. Importantly, as India's urban population increases, there is a need to integrate energy-efficient and -sufficient technologies in different sectors, such as buildings, transport, water, waste, and public services, to reduce carbon emissions and achieve low-carbon development. This integrated SEM will ensure the optimal utilisation of available resources and reduce reliance on unsustainable energy sources.

To this end, The Energy and Resources Institute (TERI), India, in collaboration with the University of New South Wales (UNSW) Sydney, Australia, organised a Knowledge Exchange Workshop[1] wherein sector experts and urban practitioners from urban local bodies, policy think tanks, academic and research institutions and industry focused on addressing sector challenges and enablers for energy management. Through group discussions moderated by sector experts, the participants deliberated on achieving integrated SEM in Indian cities and the way forward.

Presenting the key outcomes of the Workshop, this Policy Brief highlights the challenges, enablers and recommendations for making Indian cities energy smart. It aims to mainstream SEM into urban planning and policy frameworks of Indian cities. The Policy Brief will contribute towards knowledge creation, communication and awareness for urban planners, policymakers, industry, research institutions, and academics in India and Australia.



Key questions addressed at the Australia-India Knowledge Exchange Workshop on 'Smart Energy Management for Sustainable Cities'

[1] The Australia-India Knowledge Exchange Workshop on 'Smart Energy Management for Sustainable Cities' was organised in a World Café format at TERI, New Delhi, in December 2018. The aim of the UNSW Sydney – TERI collaboration initiative, supported by the Andhra Pradesh Capital Regional Development Authority (APCRDA) and industry partners Mahindra Group and DuPont India Pvt. Ltd., is to develop and strengthen long-term cooperation between India and Australia on SEM in cities.

WHAT IS 'SMART ENERGY MANAGEMENT'?

In order to build an understanding of SEM, it is important to first familiarise with the concepts and principles of energy management, and then develop insights into how to integrate it into the context of smart cities. Energy management can be defined as the science involved in planning, directing, controlling energy supply and consumption to maximise productivity and comfort, and to minimise energy costs and pollution through conscious, judicious and efficient use of energy (Energy Lens, 2018). In simpler terms, energy management involves energy savings. In terms of energy savings, energy management entails the process of monitoring, controlling, and conserving energy in any given context. It involves optimised energy utilisation, management of energy resources, and active energy efficiency.

As urban areas are expanding rapidly, managing the energy footprint is one of the challenging goals that cities face. With the development of existing cities and their transition to smart cities, energy management has become an integral component of urban transformation. A smart city is a sustainable and efficient urban centre that aims to provide residents with a high quality of life by optimising resources (Calvillo et al., 2016). Smart cities are expected to become more autonomous and manage their energy footprint more efficiently, taking into account local resources and the needs of various stakeholders. In this context, SEM entails understanding the potential of energy management as a basic building block for smart cities.

In this Policy Brief, SEM is defined as follows:

> "*Smart energy management is a component of smart city development aiming at a site-specific continuous transition towards sustainability, self-sufficiency, and resilience of energy systems, while ensuring accessibility, affordability, and adequacy of energy services, through optimised integration of energy conservation, energy efficiency, and local renewable energy sources. It is characterised by a combination of technologies with information and communication technologies that enables integration of multiple domains and enforces collaboration of multiple stakeholders, while ensuring sustainability of its measures.*" (Mosannenzadeh et al., 2017, p.57).

Figure 1 visualises the definition of SEM by introducing all its dimensions.

The mainstreaming of SEM mainly involves the convergence of technology with energy systems, enabling policies, strategies, institutional changes, awareness, training and capacity building programs, energy conservation measures, energy audits, etc.

Table 1 provides a few examples of SEM initiatives across the world.

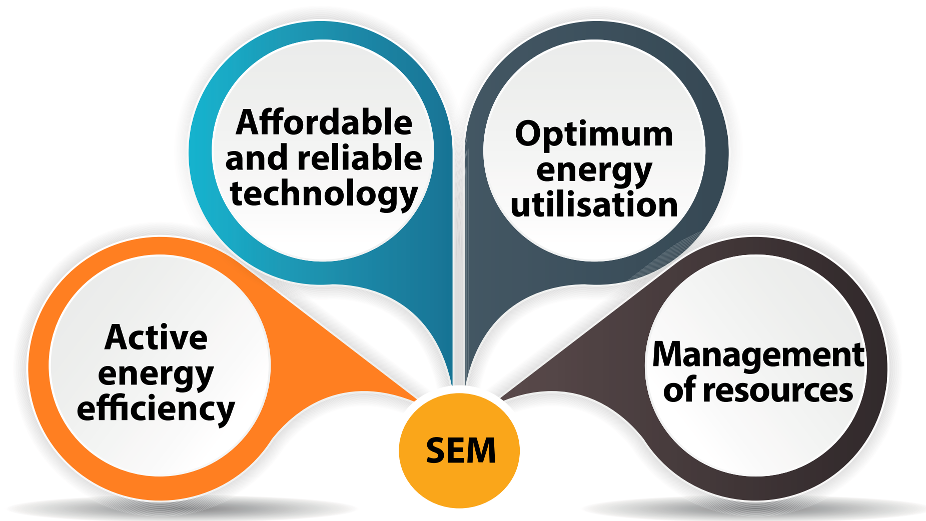


Figure 1 Features of Smart Energy Management (SEM)

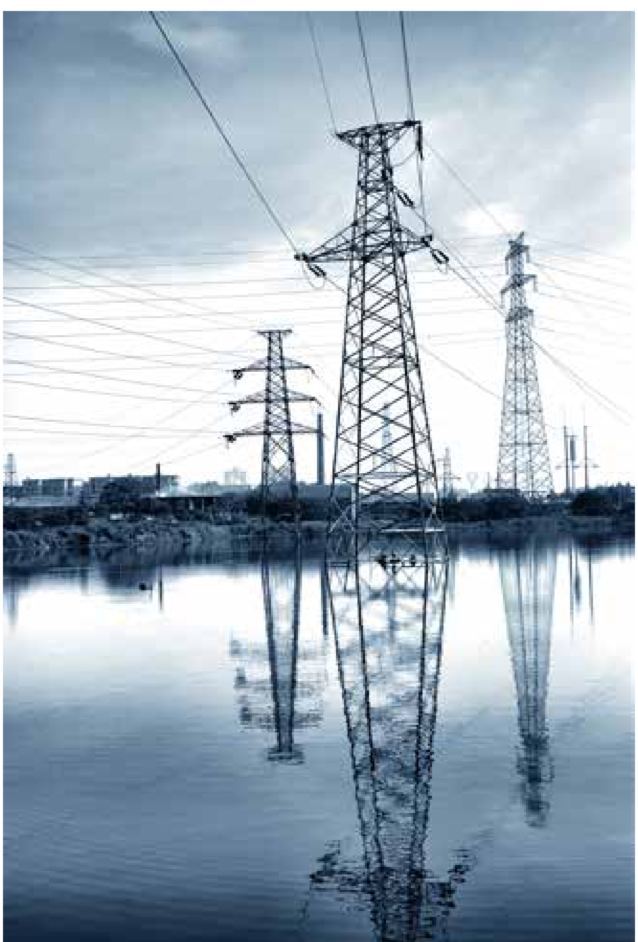
Table 1: SEM Initiatives in Cities

City	Measures under Smart Energy Management Initiatives in Cities
1. Rajkot, India 	Rajkot has taken comprehensive actions for reducing emissions and improving energy security by improving uptake of renewable energy, providing better waste management practices and expanding the city's sustainable mobility infrastructure including public transportation. **Measures** • A total of 3162 kWp solar rooftop PV installed in residential, educational, commercial, industrial, and municipal buildings. Additional 7.49 MW solar rooftop PV project proposed to be installed. • Green building design introduced which demonstrates reduced energy demand and use of renewable energy in affordable housing schemes. • There is a 10.7 km operational Bus Rapid Transit System (BRTS) out of the proposed 63 km long network. 11 BRTS diesel buses proposed to be replaced with electric buses. • 18 decentralised waste to composting plants proposed in each ward (5MT capacity each) to reduce pollution from waste transportation. *Source: WWF (2018)*
2. Pune, India 	Pune is addressing climate-related challenges by enhancing its sustainable mobility plans, promoting energy-efficient measures, improving waste management infrastructure, and promoting renewable energy. A dedicated Energy Saving Cell has been set up to undertake energy saving actions. **Measures** • Comprehensive Mobility Plan developed to emphasise on sustainable modes of transportation. • Energy-efficient retrofits for HVAC and lighting systems installed at an industrial park and municipal buildings. • 700 MT municipal solid waste-to-energy plant set up which feeds electricity into the grid. • About 16,000 high pressure sodium vapour streetlights replaced with LED fittings leading to 40%–45% energy savings. • Promoted wind–solar hybrid systems and solar power installations (rooftop PV, water heaters, street lights, etc.). *Source: WWF (2018)*
3. Quezon City, Philippines 	In Quezon city, Philippines, the availability of technical assistance from World Bank Institute (WBI) as part of the Energy Efficient Cities Initiative enabled the City's LED streetlight initiative. It helped to improve energy efficiency in delivery of city services, and reduce costs and environmental impacts of energy use. **Measures** • Converting 25,000 streetlights to LED technology and expanding street lighting to areas currently not illuminated. • Installation of at least 5,000 luminaires annually from 2015 to 2018, for a minimum total of 20,000 retrofitted luminaires over four years. In addition, 5,000 luminaires were replaced with LEDs in 2013–14. *Source: ESMAP (2016)*
4. New York City, USA 	The Joint Transportation Management Center (JTMC), based in New York City, is an example of a smart transport system and is the largest transportation center in North America. Intelligent transportation helps in improving overall situational awareness, enhancing interoperability, and in improving the ability to share information rapidly. **Measures** • JTMC's Converged Security and Information Management (CSIM) installation and PSIM platform covers 120 miles of the state arterial system and incorporates more than 700 cameras, 700 vehicle detectors, 110 variable message signs, and 7 highway advisory radios. • Focused on around-the-clock coordination and communication to manage daily transportation incidents and reduce congestion on some of the busiest expressways in the world. *Source: Ismail (2018)*

EXISTING POLICY LANDSCAPE

The Government of India (GoI) has been developing policies and programs to guide the mainstreaming of SEM in urban planning. In order to meet the energy needs of citizens and reduce carbon emissions, the Indian government has adopted a two-pronged approach, i.e., focusing on supply and demand. On the generation side, greater use of renewable energy, mainly solar and wind, is being promoted. On the demand side, efforts are being made to improve energy efficiency through a variety of innovative policy measures that fall within the umbrella of the 2001 Energy Conservation Law.

Some of the key policies adopted by the GoI over the past decade to integrate SEM into the existing energy policy landscape are discussed here:



The Energy Conservation Act (EC Act), 2001, and amended in 2010

The Energy Savings Act of 2001 (EC Act), amended in 2010, was enacted with an objective to reduce the energy intensity of the Indian economy by the Ministry of Power (MoP), GoI. In 2002, the Bureau of Energy Efficiency (BEE) was established as a central statutory body to promote the implementation of the EC Act. The Act mandates the Energy Conservation Building Code (ECBC) for commercial buildings, standards and labels for equipment and appliances, and energy consumption norms for energy-intensive industries. ECBC is estimated to reduce energy consumption by 50% by 2030. In addition, the Act requires the GoI and BEE to facilitate and promote energy efficiency in all sectors of the economy.

The Act also requires state-level designated agencies to enforce the Act and promote energy efficiency in the state. Through the BEE, the Act initiated a series of energy saving initiatives in areas such as home lighting, commercial buildings, standards and home appliance labels. In the context of cities and energy management, the related program is the Energy Efficiency Labeling Program, which aims to reduce energy consumption of equipment without affecting its performance, as well as setting minimum energy standards for new commercial buildings to be constructed across India.

National Mission on Enhanced Energy Efficiency, 2010

The National Mission on Enhanced Energy Efficiency (NMEEE), launched under the National Action Plan on Climate Change (NAPCC), is based on the 2001 Electricity Law and is also overseen by BEE. The Energy Efficiency Services Ltd. (EESL) was created as a business entity to provide market leadership. The goal of NMEEE is to meet the country's energy demand and provide energy efficiency. At its full implementation stage, NMEEE intends to save approximately 23 million tons of fuel per year and reduce GHG emissions by 95.55 million tons per year (Rattani, 2018). The first cycle of the Perform, Achieve and Trade (PAT) initiative (from 2012-2015) resulted in reduction of 31 million tonnes of carbon emissions, which was approximately 1.93% of the total emissions of India (Rattani, 2018).

Though BEE recognises NMEEE as one of its key missions due to the success of PAT, it requires effective investment mechanisms and financial instruments (e.g., energy-saving certificates) to support energy efficiency. In addition, the mission needs to pay more attention to inter-departmental linkages and close coordination between the energy demand and supply sectors.

National Mission for Sustainable Habitat, 2010

The National Mission on Sustainable Habitat (NMSH) was envisaged under the NAPCC with the goal of integrating both climate adaptation and mitigation into urban planning. This is intended to be achieved by improving the energy efficiency of buildings, managing solid waste and shifting to public transport. The ECBC for new commercial buildings was launched under the NMSH. The code is estimated to achieve a 50% reduction in energy use by 2030. Under this mission, the BEE has also developed design guidelines for energy-efficient multi-storey residential buildings in composite and hot dry climates.

In the context of green buildings and energy efficiency, green building codes were incorporated into the Central Public Works Department (CPWD) workbook. Draft building by-laws were published to help the state and regional governments incorporate their necessary provisions into their respective building by-laws.

Several of the activities envisaged under the NMSH have been undertaken under Atal Mission for Rejuvenation and Urban Transformation (AMRUT), such as the implementation of pedestrian, non-motorised and public transport facilities, and the creation and upgrading of urban green spaces, parks and recreation centres.

National Solar Mission, 2010

The National Solar Mission (NSM) launched under the NAPCC envisioned a comprehensive strategy to develop grid-connected and off-grid applications of solar energy in a phased manner through a comprehensive research and development (R&D) program. Under the Ministry of New and Renewable Energy (MNRE), the objective of the NSM is to provide an enabling environment for solar technology penetration in the country both at a centralised and decentralised level. NSM's original target was achieving 20 gigawatts (GW) of grid-connected solar power plants along with separate targets for solar water heating, solar street lighting, solar cooking, cooling, and other applications.

It focuses on deployment of both off-grid and grid-connected rooftop PV systems across the country and also on the development of solar cities. The Solar Cities program was designed to motivate the city governments to adopt renewable energy technologies, and energy efficiency measures target to achieve a minimum of 10% reduction in projected demand of conventional energy at the end of five years across different cities. In 2014, as part of the ambitious mission to provide Electricity for All, and other initiatives, the target of establishing grid-connected solar power under the NSM was revised from 20 GW to 100 GW by 2022.

Smart Cities Mission, 2015

The Smart Cities Mission by the MoHUA was launched in 2015 to address the governance and infrastructure concerns of the growing urban population of cities, and to promote quality of life. By integrating the Internet of Things (IoT) technology, the Mission aimed to integrate smart technologies in different sectors to achieve sustainable urban development in an energy-efficient and cost-effective manner. The smart city proposals entailed two major aspects: (1) Pan City Project, which includes information and communication technology (ICT) solutions such as Integrated Traffic Management System (ITMS), automated

city level waste collection, e-Governance, and rooftop solar panels in government buildings; and (2) Area Based Development (ABD) Project, wherein a small area within the city is identified and is developed with identified smart solutions for improving its infrastructure which becomes a prototype for other parts of the city.

The Mission aims to create urban spaces which are energy-efficient to reduce the burden on existing resources. As per the Mission guidelines, 80% of the buildings in the smart cities need to be energy-efficient with a 'green building' design and 10% of the Smart City's energy requirement should come from solar energy.

Draft National Energy Policy, 2017

The National Energy Policy (NEP) prepared by NITI Aayog focuses on energy access for all, reducing dependence on fossil-fuel imports, promoting low-carbon development, and sustainable economic growth. Considering energy is handled by several Ministries, this policy aims to achieve national energy objectives through coordination between different Ministries. The NEP aims to mainstream energy technologies and provide consumer with energy choices and prepare the Indian economy to be 'energy ready' by 2040. Demand-based strategies relevant to integrating energy management for sustainable cities have been proposed under the NEP for the transport, buildings, and household (cooking) sector. Under the transport sector strategies, such as transit-oriented development, modal shift to rail-based mass transport systems, promotion of electric and hybrid vehicles, ICT solutions, etc., have been proposed. Under the buildings sector, shift towards energy-efficient building materials, enforcement of ECBC, better urban planning, adoption of high efficiency lighting technologies and appliances, etc., and under housing sector, a shift towards modern fuels for cooking, and improvement in the efficiency of cooking fuels and stoves has been proposed.

Draft National Cooling Action Plan, 2018

India mostly experiences tropical climate and with its cities undergoing rapid urbanisation, cooling requirements are projected to rise by 2.2 to 3 times (2017 baseline) in the next decade (Alliance for Energy Efficient Economy, 2018). The implications of this increase will be significant through increased power generation capacity, peak load, and carbon footprint. It is against this background, the Ministry of Environment, Forest and Climate Change (MoEFCC), GoI, is developing a draft National Cooling Action Plan (NCAP) with an objective of outlining strategies to promote sustainable and smart cooling practices across the nation for the next two decades. The NCAP covers cooling growth scenarios and strategies under: comfort cooling in buildings; cooling for transportation; cold chain & refrigeration; air conditioning & refrigeration technologies; servicing sector and cross-cutting policy and regulations.

SMART ENERGY MANAGEMENT IN DIFFERENT SECTORS

Cities are complex ecosystems that cover a wide range of areas including buildings, mobility, water management, waste management, and public services. To understand the potential of integrated SEM for Indian cities, the Workshop focused on identifying the challenges and opportunities for adopting SEM. The deliberations centred around existing policies and strategies that apply to urban SEM in different sectors such as buildings, waste management, water management, transportation, and public services.

Drawn on the findings of the Workshop, the following discussion identifies SEM solutions and strategies for each sector and the challenges that hinder the adoption of SEM in Indian cities (Figures 2 & 3).

Enhancing sustainable energy management of buildings

Old or new, public or private-owned, commercial or residential, single or multi-occupant, buildings are facilities where people live, work, and play. They form the landscape of a city and are home for its people. At the same time, buildings are the largest energy consumers. Buildings account for over 40% of India's energy consumption – this will soon increase to nearly 60% (Chedwal et al., 2015). In buildings, a variety of energy services such as cooling, heating, hot water, lighting, electricity, and natural gas, are used every day to achieve occupant safety and comfort. These amenities (considering construction and energy usage) are responsible for three-quarters of total GHG emissions in urban areas (Calvillo et al., 2016). Therefore, cities need to make their buildings and housing energy smarter: more efficient, green, and sustainable.

The main objective of SEM solutions in buildings is to minimise the environmental impact of various energy services on the building lifecycle and reduce energy costs (Mosannenzadeh et al., 2017). They should be able to optimise energy consumption and demand, manage occupant comfort, and help create household energy independence that will help sustain the grid (ibid.). SEM solutions in buildings fall into three categories based on their applicability: i) solutions that address energy consumption by providing efficient control of building energy systems; ii) solutions that deal with energy demand response; and iii) solutions that integrate

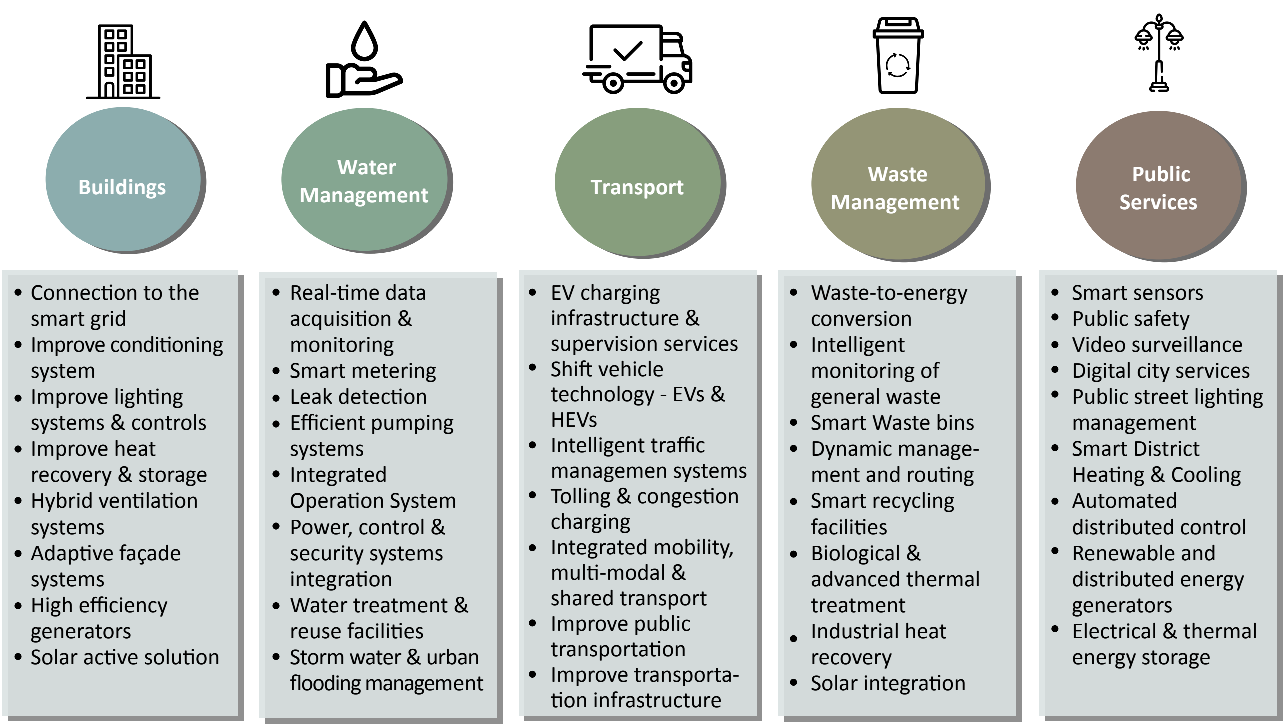


Figure 2: SEM in different sectors

solar passive design and sustainable materials (Calvillo et al., 2016).

By integrating energy generation, storage, distribution and automation, the solutions in the first approach provides greater comfort, functionality, and flexibility. In fact, optimisation of operation and management can save 20% to 30% of building energy consumption without changing the system structure or hardware configuration (ibid.). Within this approach, variable speed chillers, home temperature automation control systems, and adaptive fuzzy comfort controllers are latest focus of smart Heating, Ventilation, and Air Conditioning (HVAC) systems efforts. Lighting controls and features such as appliance control gears, day lighting integration using Building Information Modeling (BIM) tools, occupancy sensors, fixtures with photometric characters, and light-emitting diode (LED) lamps are common smart lighting solutions.

Demand response is another approach. In general, most buildings are passive consumers of energy. However, in order to achieve the desired energy objectives, the role of buildings must shift from being passive and unresponsive energy users to active participants in the energy system (Karnouskos, 2011). This paradigm shift can be achieved by demand-response schemes facilitated by micro-grids, by applying information and control systems to manage loads and consumption, and by energy storage devices (Calvillo et al., 2016). Within the micro-grid concept, other variants are commercially available, based on the scale and type of application: i) nano-grids (from one household up to a small building or small group of houses), ii) combined heat, cooling and power systems, district energy networks and micro-grids with controlling and scheduling renewable sources and storage on a medium-size scale (neighborhood, district, or small town) (Guan et al., 2010).

In the passive-systems area, elements to consider include building thermal insulation, thermal mass, window placement and glazing type, and shading (Pulselli et al., 2009). Solutions in other approaches are most effective when combined with building insulation and solar passive solutions.

Some of these smart building energy solutions are already being implemented in Indian cities. For example, smart metering, smart lighting, smart grid and energy internet, rooftop solar, net metering, LEDs, day lighting, and smart HVAC systems are being used to achieve a smart building architecture (Arunkumar and Malur, 2018). However, due to insufficient knowledge and limited expertise (Rana et al., 2018), many other advanced solutions (e.g., Smart Building Energy Management Systems, micro- and nano-grids, home automation controls) are limited to small-scale or pilot projects. The large-scale application of SEM technologies in buildings will help engineers, planners and designers in India to achieve the lowest energy cost targets and zero environmental impact on the building life cycle.

With the Smart Cities Mission and the mission of harnessing renewable energy, the future of smart energy technologies in Indian architecture is very bright, and this area will significantly contribute to the future of the technological revolution. In addition, by deploying smart technologies, conventional buildings can be transformed into smart energy buildings.

Improving the water–energy nexus

In order to ensure the effective management of water, the nexus between the water and energy sectors cannot be ignored. Water is a basic requirement for meeting the energy demand and supply. Evidence shows that thermal power plants account for 87.8% of the country's total industrial water consumption (TERI, 2017). However, the water sector currently faces several problems and challenges that hinder the effective management of water resources. For example, India accounts for 18% of the world's population, but only 4% of its water resources (TERI, 2017). Due to limited resources, the per capita water availability is on a decline, which increases resource pressure on the country's energy requirements. There is also loss of water in urban supply systems due to inefficient distribution mechanisms.

A major concern in management of the water–energy nexus is that the supply systems have been functioning independently. An integrated approach is required to ensure that the energy and water sectors are not managed in silos.

SEM of water generally refers to "a holistic approach to managing this priceless resource, and the infrastructure systems surrounding its sourcing, treatment and delivery" (Environmental Leader, 2018). SEM is needed to identify energy utilised for water consumption, supply and distribution—either for public or private usage. This will improve efficiencies in the water systems and reduce wastage.

Smart technology in the water sector usually consists of four components – (a) Digital output instruments (meters and sensors), which collect and transmit information in real time; (b) Supervisory Control and Data Acquisition (SCADA) systems, which process information, and remotely operate and optimise systems; (c) Geographic information system (GIS), which store, manage, and analyse spatial information; and (d) Software applications, which support modelling infrastructure and environmental systems by managing and reporting data to improve design, decision-making, and risk management (Development Asia, 2018).

Water is a significant requirement for coal-based power plants, nuclear power plants as well as for renewable energy production. The different stages where water is utilised indispensably include extraction and refining of fuel and in thermal production of electricity. A Reservoir Water Supply System helps to optimise water supply levels by estimating demand (Development Asia, 2017). Other systems that support water monitoring are the Real-time Hydrological Data Acquisition and Processing Systems that collect water levels, water quality, and other relevant data via satellite imaging and other communication technologies; and the Generation Integrated Operation Systems that monitors dam and weir operations remotely (Ibid.).

The energy demand sector includes the agricultural, construction, industrial, and household energy sectors (TERI, 2017). For example, the percentage of households with electricity supply increased from 55% in 2001 to more than 80% in 2017 (CPR & Prayas, 2017). This scenario reflects the increase in household energy demand and the consequent water demand. MoHUA's Smart City Mission aims to implement smart water solutions that collect real-time meaningful and actionable data from existing water networks (Vaidya, 2018). Utilities can use this information to effectively distribute water. The Mission's emphasis on Artificial Intelligence (AI), smart sensors, and technologies will improve leak detection by pinpointing leak locations, eliminate false leak alarms, enhance real-time monitoring of the network, and improve water quality issues and customer services (Vaidya, 2018). An efficient pumping system is a key strategy to improve the household water management. Emphasis on the reuse and recycling of wastewater in buildings should be supplemented by a decentralised water purification system at the city level.

To reduce the energy footprint of water and minimise wastage, Indian cities have begun to take some measures. The efficiency of water pumping systems is being improved in cities with appropriate rationalising and pricing mechanisms. In *Bengaluru*, some apartment buildings have been built with smart water metering, which facilitates hourly water tracking and remote management of leaks (Raj, 2018). The Indian Green Building Council's (IGBC) Green Cities rating system provides incentives to reduce water consumption and aids reduction by metering and monitoring water consumption. Alternative energy sources are also being utilised in high water-consuming sectors. For example, solar energy is being used for electricity generation to ease the burden of water-intensive thermal power production processes.

In order to integrate SEM into the water sector, several factors need to be considered. Some of the challenges facing the water sector are the lack of proper metering, wherein the true cost of water prices is not calculated. Evaluation and water pricing mechanisms to measure the efficiency of the water systems (e.g., pumps) are rare. The automation of the water systems is very limited. The limited capacity of a household to heat water at any time (e.g., sun availability) is a challenge for renewable energy in water sector. In addition, spatial, temporal, socio-economic changes, and other political conditions can affect water availability. With the help of SEM practices, water and energy losses are bound to decrease and the efficiency of the water system can be improved.

Achieving smart and low-carbon mobility

Transport plays a pivotal role in the development of a country. A transportation network fosters passenger and freight movement across the country, thereby increasing national productivity and socio-economic growth. The increase in transport demand has made the transport sector one of the most energy-intensive sectors in India. Currently, the total energy consumption in transport sector is 24% (TERI, 2018), and 98.5% of the total energy consumption is based on petroleum products (TERI, 2016). The transport sector accounts for 13.2% of the carbon emissions from fuel combustion, with road transport accounting for the highest share of 87% (UIC/IEA, 2016). Amidst the growing concerns of energy security and climate change, there is a realisation that the transport sector should lower its dependence on fossil energy, overall energy consumption and carbon footprint.

The energy consumption and carbon emissions of the transport sector are typically determined by factors such as vehicle efficiency, vehicle use and distance travelled, fuel and energy types, and overall system efficiency of transport infrastructure (Gulati, 2012). To promote energy-efficient and low-carbon growth in the road transport sector, the government has introduced several policies and programs across passenger and freight segments. The main focus of the policies in this transport segment is on the improvement of vehicular technology through the implementation of progressive fuel efficiency norms and electrification.

With an objective to promote energy-efficient low-carbon growth of the road transport segment, government has introduced two major programs: the Vehicle Fuel Efficiency Program and the National Electric Mobility Mission Plan (NEMMP) 2020. These are applicable for both passenger and freight road transport in India and are being implemented in a phased manner. Under the Vehicle Fuel Efficiency Program, the implementation of Fuel Economy is an effective regulatory instrument to reduce the average fuel consumption of vehicles. In 2017, the Ministry of Road Transport and Highways (MoRTH) came up with the first set of fuel economy norms for Light Duty Vehicles (LDVs) in passenger segment. These standards are based on the Corporate Average Fuel Economy (CAFE) norms and define the targets in terms of fuel consumption in litre/100 km.

Under the NEMMP, launched in 2013, the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme was launched in 2015 by the Ministry of Heavy Industries and Public Enterprises to incentivise the

production and promotion of electric vehicles (EVs). In addition to the private vehicle segment, the government has introduced EVs in multimodal public transport. In 2017, Nagpur became the first city in India to launch an electric mass transit project in India. A fleet of 200 electric vehicles (100 electric taxis and 100 e-rickshaws) was procured, and a cab aggregator provided the service platform for running the EVs. Further, several mobility solutions such as public bicycle sharing scheme, intelligent transport management systems, electric feeders for last/first mile connectivity, integrated transport management platforms, and development of ICT applications have been proposed by several smart cities within the Smart Cities Mission.

The future of low-carbon transport should be highly efficient electric cars running on renewable electricity, a shift from private cars to public transport, better urban planning and investment in options that promote non-motorised transport (NMT) such as cycling and walking. As the transport sector has implications on various other sectors, a cross-sectoral approach that incorporates reviewing of economic and environmental feasibility of sustainable mobility options should be undertaken. To achieve sustainable and low-carbon mobility in cities, the challenges highlighted in the discussions were the need for contextualised transport choices, informed decision-making by policymakers, and sensitisation of policy to citizens.

The recommendations suggested in the discussions included the promotions of cab aggregators/service providers such as Ola and Uber and provision of subsidies for EVs. NMT options, such as cycling, observed in various European countries, were highlighted as a recommendation. An agile approach to policy was discussed wherein going back to traditional planning methods and regulations were suggested as a viable option. Cities also need to promote innovative solutions using ICT and efficient data and energy management. Policy inputs from all sectors need to be taken into consideration. Policies for transport sector should not be developed in isolation. The way forward would thus involve a mandate of mobilising SEM at the national level as part of the vision on smart cities.

Optimising waste management processes

From 2000 to 2015, the urban population of India almost doubled, while the amount of waste generated by the population increased by 2.5 times (Sachhdeva, 2018). In addition, while the urban population has an annual growth rate of 3%–3.5%, urban waste generation is expected to increase by 5% per year (Sambyal, 2016). In this scenario, solid waste management is a major concern for cities. It is estimated that India's waste generation will reach 436 million tons by 2050 (NIUA & BEE, 2015). Effective waste management requires data management and integration at different levels, promoting the private sector and developing linkages between different sectors. Further, municipalities will need to focus on developing institutionalised and environment-friendly mechanisms to support proper waste disposal and better quality of life.

Intelligent energy management solutions that convert waste into useful energy can reduce the amount of waste generated and optimise the waste management process. A typical Waste to Energy (WTE) plant usually requires a minimum input of 300 TPD solid waste so as to make the system economically viable (Arunkumar and Malur, 2018). If large amounts of urban waste generated can be converted to energy, it can reduce the burden on conventional energy sources and the need for open space to dump unrecyclable waste. By 2050, India's WTE potential is estimated to become 556 megawatts (MW). However, these plants require diligence, adequate supply of quality waste, market infrastructure, and technical capacity (NIUA & BEE, 2015). Through proper support and the provision of smart technologies, municipalities can develop an active energy generation sector that has co-benefits for other sectors.

Effective technologies can be used for SEM in different areas of waste (collection, processing, and disposal). For example, Radio Frequency Identification (RFID) technology, Global Positioning System (GPS) routing systems and vacuum systems can reduce the time and effort spent on collection. In waste treatment facilities, mechanical biological treatment and refuse-derived fuel (RDF) facilities ensure proper disposal of hazardous waste. Moreover, sanitary landfills, bioreactor landfills, and solar integration mechanisms are treatment technologies that help convert excess waste into profitable energy.

The informal waste recycling industry is the entry point for introducing innovative and smart solutions. For example, intelligent recycling solutions ensure that informal waste

sorting methods, such as manual rag-picking at landfills before the segregated waste is sent to recycling plants, are not only technically more advanced but also faster and safer to use for the workers. As a way forward, a smart waste management plan needs to be supported with the concept of circular economy.

According to *Swachh Bharat Mission* (Urban) data for 2018, 43% of the total urban wards in India are now segregating their waste at the source (Sambyal & Agarwal, 2018). In 2017, door-to-door collection coverage increased from 53% to 80% (ibid.). In cities such as *Panaji, Indore, Mysore* and *Muzaffarpur*, there is a waste separation system, wherein separated waste is brought to the processing centre. Then, compost is made from wet waste, while only inert waste goes to the landfill. Sambyal (2016) elaborates that *Alappuzha* in *Kerala* prioritises segregation and reuse of waste at the household level, making it one of the cleanest cities in India. It has accomplished decentralised waste management; 80% of the households now own biogas plants and pipe composting systems. As part of the Clean Home Clean City programme, *Alappuzha* launched *Thumburmuzhi* in 2013, a model aerobic composting plant that composts animal carcasses (Sambyal, 2016).

A key challenge facing the waste sector in India is the need to increase manpower at the collection level. Waste segregation is an important obstacle and remains a daunting task. Despite the existing intelligent mapping and routing technologies, the segregation of waste, especially at the household level, is still limited. The sector requires a higher utilisation of economical and user-friendly technical solutions. Another core issue in the sector is the lack of accountability and transparency resulting from the monopoly and control of a small number of private companies. Due to the limited knowledge of stakeholders (sometimes corruption) and the lack of innovative solutions, the methods used are not the optimal for effective waste management. Therefore, it is important to develop capacity building and awareness programs for responsible authorities and relevant citizens to respond to behavioral changes and incorporate smart practices into the waste management sector.

Enhancing efficiency of public service delivery

As competition between cities in India becomes more and more intense, city governments must increasingly work to ensure a high quality of life for their citizens. The quality of public services plays an important role in making a city an ideal place to live and work (Albino et al., 2015). In cities, a range of public services such as street lighting, security management, video-surveillance, weather systems, and communication infrastructure provide safety, security, and information for citizens, while increasing the cities' competitiveness (Belanche et al., 2016). These public services need to be integrated with smarter, more energy-efficient, and more innovative solutions for better service operations, management, and governance.

SEM in public services helps city governments and utilities maintain and improve energy use, and to maximise the efficiency and quality of city services. Three different types of SEM solutions exist in the public services sector: i) solutions that conserve, control, and monitor energy generated and distributed by utilities; ii) solutions that store energy generated by customers or third-party members or utility grid; and iii) solutions that generate energy from natural resources, thereby creating relative or total energy independence from the grid (Calvillo et al., 2016).

A smart grid is an important solution in delivering electricity from utilities to industrial, commercial, and residential zones in an efficient, reliable, and secure manner (Calvillo et al., 2016). A smart grid is composed of separate energy networks capable of exchanging power and operating independently in real-time (ibid.). With the aid of such intelligent grids in micro/macro scales, not only the wasteful use of energy can be decreased, but also the utilisation of renewable energy can be increased (Hossain et al., 2016). Smart sub-stations and smart metering are the next steps in this direction. Existing evidence highlights that smart substations (Huang et al., 2017) and advanced metering infrastructure (Sharma and Saini, 2015) improve continuity of distributed supply and also have a positive impact on energy savings.

Energy storage solutions (ESS) are used to store different kinds of energy (e.g., electric, thermal, kinetic). Within city public services, ESS can be used to integrate renewable energy and in the delivery of demand-response schemes. An important advantage of ESS is that customers or third-party energy producers can store energy from the utility grid during lower price periods, and use it during higher price periods. Recent advances in energy storage technologies include batteries (sodium–sulphur, sodium–nickel chloride, and lithium-ion), super conducting magnetic energy storage (SMES), super-capacitors, flywheels, hydroelectric storage, hydrogen fuel cells, compressed-air energy storage, thermal storage and hybrid ESS (Calvillo et al., 2016; Dubal et al., 2015). Key applications of these technologies include battery-based systems for grid, micro-grid, and small-scale renewable energy technologies, smart charging plug-in for

EVs, thermal ESS for thermal energy technologies used for residential, commercial, and industrial use.

Finally, it is important to note that one of the goals of a smart city is to gradually migrate its electricity, thermal, and data infrastructures to a full renewable energy scheme (Mathiesen et al., 2015). Cities around the world are proving that cities that rely solely on state/national grids are not smart and are rethinking how to localise electricity consumption, provide low-carbon heating and cooling, and recycle energy and resources within the city to maximise effectiveness. Solutions that support this approach include renewable energy technologies, such as solar photovoltaic (grid-connected, rooftop, off-grid, new solar technologies), solar thermal collectors, concentrated solar-power plants, small-scale and utility scale wind turbines, and geothermal energy. Less impactful, other non-renewable sources, such as combined heat and power (CHP) with natural gas and biomass generation, can be better alternatives to conventional generation.

City governments and utilities in India are already implementing a few smart energy solutions in public services. For example, city-level district cooling systems, smart grids, smart metering, net metering and integration of renewables are planned or already being used (Arunkumar and Malur, 2018). However, lack of effective policy and regulations at the central, state, and city levels along with inadequate guidelines, standards, and business models, act as barriers for large-scale utilisation of widely available public-service based SEM technologies (e.g., energy storage, smart micro-grids). In addition, integration of information modelling into smart city management infrastructure (climate monitoring stations, lighting and outage management controls, underground utilities monitoring infrastructure, and data and communication management stations) is a key thrust area.

After the recent announcement of 100% electrification, the GoI is making all efforts to provide 24X7 reliable power supply for all citizens and facilitate delivery mechanisms that are reliable and transparent. Further, with the launch of the Smart Cities Mission, water and gas utilities, transport, telecommunications and disaster management organisations will need to be equipped with latest technologies for improved operational efficiency and successful integration into the smart city systems. It was highlighted in the workshop discussions that for service delivery, both private contractors and public authorities would have to work together to ensure tools for SEM are utilised for achieving a primary objective of public safety of citizens. The application of SEM solutions in public services can help achieve these targets through efficient distribution and transmission planning, transformation of utilities, and technology transition (Mosannenzadeh et al., 2017).

Buildings	Water Management	Transport	Waste Management	Public Services
• Limited energy storage, heating & cooling technologies • Insufficient knowledge and expertise for increasing efficiency • Limited use of smart building architecture techniques • Limited use of renewable energy sources • Low-scale implementation of innovative projects	• Inefficient supply and distribution systems • Low emphasis on reuse & recycling of wastewater • High water losses • Limited smart technologies & real-time data collection • Lack of decentralised treatment systems • Limited utilisation of alternate energy sources	• Lack of contextualised low-carbon mobility solutions and energy-efficient infrastructure • Limited enforcement of progressive fuel efficiency norms • Low penetration of eco-friendly vehicle options • Limited public transportation facilities • Low integration of ICT solutions and data management	• Low manpower resources and lack of citizen awareness • Absence of effective waste segregation, and smart technologies for waste management • Limited waste-to-energy conversion • Limited intelligent recycling solutions • Lack of overall accountability & transparency	• Low integration with smart systems • Limited utilisation of renewable energy solutions • Limited delivery of low-carbon public services • Insufficient data management & infrastructure for operational efficiency • Lack of inter-departmental coordination • Ineffective policy & regulation frameworks

Figure 3: Challenges of SEM in different sectors

KEY OVERALL CHALLENGES

In addition to the sectoral challenges (Figure 3), there are a range of challenges that cut across through the different sectors. Overcoming these challenges is necessary to facilitate and accelerate the successful accomplishment of SEM projects. Therefore, it is important to identify these challenges in order to efficiently allocate efforts and resources to abate the key obstacles hindering effective action. For a better understanding, the challenges and implementation barriers for SEM have been enumerated below:

- **Policy** – India lacks long-term and consistent SEM plans and policies. Despite, or perhaps because of, overlapping policies and complex urban governance arrangements, SEM governance in India remains fragmented and lacks political commitment and support on the long term.
- **Administrative** – There is a lack of portfolio alignment between different sectors, and lack of good cooperation and acceptance amongst partners remains a major challenge. Long and complex procedures for authorisation of project activities, complicated and non-comprehensive public procurement, difficulties in the coordination of high number of partners and authorities, and fragmented ownership are major barriers for scaling-up of projects. Public participation is rare and resources (institutional mechanisms, human, infrastructure, and skills) to disseminate information are limited.
- **Legal and Regulatory** – The extent of favourable and effective regulations, and financial incentives for innovative and new technologies is insufficient. The lack of consistent regulations to standardise technologies is a major barrier.
- **Market and Financial** – Limited access to capital and insufficient external financial support/funding for projects combined with economic crisis, risks and uncertainty in new technologies, and high costs of products and materials remain impediments for large-scale application of SEM solutions.
- **Socio-Environmental** – Government-led initiatives, such as demonstration and pilot projects, are needed for the majority of SEM actions in India. Negative effects of SEM-related (e.g., solar and wind projects) project interventions on the social and natural environment may create inertia and interest in public (Yenneti et al., 2016).
- **Technical** – Procurement businesses, skilled and trained personnel. and proven and tested solutions and examples are insufficient. Industry interest in SEM projects is limited, voluntary, and without strong influences, as the area is new, and full of risks and planning deficiencies.
- **Information and Awareness** – There are very few information tools and educational resources to help public and businesses uptake SEM solutions. Awareness amongst public authorities, potential users, and consumers is very weak. SEM solutions are commonly perceived as complicated and expensive by governments, industry, and the public.

WAY FORWARD FOR ACHIEVING INTEGRATED SMART ENERGY MANAGEMENT

Transforming India's urban centres into energy-efficient and sufficient cities requires integration of energy management in different sectors. SEM can only be achieved through collaborative effort and commitment across governments, practitioners, utilities, regulatory commissions, and industry. There is a range of actions that governments and policymakers can promote to address energy-related challenges and achieve successful SEM in cities.

Integrated policy governance and effective decision-making

Energy management has traditionally been a part of either national or state government policy, while urban development and smart cities fall under the purview of state and city-level governments. As the relation between energy and urban development becomes stronger, integration of SEM initiatives into all relevant government policies and operations become imperative. This should be supported by effective decision-making processes.

Better governance will help the central and state governments, and other stakeholders involved in different sectors to better coordinate to improve the effectiveness of energy management in smart cities-related policy decisions and public participation.

SEM can be converged with the existing policy programs by:

- Establishing an inter-sectoral coordination committee that ensures integration, cross-referencing and liaison between appropriate organisations in buildings, transport, water and waste, and public services.
- Including SEM frameworks and initiatives in amendments or reviews of relevant national and local policies, such as Smart Cities Mission, relevant missions under the NAPCC (e.g., NSM, NMSH and NMEEE), city master plans, urban development plans, building regulations, urban sectoral policies, and procurement arrangements.

Each of these actions can promote accountability and transparency in the decision-making process, which will contribute to smart energy governance in smart city development.

Provide better resources and infrastructure for technological advancements

Resources, such as humans and equipment, are required for performing the intended SEM functions in smart cities. Funding and developing infrastructure for large-scale applications of SEM initiatives remains a challenge, therefore governments must focus on innovative financing

mechanisms and participation by both the public and private sectors. Governments should introduce adequate resources to drive informed decision-making, for investment prioritisation in technology development, and to promote the scaling-up of SEM initiatives.

Policies and resources that support continued R&D of new technologies is crucial for promoting large-scale applications of SEM initiatives in cities. Domestic R&D reduces the relatively high import and capital costs of smart energy technologies, enhances the possible revenue streams of smart energy technology businesses through increased applications in ancillary services markets, and promotes the viability of advanced and next-generation smart energy technologies (Zame et al., 2018). R&D funding for smart energy systems and technologies should include such diverse areas as the smart grids and meters, district heating/cooling, building automation and control systems (BACS), energy storage technologies, and high efficiency distributed energy systems.

Pilot and demonstration projects are particularly critical to demonstrate the feasibility of new technologies. Successful demonstrations reduce the risk of investing in these technologies and help secure private investments in large-scale smart energy technologies and systems (Zame et al., 2018). Examples of technologies that have shown to be feasible through small-scale demonstration projects include co-generation, tri-generation, compressed air energy storage (CAES), and next-gen battery technologies (such as sodium-sulfur batteries and liquid electrolyte low batteries) (Sioshansi et al., 2012).

A combination of resources, infrastructure, R&D and pilots is essential to reach the full potential of an effective SEM system as envisioned in this document.

Develop information, education and communication (IEC) strategies for stakeholder awareness and engagement

Policies, actions, and programs that increase stakeholder engagement, induce behaviour change, encourage the adoption of smart energy solutions amongst the home and business stakeholders, and increase education and awareness amongst the public, private sector and other stakeholders are necessary. Primarily, policies and initiatives that inform the public and stakeholders about the benefits of SEM can be implemented.

Some of the suggested measures are listed as follows:

- Develop and implement a range of fiscal incentives, grants or subsidies, access to finance, tax breaks, and product rebates can be employed by governments to engage business, industry, and civil society.
- Promote media campaigns (TV, radio, press, social media), printed materials (such as brochures, pamphlets, advertisements, posters, leaflets, and electronic newsletters), national campaigns and competitions, conferences and events, online tools and websites, and exhibitions.
- Engage business, industry 'champions', builders, planners, architects, transport networks, real estate organisations, energy consultants, and energy managers in enterprises in projects (e.g., community organisations in district cooling/heating projects), and outreach programs.
- Develop comprehensive guides, compendiums, data bases, and handbooks that bring together global and national best practices, examples, methodologies, technology solutions, and existing policies, measures, and programs.

Establish performance goals for effective implementation and monitoring

The effectiveness of policy implementation depends on the performance outputs. To this end, governments should set a range of performance targets and measures to achieve the required outcomes. A long-term performance framework should be developed to ensure on-going SEM initiatives and intrinsically energy-efficient and -sufficient new assets. The framework could include specific responsibilities and obligations for agencies, accountable for managing sectoral policies, setting goals, monitoring performance and reporting against these goals, and measuring outcomes.

The performance goals could be of different types:

- quantitative goals (e.g., energy use targets in terms of a performance indicator, target level of renewable energy as a percentage of total energy use, target level of GHGs)
- action-oriented goals (e.g., upgrade nominated facilities, launch awareness programs)

The performance goals should be periodically monitored, analysed, and updated to realise the government's commitment to the policy. This information shall be assembled for annual reporting purposes, where appropriate (e.g., all annual reports and management plans). The information shall include details for each sector (e.g., buildings, transport, public services).

Governments should use each of these recommendations as a starting point; the recommendations are not intended to be prescriptive or exhaustive.

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The Energy and Resources Institute (TERI) is an independent non-profit organisation, with capabilities in research, policy, consultancy and implementation. TERI has multi-disciplinary expertise in the areas of energy, environment, climate change, resources, and sustainability.

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