# 7. URBAN ENERGY SYSTEMS IN INDIA: INSIGHTS FROM COMPLEX SYSTEMS THINKING

**Naresh Signh and Poorva Israni**

## ABSTRACT

*The fossil fuel-based energy systems require accelerated transitioning towards renewable energy provisions in order to reduce carbon emissions. Urban energy systems are commonly called socio-technological systems, that have interconnections with the political, environmental, and economic landscape of the urban areas. These inter-sectoral linkages, the constant evolution of stakeholder's priorities and relationships, and their conflicting objectives in the urban energy landscape make urban energy systems a complex system. Asserting the need to comprehend the challenges of transitioning towards sustainable energy systems, it appears desirable to view urban energy systems as complex systems. Based on recent literature on urban energy systems and complex systems thinking, the paper initially discusses the characteristics of urban energy systems. It aims to demonstrate the relationship of urban energy systems with social, technological, environmental, political, and economic aspects of urban areas. It further emphasizes the need and the approaches to recognise urban energy systems as complex systems due to the presence of factors, such as multiple stakeholders, the interconnectedness of the agents, changing dynamics, and adaptive processes in the systems. This paper takes the case study of the city setting of Bhopal, Madhya Pradesh, and considers its urban Solar City Master Plan to better understand the essence of complex energy systems. Against this background, the aim of the paper is to understand the application of complexity economics and systems thinking to the transition of urban energy systems from fossil fuels to renewables. In addition, the paper intends to explore how examining the urban energy systems through the lens of complexity economics and systems thinking can be valuable in formulating policy interventions towards sustainable urban energy transitions.*

Key Words: energy systems, urban, system thinking, energy transition, energy policy, sustainable energy

## INTRODUCTION

Fossil fuel-based energy systems require accelerated transitioning towards renewable energy provisions in order to reduce carbon emissions. The path to achieving a low carbon economy significantly entails the substitution of fossil fuel-based energy options with renewable energy alternatives. Decarbonisation of the energy sector is critical to reduce energy-related carbon dioxide emissions and to subsequently mitigate the effects of climate change. Globally, most of the energy usage has been in urban areas. In this context, it becomes crucial to understand urban energy systems as they are central to sustainable energy transitions.

In responding to the impacts of climate change, several countries in the world, including India, are looking for energy transition pathways. The energy transitions entail a substantial shift from fossil fuels to renewables. The data shows that approximately 75 percent of the final global energy is used in the urban areas, and these urban areas are responsible for approximately 70 percent of the global carbon dioxide (CO2) emissions (Bai et al., 2012). Contemporarily, India is the third-largest energy user in the world, contributing to 7 percent of the global anthropogenic greenhouse gas (GHG) emissions in 2018 (Tong et al., 2021). Additionally, data from Oxford Economics shows that 17 amongst the top 20 fastest-developing cities in the world are situated in India, Surat being at the top of this list""""""(Global Economic Research: 17 of 20 Fastest-Growing Cities in the World Will Be from India, n.d.). This urban evolution will include energy provisions for residential and commercial buildings, urban mobility, and other urban spaces, eventually adding to the global energy consumption. India is witnessing rapid urbanisation, leading to an increase in GHG emissions. India's per capita CO2 emissions stand at 1.8 tonnes, which can be considered much lower than the world average of 4.2 tonnes. However, in 2017, India's CO2 emissions increased by 4.6 percent. Since then, the country's CO2 emissions have accelerated steadily, with an average growth rate of 6 percent in the decade of 2007-2017 (Andrew, 2017). This can be attributed to India's increasing population and non-eco-friendly urban development. Urban expansion thus opens up possibilities of incorporating and expanding renewable energy infrastructure along with improving the efficiency of energy usage. In this background, it can be implied that a thorough understanding of the urban energy systems in India is central to sustainable energy transitions and climate change mitigation measures.

While systems thinking as a concept is becoming popular in the sustainability space, interventions have failed in being systemic. For example, in sustainable urban planning, there has been an excessive emphasis on systems engineering and infrastructure than on people. At a global scale, most sustainability transformations are not driven by systems-wide change (Voulvoulis et al., 2022). A potential reason for this can be that the majority of interventions do not target root causes but instead deal with symptoms. At present, a complex systems thinking approach has not been undertaken and integrated in any country towards policy development dealing with the current transition to renewable energies. The fact that current socio-technical systems and the shift to renewable energy sources involve complex system dynamics is rarely acknowledged. This has hindered the adoption of finding alternative solutions to effectively adapt to the unpredictable change in the availability of energy as well as significant shifts to renewable energy sources. The understanding of complex systems thinking can help in identifying the path-dependent capabilitiesof solving the root and leading causes.

The link between urban cities and climate change interventions has been undergoing transformations, as the movement towards sustainable development has shifted the view of looking at energy management in cities to effective sustainable energy interventions and innovations in the urban areas. Earlier, cities were looked at merely as centres for energy demands.

However, the need to protect the environment due to the negative impacts of climate change has gradually led to the requirement of looking at cities as centres for sustainable urban governance perspectives and novel renewable energy technologies. The energy systems comprise a range of stakeholders such as producers, suppliers, distribution companies, and end-users. In the process of advancing towards energy transitions, the diverse range of agents in the energy systems can frequently have conflicting objectives. The stakeholders interact through physical and social networks which are institutionally and politically governed. In this context, the development of urban governance perspectives may vary as there are various stakeholder paradigms towards energy transitions. To accommodate the different stakeholder paradigms within the urban energy system, the governance structures have to consider the complex nature of the energy systems. To comprehend the complex nature and the policy challenges relating to sustainable urban energy transitions, it is pivotal to manifest the intertwined nature of the stakeholders of the urban energy systems. Urban energy systems are commonly called socio-technological systems, that have interconnections with the political, environmental, and economic landscape of the urban areas. These inter-sectoral linkages, the constant evolution of stakeholder's priorities and relationships, and their conflicting objectives in the urban energy landscape make urban energy systems a complex system as a whole (Keirstead and Shah, 2013).

## URBAN ENERGY SYSTEMS: A COMPLEX SYSTEMS THINKING APPROACH

Complexity theory provides a conceptual framework, a way of thinking, and a way of seeing the intricacies of the world. A complex system is characterised as a system that has heterogeneous elements that are interlinked, and constitute elements that adapt and transform over a period of time (Frank, 2017). Urban energy systems are largely composed of three elements—agents, objects, and the environment (Bale et al., 2015). The key agents in urban energy systems include households and business energy users, energy generators and suppliers, distribution companies, governments, and environmental regulators. The agents in the system interact with each other through networks under the influence of institutions and regulatory bodies, and they tend to have properties of adaptation and transformation. The objects in the urban energy systems include technologies, infrastructures, and environmental ecosystems. The objects change over time according to economic, political, and environmental circumstances. The third element is the environment, which encompasses social, political, and cultural facets within which the urban energy systems operate. The elements in the urban energy systems share information and learn from each other and are dynamic in nature. Against this background, urban energy systems can be understood as complex systems that have diverse and interrelated agents or objects. In addition, they exhibit complex social and technological dynamics, and can consequently be understood overarchingly as social-technological and social-ecological systems.

Complexity theory proposes that complex systems involve properties such as self-organisation, emergence, path dependence, non-linearity, evolution path and adaptive behaviour. In order to better understand the properties of complex urban energy systems, it is desirable to characterise the complex systems in conjunction with their applications to the urban energy systems:

**AGENTS** - Agents in a complex system are individuals or groups that interact with each other and are involved in the process of decision-making. Based on the conditions of the environment and their ability to influence each other, the agents adapt, learn, and respond in a system. The urban energy systems include diverse kinds of agents such as end-users, governments, power generators, suppliers, and regulators. For instance, end-users, power generators, and suppliers are in direct contact with each other in the urban energy system, and activities or decisions of one agent in the system have the ability to impact the other agents within the system. The activities and decisions of the agents are highly induced by the components of the environment such as regulations, government interventions, and technology.

**NETWORKS** - Networks provide pathways through which the heterogeneous agents in a system interact, and they have consequences for properties such as resilience mechanisms and the interrelatedness of agents (Bale et al., 2015). In urban energy systems, there can be physical and social networks, for example, there are network interactions among households or end-users, power generating companies, and distribution companies. The interactions aid in balancing the demand and supply in the urban energy system. In addition, the network interactions between agents and the technological environment in urban energy systems help in understanding user behaviour and preferences, which can be different for diverse agents. For instance, the preferences and interactions of large corporate bodies will differ significantly from the demands and preferences of emerging start-ups and organisations within the energy systems and for energy transitions.

**FEEDBACK LOOPS** - One of the key properties of complex systems is a feedback cycle. It is a cyclical structure of cause and effect. One initial change in the system is capable of inducing further secondary effects, eventually influencing the initial change. Feedback loops can be negative or positive. Positive feedback loops entail changes that increase the movement of the system away from its initial stage while negative feedback loops include those initial changes that aid in keeping the system in its original state. From the perspective of urban energy systems, increased investments in the clean energy sector can feed directly back into creating increased jobs and uplifting the local economy. Focus on a national green energy system has the capability to increase benefits for an economy, which further tends to create a cycle of economic and environmental gains. Moreover, another example of a positive feedback loop is the interactions between energy users, power generators and government institutions which influence the land use planning and management for clean energy infrastructure.

**DYNAMICS** - Complex systems are not always in equilibrium, and they are influenced by temporal or permanent changing aspects. In regard to urban energy systems, structural changes such as population dynamics, technological changes, and lifestyle changes take place. These changes can decidedly influence the dynamics of the energy systems. From a perspective of a policymaker, dynamics in urban energy systems are valuable to consider because they help in understanding the elements of a system and their embeddedness within the operational area. Taking into consideration urban environment planning, an emphasis on the dynamics of the system and their intra-interactions can be fruitful for effective program designing and implementation of sustainable energy transitions.

**CONTEXTUAL** - The elements and agents in urban energy systems are deeply embedded in the local context of the city. The urban infrastructure of a city will depend on various factors such as local economic activities, infrastructural forms, ecological systems, consumers, and their preferences and cultural backgrounds. Therefore, urban energy systems and energy transitions should be configured depending on the local context of a city. For instance, in India, the path towards sustainable energy transition should account for the societal systems, which are different in urban and rural areas. The significance of social systems should be acknowledged by observing the social preferences, types of livelihoods, and user consciousness to effectively contribute towards sustainable energy transitions.

**SELF-ORGANISATION** - A self-organising system can adapt autonomously in the system without any agent having complete control over the system (Basu et al., 2019). Urban energy systems can be self-organising, as there is no one agent that has overall control in the planning of the energy systems. There are multiple agents that make decisions at multiple levels, such as households, and governments at local and central levels, and the decisions of one agent can have implications for the complete system. In addition, the systems can be shaped by multiple policies and regulations of diverse agents. In the context of India, the formation of citizen groups and environmental advocacy groups as representatives of particular agents in the background of lack of political representation are examples of self-organisation. In terms of energy transition governance, self-organisation has the possibility to encourage faster adoption of clean energy in India.

**PATH DEPENDENCY** - A system evolves in particular directions based on its past interactions and networks. As the evolution of any system happens, dominant interactions and network patterns develop over a period of time, which eventually become norms and parts of the system (Basu et al., 2019). In urban energy systems, urban infrastructure such as grid systems and thespatial patterns of a city lead to path-dependence tendencies. These path-dependence bents are largely a reflection of historical and contextual factors, which may vary from one location setting to another. Furthermore, the path dependency of systems is a reflection of the adaptive and transformative nature of the urban energy systems.

**EMERGENCE** - The macro nature of a system emerges from the practices and interactions of microelements present within. The agents are not rational and are capable of having bounded rationality. In this background, the nature of the system cannot be predicted on the basis of past information because of the non-linearity aspect of the agents. Agents are subject to new types of interactions and can change their ways of conduct or operation. The existence of multiple non-linearities can exhibit aggregate trends and patterns but cannot predict the whole system and its subcomponents (Labanca, 2017). For instance, future energy demands cannot be predicted on the basis of past energy demands, because the emerging multiple non-linear factors in the system could be impossible to predict due to the interactions of the agents.

**CO-EVOLUTION** - In a complex world, systems co-exist with other systems. For instance, the urban energy systems are made up of subsystems along with being interdependent on elements such as water, transport, and food production, to name a few. The subsystems in the urban energy systems are technologies, government institutions and their regulations, energy users and their practices, and other ecosystems that collectively evolve. A change in one subsystem can impact other subsystems or the system as a whole. Inurban energy systems, environmentally conscious consumer behaviour can stimulate the need for new technologies or vice versa. The property of co-evolution is an important facet in public policymaking as stimulation in one component of the system can help increase the interactions between the other agents.

**LEARNING AND ADAPTATION** - The interconnectedness and constant interaction of the various stakeholders aid the agents to learn and adapt in the system, along with being able to retain the historic structures. Due to changes in the environment of the system, complex systems can adapt to take the advantage of the system variations. For example, smart meters give information relating to energy efficiency, and consumers can learn and adapt as per the information provided in the system. Likewise, the information can be in the form of technological and political changes.

## URBAN ENERGY SYSTEMS: RELEVANCE OF COMPLEXITY FOR POLICYMAKERS

The diverse nature of urban areas across the world signifies the need for considering complexity theory in urban sustainability governance and energy transitions. With the increasing focus of governments, policymakers, and development professionals on sustainable development, the focus is now shifting from linear approaches to multi-dimensional aspects of governance and advancement. A linear approach in policy designing is bound to produce externalities and unintended outcomes. To understand the multi-dimensional approaches needed towards effective urban sustainability governance, it is crucial to comprehend the complexity of the whole urban energy system and its subsystems. The identification and analysis of the complexities of urban energy systems are relevant for the policymakers, as they help perceive the existence of the non-linear interactions of agents, along with the uncertainty of the system. Grasping the uncertainties and non-linearities is central to effective public policy designing and implementation.

## CASE STUDY: BHOPAL'S SOLAR CITY MASTER PLAN

### 1. Bhopal City at a Glance

Bhopal is the capital city of the state of Madhya Pradesh, which is located in the central part of India. It is situated on a hilly terrain within the Malwa Plateau, lying between the geographical coordinates of $23^{0}16'$ North latitude and $77^{0}22'$ East longitude. The city is well connected through rail, road, and air, and is a major hub of educational, political, administrative, and industrial activities. In this context, Bhopal is one of the cities in the state that drives the economic progress of the region, and hence, it is viewed as an attractive destination for investments. The city is spread across 285.9 square kilometres, and it has a population of approximately 24 lakhs (District Energy in Cities Initiative, 2017). The major economic activities in Bhopal are manufacturing and engineering predominantly electrical goods and transportation equipment; tourism; and the administrative sector.

### 2. Bhopal's Solar City Master Plan

Bhopal has a humidsub-tropic climate with a hot summer season, mild and dry winters, and a humid monsoon season. The city has numerous lakes which add to its picturesque and pleasant weather. However, of late, global warming has been impacting the city of Bhopal, its famous lakes, and its huge green cover. According to the data from United Nations Environment Programme (UNEP), Bhopal's temperature has been increasing by 0.075 degrees celsius per year, which can be considered as a large increase as per climate change trends (Sirothia, 2016). Against this background, Bhopal aims to utilize its land parcels towards making itself a sustainable urban habitat.Bhopal is one of the cities to be selected by the Ministry for New and Renewable Energy to be advanced under the Development of Solar Cities Programme. Currently, Bhopal has an on-grid solar system that is connected to the city's main power grid. The installed inverters integrate the current from the solar photovoltaic modules with the current from the grid to provide electricity to commercial and residential properties. The solar systems in Bhopal can also offload the excess current, if any. Making headway, Madhya Pradesh plans large-scale solar energy projects to promote decentralised and off-grid solar applications.

Under the larger ambit of the Solar Cities Programme, Bhopal's Solar City Master Plan was developed in 2011, which aimed to reduce the energy consumption of the city by 17 percent by the year 2018, through the adoption of renewable energy infrastructure (District Energy in Cities Initiative, 2017). However, the state has not been able to meet its targets, as it has shown a consistent lack of decisive action. The plan has been disappointing in terms of physical advancement, and this can be attributed to delayed disbursement of funds from the government, unsatisfactory project planning and monitoring, delayed procurement planning, insufficient institutional capacity, lack of stakeholder consultation, and lack of technical and social awareness amongst the households and individuals for renewable energy and energy efficiency. Along with this, the planning of the Municipal Corporation of Bhopal towards making the city a solar city has paved the way for encroachment possibilities around the catchment areas of the lake ("Residents Point at Loopholes in City Master Plan Draft," 2020). This has led to conflicts between the citizens and the government administration as solar infrastructure near the lake areas can damage the water ecosystems of Bhopal. These loopholes have highlighted the complexity of the urban energy systems. In the context of Bhopal and its Solar City Master Plan,complexity theory can contribute significantly in three areas to understand the components of the urban energy systems and their interactions.

- **System Awareness of the Urban Energy System** - The diverse set of elements and their interactions in complex urban energy systems can be challenging to perceive. Therefore, it becomes important for all the stakeholders to develop an awareness of the system, including the system dynamics, path dependencies, feedback loops, interlinkages of the agents, and the capability to adapt and transform. In the case of Bhopal's Solar City Master Plan, various agents such as planning authorities, real estate developers, architects and civil engineers, electricity distribution companies, state energy agencies, environmental planning and pollution control, installation contractors, and end-users should conceptually map the urban energy system to better understand the various subsystems of the urban energy system. In due course, this can be conducive for energy transition infrastructure planning, urban policymaking, and strategy devising.

- **Interlinkages and Embeddedness of the Urban Energy Systems** - Cities are highly dynamic where urban energy systems and urban infrastructures are embedded parts of the larger system. This is in contrast to the conventional way of viewing cities as static, and as systems with fewer interactions. In this context, the urban energy system of Bhopal should consider the heterogeneity of the subsystems existing in a large system such as the water systems, forest areas, and local areas. This supports policymaking and urban governance by looking at the subsystems within the system and their multiple non-linearities.

- **Context of the System** - During urban sustainability planning and governance, it is crucial to consider the contextual foundation of urban areas, and its further implications on energy systems. The contextual foundation largely includes the type of terrain and present land use planning, types of population, the evolution of the city's energy system, awareness of the residents, and other nearby ecosystems. This will facilitateinterlinkages between urban areas and their energy systems, and their ability to shape and be shaped by each other.

## 3. Policy Recommendations

Urban areas and their energy systems have immense potential for sustainable transitions and climate change mitigation (Soni, 2015). In the interest of realising this potential, a resilient design for energy system infrastructure that can assess the non-linearities of the system is required. The following policy recommendations and key aspects can be adopted by policymakers in the city of Bhopal and overarchingly in other urban settings to stimulatesustainable energy transition practices:

- Policymakers should avoid the possibility of failures in sustainable energy transitions by taking a preventive maintenance approach. Catastrophic failures are not generated by the malfunctioning of broken units;they are created due to the relationships and interconnectedness between the sub-parts of the complex system (Dekker, 2011). In urban energy systems and their sustainable transitions, with the introduction of new technologies or a new policy in one urban energy subsystem, policymakers should assess and analyse their unexpected consequences on other subsystems to mitigate potential risks. The understanding of the connections in the system can aid in preventing errors by detecting the potential causes of failure and adverse events (Kumar, 2020). Moreover, this approach can be favourable to building resilient sustainable urban energy systems by identifying the impacts of diverse variables on the system and subsequently devising contingency plans. This approach of anticipatory management practices will build the skills of policymakers and leaders to foresee and adapt to emerging or actual adverse situations.
- For progressive transitions to renewables, along with the accelerated sustainable energy infrastructure, the emphasis should be placed on integration of social practices and technical innovation to capacitate the dynamic interactions between the renewable energy sources and energy end-users (Labanca, 2017). This can be done by taking into

consideration the current practices of energy consumers and focusing on their demand management for renewables. The policymakers should make a connection between the energy infrastructure and the behaviour of the people concerning sustainable energy transitions. There is a need to develop a new paradigm in social practices towards sustainable transitions by establishing configurations of technology, community practices, and climate education.Furthermore,it is important to recognize the significance of funding for indigenous technological advancement to upscale the renewable energy sector.

- Robust energy system planning requires taking into consideration various aspects such as energy access, affordability, secured energy supply, environmental impacts, and investment needs. For effective sustainable energy sector development, capacity building of the working staff and personnel is important. This can be done by a combination of online software training, workshops that provide hands-on experience, and courses that focus on strengthening technical capabilities.
- To enhance the capabilities of the leaders in sustainable urban energy systems, an outlook of complexity-informed leadership can be adopted (Styhre, 2002). The sustainable transition changes in the urban energy systems can be scrutinized by the leaders within a complexity theory framework. This will assist the leaders to question the linearities and direction of changes in the urban energy systems. Complexity-informed leadership will help people at the policymaking level and those in senior positions within the system to understand the organisational changes, which are dynamic due to succeeding activities and the interconnection among the activities.
- Sense-making tools are helpful in dealing with complex situations. In this context, strategic thinking using sense-making tools and techniques such as the Stacey Matrix and Cynefin Framework can be used. These sense-making tools can aid decision-makers by providing them with a

sense of place from which they can view their perspectives (Farrar, 2020). These tools can enable policymakers and leaders to equip themselves with the appropriate lens to view the contemporary and prospective approaches concerning sustainable urban energy transitions.

- The stakeholders in the urban energy systems should be thoroughly made aware of the urban energy systems as social-ecological and social-technical complex systems. A better understanding of the technical, ecological, and social interactions in the transition process can markedly improve the communications and reciprocal interactions among the consumer practices, technical systems, and non-human agents, andin due course, this canaccelerate sustainable energy transitions.

## CONCLUSION

Renewable energy is becoming an increasingly necessary source of powerglobally. Yet, there remains some technical challenges in the electricity network. For example, solar energy is clean and carbon free but is weather dependent and requires expensive energy storage systems. Hence, it becomes important to diversify the energy mix such that the energy grids can function without any disruptions. In this regard, viewing the energy sector within a systemic thinking framework can support the project planners, managers, and policymakers and concentrate the focus on energy security as well.

An understanding of urban energy systems through the lens of complexity theory contributes to identifying each element and their interactions within the system and beyond. It can be posited that there is great potential for policymakers and the government administration to gain insights into the different agents, interactions, dynamics, and potential outcomes of policy interventions in the urban energy systems. The complex systemic perspective encourages recognition of the dynamic and evolving interactions inside and outside the system and gives a considerably needed retreat from the contemporary linear approach towards sustainable energy transition interventions.

The challenge that remains with complex systems thinking is its large-scale adoption by the policymakers due to the intricate communication of its concepts and lack of substantial results of its applications. However, at present, complex systems thinking provides a significant starting point to think in a certain way about sustainability and other potential domains with significant development gaps. Hence, this field of study can have influential impacts on designing interventions towards sustainable urban energy systems. Although complex systems thinking is in its initial stage, it is capable of providing important contributions towards solving the global sustainability crises.

## REFERENCES


1. Frank, B. (2017). Urban Systems: A Socio-Ecological System Perspective. *Sociology International Journal, 1*(1), 1–8. https://doi.org/10.15406/sij.2017.01.00001

2. Grubler, A., Bai, X., Buettner, T., Dhakal, S., Fisk, D. J., Ichinose, T., Keirstead, J. E., Sammer, G., Satterthwaite, D., Schulz, N. B., Shah, N., Steinberger, J., Weisz, H., Ahamer, G., Baynes, T., Curtis, D., Doherty, M., Eyre, N., Fujino, J., … Sathaye, J. (2012). Urban Energy Systems. Global Energy Assessment (GEA), 1307–1400. https://doi.org/10.1017/cbo9780511793677.024

3. Global Economic Research: '17 of 20 fastest-growing cities in the world will be from India', *India News - Times of India.* (n.d.). Retrieved October 12, 2021, from https://timesofindia.indiatimes.com/india/17-of-20-fastest-growing-cities-in-the-world-will-be-from-india/articleshow/66978406.cms

4. Tong, K., Nagpure, A. S., and Ramaswami, A. (2021). All urban areas energy use data across 640 districts in India for the year 2011. *Scientific Data, 8*(1), 1–13. https://doi.org/10.1038/s41597-021-00853-7

5. Andrew, R. (2017). Why India's CO2 emissions grew strongly in 2017. Carbon Brief. https://www.carbonbrief.org/guest-post-why-indias-co2-emissions-grew-strongly-in-2017

6. Keirstead, J., and Shah, N. (2013). Urban energy systems: An integrated approach. Urban Energy Systems: An Integrated Approach, June 1–314. https://doi.org/10.4324/9780203066782

7. Bale, C. S. E., Varga, L., and Foxon, T. J. (2015). Energy and complexity: new ways forward. *Applied Energy, 138*, 150–159. https://doi.org/10.1016/j.apenergy.2014.10.057

8. Basu, S., S. E. Bale, C., Wehnert, T., and Topp, K. (2019). A complexity approach to defining urban energy systems. *Cities, 95*(March), 102358. https://doi.org/10.1016/j.cities.2019.05.027

9. Labanca, N. (2017). Complex Systems and Social Practices in Energy Transitions. In *Complex Systems and Social Practices in Energy Transitions 482*(May). https://link.springer.com/book/10.1007/978-3-319-33753-1

10. District Energy in Cities Initiative. (2017). http://www.districtenergyinitiative.org/india

11. Sirothia, A. (2016). Bhopal clocks 9 times faster temperature rise than global average. The Times of India. https://timesofindia.indiatimes.com/city/bhopal/bhopal-clocks-9-times-faster-temperature-rise-than-global-average/articleshow/53337876.cms
12. Residents point at loopholes in city master plan draft. (2020). *The Free Press Journal*. https://www.freepressjournal.in/bhopal/bhopal-experts-residents-point-at-loopholes-in-city-master-plan-draft
13. Soni, R. (2015). Climate Change induced warming impacts on energy requirements of Urban built environment: A case of Bhopal. *International Journal of Advanced Engineering Research and Science, 2*(3). https://www.researchgate.net/publication/317752603_Climate_Change_induced_warming_impacts_on_energy_requirements_of_Urban_built_environment_a_case_of_Bhopal
14. Dekker, S. (2011). Drift into Failure: From Hunting Broken Components to Understanding Complex Systems. In *Ashgate Publishing Limited 160* (10). https://doi.org/10.4018/978-1-4666-2509-9.ch011
15. Kumar, D. (2020). Urban energy system management for enhanced energy potential for upcoming smart cities. *Energy Exploration and Exploitation, 38*(5), 1968–1982. https://doi.org/10.1177/0144598720937529
16. Styhre, A. (2002). Nonlinear change in organizations: organization change management informed by complexity theory. *Leadership & Organization Development Journal*. https://doi.org/10.1108/01437730210441300
17. Farrar, M. (2020). Reinventing Finance for a Digital World. *Cgma.Org, 40*. https://www.cgma.org/resources/reports/re-inventing-finance-for-a-digital-world-strategic-thinking-supplement.html