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Optimising Energy Efficiency in India: A Sustainable Energy Transition Through the Adoption of District Cooling Systems in Pune

Gargi Patil*, Chandani Tiwari, Samruddhi Kavitkar, Rishab Makwana, Ryan Mukhopadhyay, Saana Aggarwal, Nishika Betala, Rishika Sood

Symbiosis School of Economics (SSE), Symbiosis International (Deemed University), 411004 Pune, India

* Correspondence: Gargi Patil (gargi.patil@sse.ac.in)

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Abstract: The global energy crisis presents a significant challenge that impacts not only human populations but also ecosystems and biodiversity. In India, the demand for energy has escalated rapidly, driven by industrialisation, urbanisation, and population growth, resulting in increased pressure on both conventional energy sources and environmental systems. This study aims to evaluate the Energy Efficiency (EE) and renewable energy policies in India, examining the balance between economic growth, environmental sustainability, and government action. The "E-score" methodology is employed to assess the EE performance across selected Indian states, highlighting critical gaps in policy implementation and providing insights into opportunities for improvement. Furthermore, the feasibility of implementing District Cooling Systems (DCS) in Pune is explored, with the city selected as a representative case study due to its growing urban landscape and climate challenges. The adoption of DCS, a highly efficient cooling technology, is considered a promising solution to address urban heat islands and reduce the energy consumption associated with conventional cooling methods. Through a comprehensive analysis, this research underscores the necessity of an integrated approach that incorporates economic, environmental, and social dimensions in the formulation of sustainable energy strategies. The study further advocates for proactive measures at local, state, and national levels to facilitate a seamless transition to renewable energy sources and achieve long-term energy sustainability. The findings emphasise the importance of developing adaptive policies that are aligned with the broader objectives of climate change mitigation, highlighting the potential of DCS as a key component in India's energy transition. By contributing to the understanding of effective energy management and policy frameworks, the study provides valuable insights for policymakers, urban planners, and energy practitioners in the pursuit of a sustainable and resilient energy future for India's cities.

Keywords: Climate change; Energy Efficiency (EE); District Cooling Systems (DCS); E-score; Pune; Sustainable energy transition; Renewable energy policies; Urban heat island

1. Introduction

Climate change encompasses long-term shifts in temperatures and weather patterns, predominantly caused by human activities such as burning fossil fuels, urbanization and extensive industrialization. This leads to rising temperatures, intensifying extreme weather events, biodiversity loss, and ocean acidification across countries worldwide. The frequency of weather-related disasters has greatly increased, with climate-related disasters growing by a factor of five over the last 50 years (1974-2024). The year 2023 has been recorded as the warmest year with global temperatures exceeding 1.5℃ above the pre-industrial levels for almost 50% of the days in a year (Climate Copernicus, 2024). In 2022, global energy-related CO_2 emissions were approximately 14.7 billion metric tons. Further, almost 3.6 billion people live in areas that are highly susceptible to climate change impacts (WHO, 2023).

Strategies to combat climate change include transitioning to renewable energy resources, enhancing EE, and implementing sustainable land-use practices. Furthermore, adaptation strategies are designed to bolster resilience to climate-related disasters. Despite progress in awareness and action, there is a pressing need for more ambitious global efforts in order to limit the temperature increase and mitigate its severe consequences. The urgency of addressing climate change is underscored by its profound impacts on ecosystems, economies, and societies worldwide, highlighting the need for collaborative and coordinated action at both national and international levels to mitigate its impacts and protect the planet for future generations (Evans, 2024).

EE refers to the practice of utilizing reduced amounts of energy to achieve equivalent outcomes, observable in residential, commercial, and industrial settings. This approach is crucial for addressing climate change while also mitigating elevated energy costs. Measures such as setting minimum appliance standards and using technological gadgets like smart meters and LED lighting have greatly helped the global community in this domain. Further supportive government policies, economic benefits, and international cooperation have played a vital role in fostering these efforts. However, the problem still continues, and some circumstantial and behavioral obstacles impede the common use of the energy-saving methods. These obstacles will require an unyielding commitment, investment, and innovation at local, national, and global levels (CLEAN, 2024).

EE is a significant part of the process of cutting down carbon emissions to net zero through the process of decarbonization. Consequently, technology is a potential energy saver that is oriented towards 'green' solutions, along with its purported benefits such as economic growth and lowered emissions. Yet only through further and targeted actions can climate change be comprehensively addressed. The cooperation of all governments, businesses, and civil societies worldwide is a prerequisite for speeding up the process of adopting energy-efficient technologies, thereby ensuring sustainable energy use for future generations (EPA, 2024).

The global perspective emphasizes the need for transitioning to renewable energy sources in order to mitigate climate change and improve energy security. The international community acknowledges the necessity of rapid technological innovation to facilitate this transition and achieve sustainable energy objectives. Energy transition scenarios at both the national and state levels continue to emphasize the significance of reducing energy demand and increasing the proportion of renewable sources in the energy mix. The implementation of policies and strategies that facilitate the transition to sustainable energy systems is a critical responsibility of governments at local, state, and national levels (Gallagher, 2013).

India's primary energy demand surged from over 450 million tons of oil equivalent in the year 2000 to approximately 770 million tons by 2012. Projections suggest that this figure might increase to 1,250 million tons—as anticipated by the International Energy Agency—and 1,500 million tons—according to the Integrated Energy Policy Report—by the year 2030. This expected growth is ascribed to multiple factors, primarily depending on escalating incomes and economic advancement, which subsequently stimulates demand for diverse energy services, such as lighting, cooking, transportation, industrial production, and office automation (Ministry of Power, 2024).

According to the studies conducted by World Resource Institute (WRI) 2017, India's carbon emissions contributed to nearly 6.65% of total global carbon emissions, standing at fourth place. While China tops the list (26.83%), USA (14.36%) follows, and the EU (9.66%) standing at number three. As per a report from the Centre for Monitoring Indian Economy (CMIE), India imported 171 million tons of coal in 2013–2014, which increased to 213 million tons in 2017–2018. Thus, it is imperative to find alternate and renewable sources for generating electricity. India will therefore need to have a swift transition to renewable energy technologies in order to attain sustainable growth and economic development and avoid catastrophic climate change-related issues (Blondeel & Van de Graaf, 2018).

The shift to renewable energy resources plays a vital role in securing sustainable energy with lower emissions for future generations. Renewable energy technologies are widely recognized for their potential to meet the electricity demand and reduce emissions. In this context, India has recently established a sustainable path for its electricity supply and to cover its energy requirements (Kumar & Majid, 2020).

The evolution of India's climate change policy is increasingly acknowledged as a pivotal element in the international climate change negotiations. The challenge of reconciling climate change objectives with domestic priorities—especially economic growth, unemployment, poverty reduction, and urbanization—has become more evident than it has ever been in the recent past. The introduction of the National Action Plan on Climate Change (NAPCC) in 2008 signifies a considerable shift in India's climate diplomacy. It embraces a multi-tiered governance approach that emphasizes the interconnectedness of policy decisions across international, national, and local levels. This framework also outlines current and prospective policies and programs aimed at addressing both climate change adaptation and mitigation and thereby promoting sustainable development (MoHFW, 2018).

India has set ambitious climate change targets, including a pledge to produce 50% of its electricity from non-fossil fuel or renewable energy resources by 2030 and to achieve net zero emissions by 2070 (Narain, 2021). Research by Orlove et al. (2020) highlights the necessity of comprehending the various factors that influence decision-making processes related to climate change adaptation and mitigation. Furthermore, it advocates for the incorporation of broader policy considerations into climate-related decisions, which can enhance stakeholders' knowledge of India's climate change policy frameworks and promote opportunities for collaborations (MST & MES, 2023).

India at present is undergoing a transition towards renewable energy resources (such as solar, wind, and hydro) as a means to effectively reduce carbon emissions, with the launch of NAPCC (MoHFW, 2018). Zhang (2024) highlights the importance of reducing dependence on fossil fuels for electricity generation and increasing the share of renewables in the energy portfolio in order to address energy access, security, and greenhouse gas (GHG) emissions. The discourse also includes the challenges in implementing renewable energy projects while offering recommendations for enhancing technological advancement, optimizing the application of renewable energy in combating climate change issues, and fostering sustainable development in India.

Maharashtra is one of the most industrialized states in India. It is also a state with the highest Gross State Domestic Product (GSDP). Maharashtra is experiencing an increase in average temperature, lightning and storms, and flooding, leading to greater variability in rainfall distribution (Shekar, 2024). This poses challenges for climate-sensitive sectors such as agriculture, water, and forests, highlighting the need for cleaner forms of energy, energy-efficient systems, and climate-proofing of public infrastructure.

However, in Maharashtra, several energy-efficient measures are being implemented in order to address the challenges posed by climate change. These measures include the promotion of solar rooftop power generation in urban areas, which has significant potential in all types of buildings (commercial, industrial, and residential). Additionally, the state is focusing on policy support at the regional level to lower the technology costs and aid the effective implementation of energy-efficient systems. These measures are aimed at enhancing EE and reducing the environmental impacts of energy consumption in Maharashtra (TERI, 2014).

Urban areas, encompassing small towns and cities, account for two-thirds of the total emissions in India. According to a study, the amount of emissions produced per person in urban Indian families is 16 times higher than in rural households, nearly equivalent to emissions in modern global cities. Wealthy urban regions therefore have a greater need to decrease emissions per person (Franco et al., 2017). The city of Pune has been selected as a case representative for the application of effective energy saving strategies and to test the feasibility of the DCS. Pune is widely recognized as one of the most rapidly developing cities in the Asia-Pacific region. Presently, it ranks as the ninth most densely populated city in India, boasting a population of around 5 million. This number is projected to surge to over 10 million by 2030, with the greater metropolitan region expanding to accommodate 14 million inhabitants (Harhare, 2023).

Pune city encounters distinct obstacles in the execution of the energy-efficient initiatives across its various wards. The inconsistencies in policy enforcement and resource distribution impede the achievement of sustainable results with respect to climate change mitigation. By prioritizing local efforts, the overarching objective of decarbonization and energy sustainability in India's swiftly urbanizing areas could be achieved (PMC, 2013).

2. Objectives of the Study

1) To examine the EE of select Indian states using the "E" score methodology, while focusing on five key indicators.

2) To test the applicability of DCS and provide recommendations for Pune city (in India).

3. Literature Review

3.1 EE at Global, National and Local Level

Emphasizing the need for improving EE, it is crucial to look into current efficiency potentials to lower the final energy consumption and diminish the dependence on fossil fuels, which will in turn reflect sustainable energy goals. At a global scale, collaborative efforts among countries are necessary to promote and implement EE strategies and technologies. International agreements and initiatives are instrumental in establishing benchmarks and frameworks for improving EE globally. The focus is on sharing best practices and knowledge to optimize EE across nations and regions (Chen et al., 2024).

Nationally, the emphasis lies on developing and implementing tailored EE policies and regulations that align with specific energy needs and consumption patterns. National governments are responsible for providing incentives, setting targets, and monitoring progress toward EE in multiple sectors, requiring coordination between government agencies, industries, and relevant stakeholders (Yu et al., 2017).

At the local level, grassroots efforts and community participation are keys in promoting EE. The initiatives must focus on raising awareness, implementing energy-saving practices, and fostering a culture of sustainability within neighborhoods and municipalities. Local governments play a pivotal role in supporting EE programs at the community level, empowering local people and contributing to significant reductions in energy consumption and GHG emissions (Chen et al., 2021).

3.2 Economic Motives and Incentives for EE

Renewable energy policies are not just confined to political motivations but are also shaped by many factors, which are local, national, or global, such as economic factors, resource availability, political forms, and cultural factors. At an international level, economic incentives, political systems, and diverse cultural beliefs would shape the development and implementation of the global renewable energy discussions and frameworks (El-Ashry, 2012).

These broad prepositions will, in due course of time, narrow down to all the countries, including India—where these determinants would guide the formulation of country-level policies and strategies on EE issues. These aspects would also be important in establishing the feasibility and success of the implementation of renewable energy policies in a country and in particular regions (Gielen et al., 2019). Furthermore, these aspects will affect community outreach, awareness levels, and support for renewable energy projects and technologies, as well as seamlessly add to the advocacy process at the local and city level (Gallagher, 2013).

The importance and adoption of renewable energy resources in achieving sustainable energy goals (SDG-7) is also emphasized at each of the three levels—from the global initiatives aimed at mitigating climate change to national strategies aimed at meeting domestic energy needs and environmental objectives to finally local projects contributing to community energy security and sustainability. This multi-level approach offers a comprehensive understanding of how these factors operate and interact across different governance scales, thereby shaping and influencing EE policies worldwide (El-Ashry, 2012).

3.3 Climate Change Mitigation at Various Levels

The United Nations Environment Programme (UNEP) prioritizes initiatives in building, lighting, and district energy to accelerate the implementation of EE policies globally. It integrates EE into environmentally friendly activities for both consumption and production. The UNEP also encourages the financial sector to invest in sustainable energy and low-carbon development, promoting EE projects. The Paris Agreement, established as a United Nations treaty in 2015 during the COP21 climate change conference held in Paris, aims primarily to limit the increase in global temperatures to below 2 degrees' Celsius relative to pre-industrial levels. Integral to this effort are the 17 Sustainable Development Goals (SDGs), particularly SDG 7.3, which emphasizes enhancing EE with the objective of doubling global progress by 2030. Both the Paris Agreement and SDG 7.3 play pivotal roles in the pursuit of the objectives addressing the issue of climate change globally (UNEP, 2015).

At present, the academic discourse emphasizes the crucial role of renewable energy resources and EE in combating the global issue of climate change through the reduction of CO_2 emissions across the globe. It signals the need for international partnerships to explore possible ways of dealing with climate change—by adopting renewables and energy-saving practices globally. Conducting a comparative effectiveness analysis is of prime importance to evaluate the outcomes of various strategies and policies across different countries and regions (Mehta et al., 2019).

At the national level, attention is directed towards how countries can harness the potential of renewable energy sources and implement EE measures to mitigate the rise in CO_2 emissions. It emphasizes the need for governments to devise viable strategies that align with their unique circumstances and undertake comparative effectiveness analysis of various methods in realizing climate change objectives (Balachandra et al., 2010).

Lastly, it is essential to examine the contributions of communities, cities, and regions at the local level in the context of climate change mitigation, further highlighting the significance of community-driven initiatives and localized strategies in reducing CO_2 emissions and fostering sustainable practices. Identifying viable approaches at the local level requires an assessment of community requirements, available resources, and inherent capabilities. Furthermore, performing a comparative effectiveness analysis is essential for measuring the impact of localized interventions and identifying the most effective strategies for addressing climate change in particular local contexts (Khan & Huq, 2023).

3.4 Climate Change Initiatives in India

With increasing population and urbanization, India may, however, struggle to achieve its objectives due to the GHG gases produced by coal power plants. Hence, to facilitate market transformation, create demand for energy-efficient products, and drive compliance with EE standards, various strategic interventions have been implemented by the Government of India (Deloitte & WEC India, 2013).

The India Energy Conservation Act, 2001, gives the government the power to set standards and labels for appliances and machinery, provide energy-saving rules for industries that have high consumption of energy, create guidelines for EE codes in buildings, and create training and certification processes for authorized energy auditors. India's "Intended Nationally Determined Contribution (INDC)" aims to promote sustainable living based on conservation and moderation, combat climate change through a mass movement for the 'LIFE' framework—'Lifestyle for Environment'—increase non-fossil fuel-based electricity to 40% by 2030, reduce CO_2 emissions intensity by 35% by 2030, and eventually reach net zero emissions by 2070, with the support of the Green Climate Fund and technology transfer mitigation (MoHFW, 2018).

Further, the NAPCC was released by the Prime Minister in June 2008. The NAPCC outlines a national strategy enabling the country to adapt to climate change and enhancing the ecological sustainability of India's development path. It emphasizes the fact that maintaining a high growth rate is essential for increasing the living standards of Indian people while reducing their vulnerability to the impacts of climate change (PIB, 2021).

3.5 Research Gaps

After an extensive review of existing literature, research gaps in EE and renewable energy policies were identified. Firstly, there is a lack of detailed examination of successful or unsuccessful local EE policies in Pune, hindering informed decision-making. Secondly, while economic motives drive renewable energy policies, there is a limited analysis of economic incentives for promoting EE strategies. Thirdly, there is a need for different frameworks comparing the effectiveness of the strategies across nations and regions. Lastly, there is an insufficient exploration of Pune's economic role in EE, highlighting the need for a detailed case study. Addressing these gaps would enhance understanding of effective energy policies, aiding the transition to sustainable energy systems both locally and nationally.

4. Research Methodology

4.1 Classification of States Using 'E' Scores: A Multi-Parameter Approach and Data Sources

To arrive at an "E" score, (applicable) indicators were selected through the existing literature. An iterative approach was used to refine the indicators, with data primarily sourced from various databases such as the World Bank, Reserve Bank of India (RBI), and Niti Aayog. Additional data was collected from the Handbook of Statistics on Indian Economy and Ready Reckoner by the Power Finance Corporation (PFC).

Reliable data sources offer important insights that help in analysis, and the frequency of updates makes the insights more valuable and practical, which helps in enhancing the study's timeline and accuracy. This paper has used various data sources for analysis. Government studies like the National District Cooling Potential Study for India are methodically gathered and are very reliable, but they are usually outdated due to the low frequency of updates (Kumar et al., 2021). The reports referred to in the study are of recent origin, which enhances the analysis, makes it valuable, and gives a good picture of the current situation of EE in Pune (Khan & Huq, 2023).

The process for deciding the "E" score for each state involves two main steps: identification and aggregation.

1. Identification of Indicators: Relevant indicators such as Gross Domestic Product (GDP) Constant, Potential Renewable Energy, Access, Affordability and Reliability, Electricity Transmission and Distribution Losses, and finally the Clean Energy Initiative are defined to summarize the "E" score—refer to Table 1.

Table 1. Methodology of indicators

Sr. No.	Name of Indicators	Methodology
1	GDP Constant	Real GDP is calculated as (National GDP divided by GDP deflator) multiplied by 100. Real GDP is considered as a dependable measure of a nation's economic growth – as it exclusively accounts for the production and is unaffected by currency fluctuations
2	Potential Renewable Energy	This includes – Resource Mapping, Techno-Economic Studies, Scenario Analysis Policy and Regulatory Framework Stakeholder Engagement
3	Access, Affordability and Reliability	It includes – per capita energy consumption, hours of electricity supplied (industry and agriculture), cross-subsidization of life-line electricity and tariffs
4	Electricity Transmission and Distribution Losses	It includes the percentage of output – which is the proportion of electricity transmission and distribution losses in relation to total electric power production
5	Clean Energy Initiatives	This includes – Clean Cooking Fuel Supply, Renewable Energy Penetration and CNG Vehicle Penetration

Source: Authors' calculations

Table 2. Categorization of states based on "E" score

Category	"E" Score	Indicators
Front-runners (Top one-third)	Composite "E" score <=1	
Achievers (Middle one-third)	Composite "E" score between 2 and 3	
Aspirants (Lowest one-third)	Composite "E" score >=4	

Source: Authors' calculations

2. Aggregation: The methodology for classifying states based on their "E" scores involves calculating the average of each indicator. A satisfaction threshold is defined for each indicator, below which states are considered deprived. States are then classified as deprived (1) or not (0) for each indicator. The total number of deprivations for each state is summed up to determine the final "E" score. This approach allows for categorizing states as front-runners, achievers, and aspirants based on their "E" scores—refer to Table 2.

4.2 Justification for Selecting the Specific Indicators

Each of the selected five indicators has been carefully chosen to give a comprehensive picture of the state's energy situation, its preparedness for renewable energy transitions, and the sustainability and inclusivity of its energy policies. Together the indicators provide a thorough and valuable picture of each state's energy performance, pointing out its advantages and regions needing focused reforms—refer to Table 1.

1. GDP indicates a region's ability to maintain, grow, and foster development plans. The indicator brings forward crucial elements of assessing a state's feasibility factors, affordability, and consistent improvements in projects. States with higher GDP generation directly correlate with higher investment in more substantial EE projects than low GDP states (Mundaca & Markandya, 2016).
2. Potential Renewable Energy is necessary in assessing the usage of natural resources, giving the policymaker a structure to make data-backed decisions. It assures the technical viability of the upcoming EE projects. This indicator says plenty about the efficiency of the concerned authorities; furthermore, a higher ranking in this indicator would mean the state is taking more initiative to reduce GHG and create more employment opportunities (Raghuwanshi & Arya, 2019).
3. Access, Affordability, and Reliability are the third indicators that are taken into consideration for the analysis. It measures the consistent efforts to raise the standard of economic activity and quality of life by improving the access, affordability, and reliability for energy. States with inadequate levels of infrastructure and constant outages hamper this particular indicator. A state's higher per capita consumption would mean better distribution policies are in place. This indicator provides a nuanced understanding of which states require more government scrutiny to improve their electricity distribution systems and employ better policies (Farber, 2012; Seatzu & Akestoridi, 2023).
4. Transmission and Distribution Losses are essential metrics to measure the robustness of EE systems. States being ranked low in this indicator would give the authorities an understanding of specific inadequacies and inefficiencies, including issues in the energy grid, outages, the need for investments in distribution infrastructure, and high-quality maintenance. On the contrary, states ranked high will directly point toward better systems, economies of scale, and provide a framework for other low-performing states to employ the same (Jagtap & Khatod, 2015).
5. Clean Energy Initiatives - access to clean fuel to all households directs a state's consistent efforts towards providing clean alternatives and improving living standards. States ranking high in this category point at consistent efforts by the governments towards lowering urban pollution by utilizing and implementing clean energy initiatives (such as use of CNG fuel over petrol and diesel for public transportation). However, states ranking low point directly at the lack of sustainable transportation and lack of urban and rural initiatives for adaptation of clean energy (Mascarenhas et al., 2020).

One of the prominent reasons behind the weighting strategy is standardization and comparability. Generalizing the different kinds of data under the binary code assesses all the states by one unit and assists the policymakers in making the required decisions with a clear understanding. Upon analyzing the data under 1 and 0, the author categorized states as front runners, achievers, and aspirants based on their aggregate scores. An overview of the scores would help the government to focus and improve on EE policies and make attempts to replicate the framework (from front-running states) to get the desired result in low-performing states. The 'E' Score makes it easier for the government to allocate its funds under different categories and in different states based on the benchmark technique and finally set the priorities. Completing this analysis will assist the government in keeping track of their progress to check if the "E" scores are improving. Lastly, this strategy is adaptable and scalable and, therefore, is easily implementable. Adding new factors (in the future) can strengthen the E-scores, giving an overall view of the states or regions (The World Bank, 2021).

4.3 Why Pune as a Reference Case?

Pune was formerly known for its pleasant environment, which was very suitable for all. However, the temperatures have been growing due to the rising population, urbanization, and expansion of concrete structures, and this makes Pune a suitable case for the study and the application of district cooling strategies (Harhare, 2023). Pune’s average temperatures have fluctuated by a substantial amount over the past two decades. The mean temperature in 2003 in Pune was 24℃, which increased to 25.1℃ in 2023. The number of registered non-transport vehicles in absolute terms has also gone up by a substantial amount, which is largely concentrated in the two-wheeler segment. A decent growth in private cars was seen as well between 2003 and 2023. Moreover, one of the most crucial factors affecting changes in temperature is the establishment of industrial areas in Pune, also known as the Maharashtra Industrial Development Corporation (MIDC). In total, Pune has 4 MIDCs and 2 on the outskirts of Pune that consist of multinational companies and local medium-sized businesses. Wastage from these industrial areas has also contributed to Pune's worsening climatic conditions (Butsch et al., 2017).

As per the PMC Environment Status Report 2018 (ESR), the average per-capita emissions in Pune have risen by 12% over a five-year period from 2012 to 2017, indicating a significant increase. This upward trend in per capita emissions raises serious concerns regarding environmental sustainability. The increase in emissions has aggravated pollution levels and contributed to various environmental challenges. These concerns, apart from increasing the rate of climate change, also pose threats to the health and safety of inhabitants of the city, manifesting in extreme heat and altered precipitation patterns. The rise in temperatures has resulted in a greater dependence on air conditioning, thereby compromising the comfort of the natural living environment (Majra & Gur, 2009).

Moreover, the shifting patterns of rainfall, coupled with the city's geographical features, heighten its susceptibility to flooding, waterlogging, and landslides. Intense rainfall, in conjunction with extensive urbanization, hampers water absorption, increasing the risk of disasters in low-lying regions, along waterways, and on sloped terrains. To address these pressing challenges and secure a sustainable future, Pune must prioritize the development of clean energy systems, effective water management strategies, and robust waste management practices. The implementation of a comprehensive climate action plan is essential for identifying and prioritizing measures to tackle these environmental concerns (PMC, 2013).

Pune, as the cultural and knowledge hub of Maharashtra, should assume a leading position in transitioning towards achieving net carbon neutrality. This would further enable Pune to become a city that prioritizes climate-smart development. Pune, however, has the potential to become an environmentally conscious and sustainable community by reducing its individual energy use and transitioning to renewable energy sources, which makes it a suitable case for the present study.

5. Discussions and Analysis

5.1 Country Level Analysis for Each Indicator

By analyzing the various indicators, the present study aims to gain a holistic understanding of the country's EE landscape. The average of the state-level score for each parameter is used to determine the country-level scores for that parameter. An examination at the national level, detailing India's strengths and weaknesses, would be invaluable in formulating efficient nation-wide policies and strategies (Pandey et al., 2022).

Following are the inferences from Table 3 linked with following Figures 1-5 for each indicator:

a) GDP (Constant)

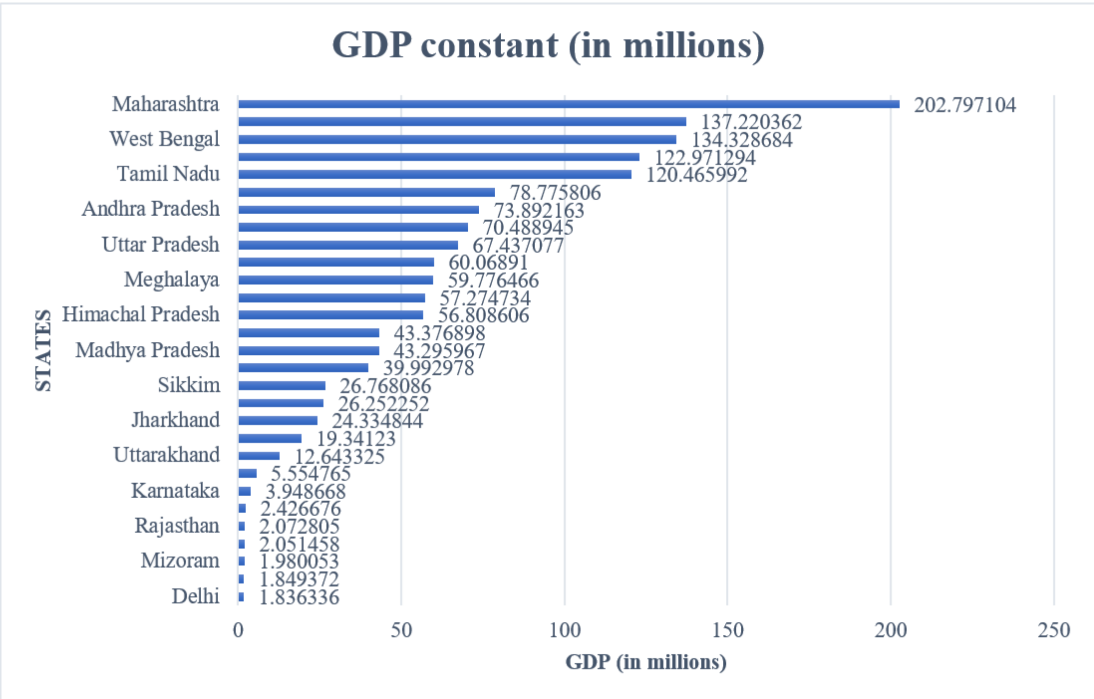

Figure 1. "E" score performance under GDP constant
Source: Authors' calculations

Table 3. All India rankings for each parameter

Indicators	Average Score	Highest Score	Lowest Score
GDP Constant (in millions)	51.725	202.797 (Maharashtra)	1.836 (Nagaland)
Potential Renewable Energy (in thousands)	47.393	271.219 (Rajasthan)	0.919 (Goa)
Access, Adorability & Reliability	46.024	67.3 (Kerala)	30.9 (Meghalaya)
Electricity Transmission & Distribution Loss	21.386	8.1 (Goa)	42.9 (Arunachal Pradesh)
Clean Energy Initiatives	18.945	67.2 (Delhi)	1.9 (Meghalaya)

Source: Authors' calculations

The average national income (GDP) is INR 51.725 million, with Maharashtra topping the list. India's states exhibit varying GDP performances, with Maharashtra, Tamil Nadu, and Gujarat emerging as economic powerhouses, showcasing robust development. Nagaland, scoring the least, faces economic challenges, reflecting disparities among states.

The real GDP adjusted for inflation, indicating Maharashtra's robust economic growth with a GSDP of INR 202.797 million. Tamil Nadu and Gujarat follow closely. Uttar Pradesh lags despite its size, necessitating strategic interventions. Nagaland faces significant economic challenges with the lowest GDP at INR 1.836 million. Maharashtra's innovative startup policy has spurred growth through infrastructure and industry-friendly measures, setting a precedent. Nagaland can emulate this success by formulating its startup policy, focusing on agriculture and tourism, improving connectivity, and simplifying regulations. Maharashtra's Chief Minister Employment Generation Program can guide Nagaland in boosting job creation and supporting micro, small, and medium enterprises (MSMEs).

b) Potential Renewable Energy

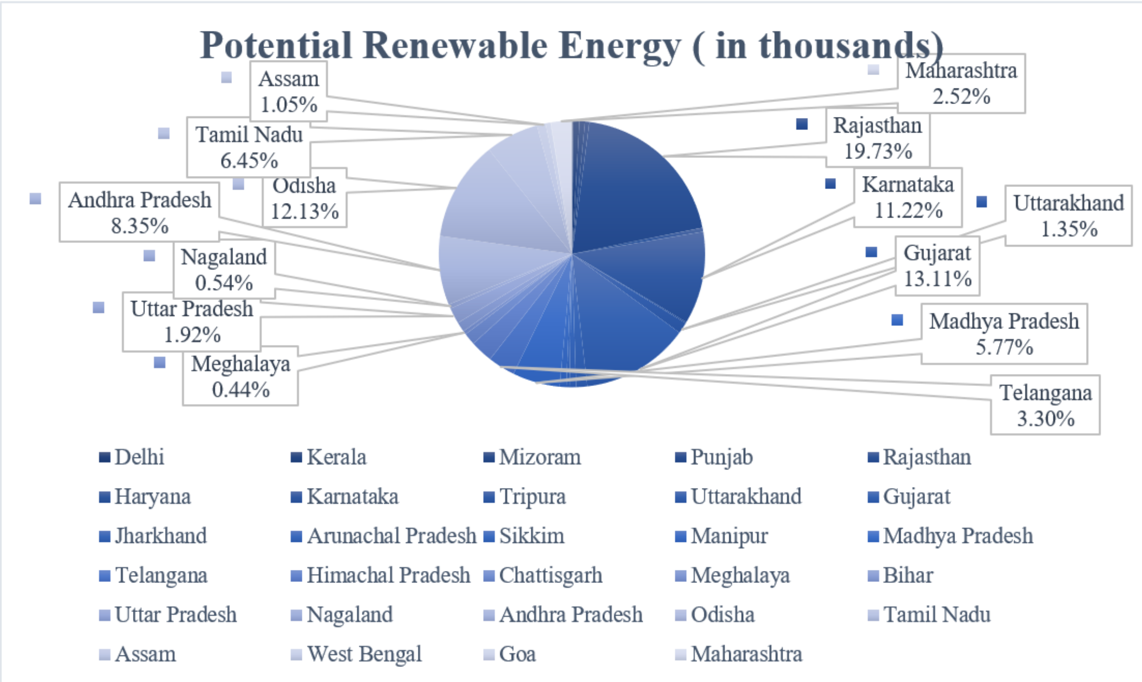

Figure 2. "E" score performance under potential renewable energy
Source: Authors' calculations

EE relies on optimizing renewable resource utilization, reducing non-renewable reliance, and mitigating environmental impacts. India boasts significant renewable energy potential, including solar, wind, biomass, small hydro, and cogeneration. As of March 31, 2021, the country's total renewable power potential is estimated at 14,90,727 MW, with solar and wind dominating. 47.393 thousand is the average score for potential renewable energy.

Rajasthan leads with a remarkable capacity and a score of 271.219, followed closely by Gujarat and Maharashtra, while Goa trails at 0.919. Goa, being a small state, scores the least for potential renewable energy. This data emphasizes the nation's renewable energy capacity and the varying state-level contributions, emphasizing the need for sustainable energy transitions nationwide.

c) Access, Affordability, and Reliability

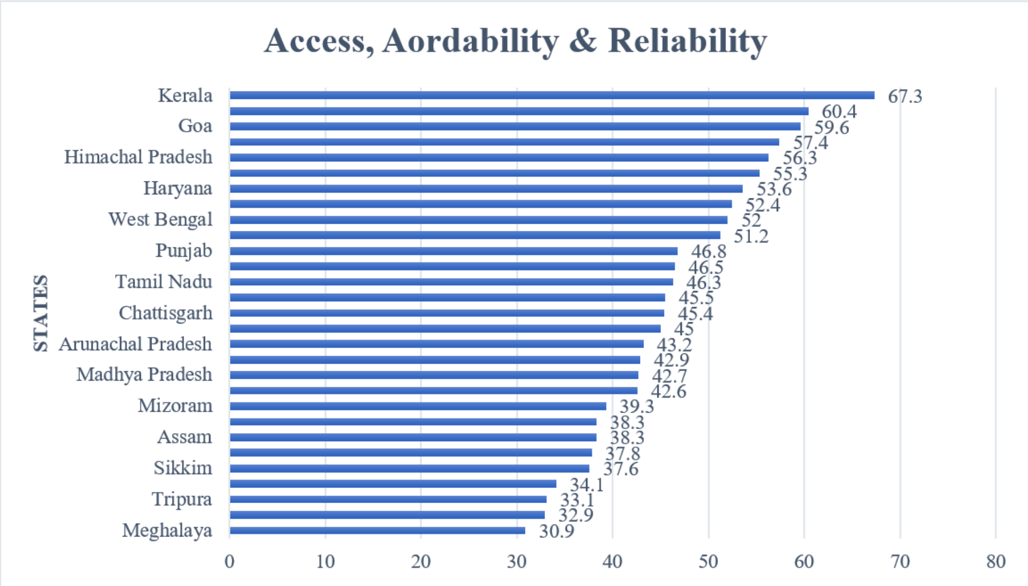

Figure 3. "E" score performance under access, affordability and reliability
Source: Authors' calculations

The Indian Residential Energy Survey (IRES) by CEEW reveals that urban areas receive 22.3 hours of electricity, while rural areas get 19.9 hours daily. States like Delhi, Gujarat, Tamil Nadu, and Kerala provide 23 hours, but Jharkhand and Bihar face outages and power cuts. Rural electrification is advanced through schemes like DDUGJY and the Saubhagya Scheme (CEEW, 2020).

46.024 thousand is the average score for access, affordability, and reliability as an indicator. In terms of access to energy, Kerala scores the maximum points (67.3), while Meghalaya gets the least scores (30.9). Kerala achieved total electrification in 4.5 years via initiatives like the Urja Kerala Mission, emphasizing green energy and grid upgrades. Kerala State Electricity Board (KSEB) also prioritizes rooftop solar and renewables. ANERT supports non-traditional energy research, like the Carbon Neutral Governance Project, promoting electric vehicles (EVs) and charging stations for fossil fuel elimination, showcasing Kerala's innovation and sustainability commitment in energy.

d) Electricity Transmission and Distribution Loss

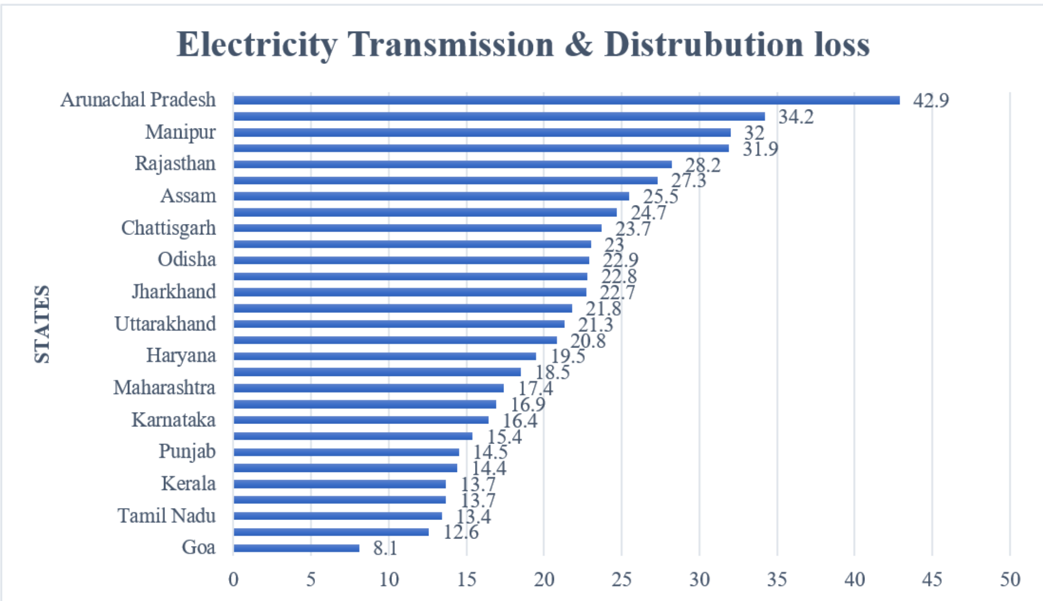

Figure 4. "E" score performance under electricity transmission and distribution loss
Source: Authors' calculations

Electric power transmission and distribution losses vary significantly among Indian states, with Goa (since it is geographically a small state) having the lowest loss percentage at 8.1% and Arunachal Pradesh recording the highest at 42.9%. Tamil Nadu, Kerala, Karnataka, and Maharashtra are efficient states, while Meghalaya, Rajasthan, Assam, and Sikkim require substantial improvements in reducing the distribution losses. High losses lead to inefficiencies, increased costs, and environmental impact, highlighting the need for infrastructure upgrades and operational enhancements. The average score for electricity transmission and distribution loss stood at 21.386.

Goa's policies aim to become an EV model by setting ambitious EV registration targets, promoting vehicle conversion, and building robust EV infrastructure. Arunachal Pradesh can improve by setting similar EV targets, focusing on infrastructure, creating employment, offering financial incentives, and aligning with national objectives. Emulating Goa's approach can enhance Arunachal Pradesh's performance and promote sustainable growth in the energy distribution and transportation sectors.

e) Clean Energy Initiatives

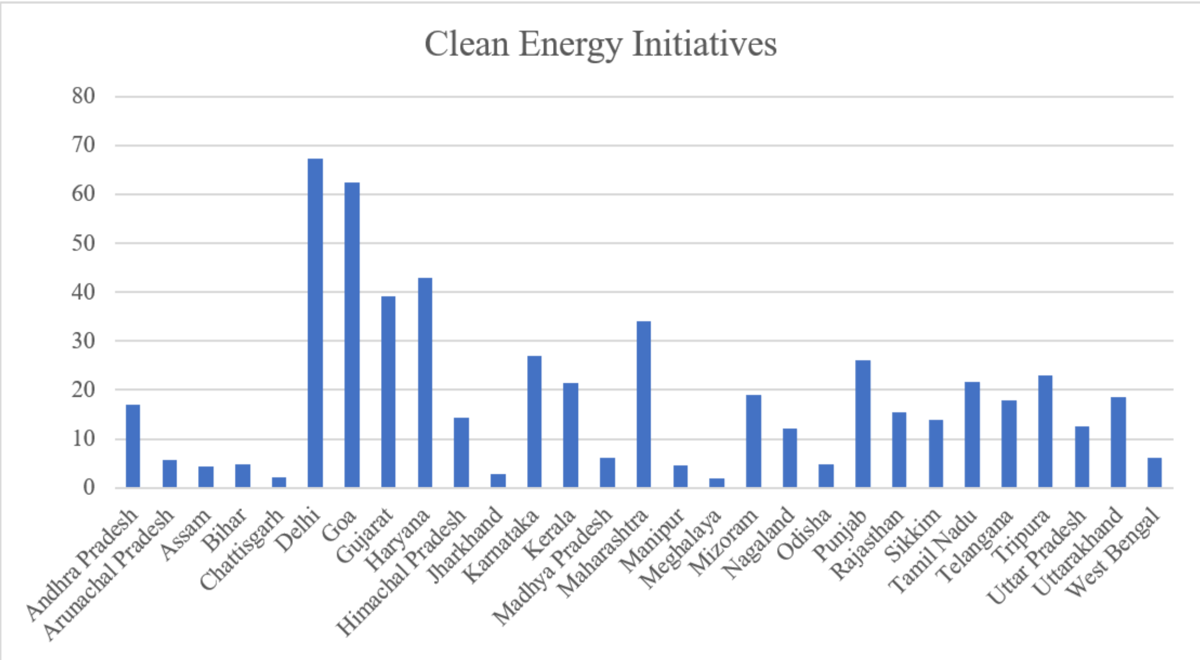

Figure 5. "E" score performance under clean energy initiative
Source: Authors' calculations

The Indian government aims to achieve 175 GW of renewable energy by 2022 and has set a new target of 500 GW by 2030. Initiatives like the Green Energy Corridors Project integrate renewable energy into the grid. The Pradhan Mantri Ujjwala Yojana promotes LPG in rural areas, while the Natural Gas Infrastructure Development Plan supports CNG and electric vehicles.

The average score for clean energy initiatives is the lowest, standing at 18.945. Delhi, being a capital city-state, tops the list for clean energy initiatives, while Meghalaya scores the least. The state governments are therefore urged to enhance their performances in terms of clean energy initiatives, as their average score is 18.945, the lowest among all indicators.

Delhi's EE efforts, led by the EE&REM Centre, include the Domestic Efficient Lighting Program and Street Light National Program, which distributes LED bulbs and replaces the conventional streetlights with energy-efficient LEDs. A 3MWp solar plant set up at the Delhi Secretariat showcases commitment to green energy. The Perform, Achieve, and Trade Cycle enhances EE in large industries. States like Meghalaya can adopt similar measures, such as LED distribution and clean energy practices, to enhance EE and reduce environmental impacts.

5.2 Parameter-Wise Analysis for India

The correlation analysis of energy variables reveals significant insights – refer Table 4.

1. Access, affordability, and reliability exhibit weak positive correlations with most variables but moderate negative correlations (r = -0.546) with electricity transmission and distribution loss, indicating room for improvement in terms of access to and distribution of electricity.
2. Clean energy initiatives show weak positive correlations with most variables; however, there is a strong

negative correlation with electricity transmission and distribution loss (r = -0.610), highlighting that electricity transmission and distribution loss needs to be reduced even in the clean energy sector. Infrastructure modernization at state level and decentralized generation and transmission of solar and wind energy, would help in reducing the losses.

3. GDP at constant prices demonstrates diverse relationships, aligning with renewable energy potential. A strong positive correlation between GDP constant and potential renewable energy (r = 0.664) suggests a good allocation of GDP for the development of the renewable energy sector, thereby harnessing its potential for future generations.

4. Potential renewable energy showcases positive correlations with all other indicators except electricity transmission and distribution loss (r = -0.088), explaining the fact that the potential of renewable energy generation is not and should not be affected by high transmission and distribution loss.

Table 4. Correlation matrix of indicators for India

Parameters	Access, Affordability & Reliability	Clean Energy Initiative	GDP Constant	Electricity Transmission & Distribution Loss	Potential Renewable Energy
Access, Affordability & Reliability	1.000				
Clean Energy Initiative	0.265	1.000			
GDP Constant	0.254	0.274	1.000		
Electricity Transmission & Distribution Loss	-0.546	-0.610	-0.396	1.000	
Potential Renewable Energy	0.088	0.105	0.664	-0.088	1.000

Source: Authors' calculations

From above, it can be seen that high electricity transmission and distribution loss emerges as a major challenge in the overall energy sector in India. In terms of reduction of electricity transmission and distribution losses, the Government of India has launched several nationwide programs and schemes. One such scheme is the Revamped Distribution Sector Scheme (RDSS), which was launched in July 2021 to focus on the modernization of substations, installing smart meters, and improving transmission lines. Another scheme named the National Smart Grid Mission (NSGM) was launched in March 2015 in order to monitor real-time initiatives like Green Energy Corridors and create a unified grid under 'One Nation, One Grid' to ensure access and efficiency in distribution across all states of the country (Dewangan, 2024).

5.3 State Level Analysis for Each Parameter

A comprehensive analysis at the state level evaluates the implementation of renewable energy initiatives that are crucial, given the nation's global prominence. Five indicators (as discussed above) have been considered, with the E-score representing the weighted sum of these indicators for each state. Table 5 indicates a significant number of states falling below the achiever category, with 13 out of 28 states in this classification. However, Gujarat, Maharashtra, and Tamil Nadu stand out as exemplary performers, demonstrating effective policies and implementation strategies in the renewable energy sector, setting a commendable benchmark for others to emulate.

Table 5. State-Wise "E" score analysis

States	Access, Affordability & Reliability	Clean Energy Initiatives	GDP (Constant)	Electricity Transmission & Distribution Loss	Potential Renewable Energy	E-Score (Out of 5)
Gujarat	0	0	0	0	0	0
Maharashtra	0	0	0	0	0	0
Tamil Nadu	0	0	0	0	0	0
Haryana	0	0	0	0	1	1
Karnataka	1	0	0	0	0	1
Kerala	0	0	0	0	1	1
Andhra Pradesh	1	1	0	0	0	2
Delhi	1	0	0	0	1	2
Goa	0	0	1	0	1	2
Punjab	0	0	1	0	1	2
Telangana	0	1	0	0	1	2
West Bengal	0	1	0	0	1	2
Himachal Pradesh	0	1	1	0	1	3
Madhya Pradesh	1	1	0	1	0	3

Rajasthan	1	1	0	1	0	3
Uttarakhand	0	1	1	0	1	3
Jharkhand	0	1	1	1	1	4
Mizoram	1	0	1	1	1	4
Nagaland	1	1	1	0	1	4
Odisha	0	1	1	1	1	4
Tripura	1	0	1	1	1	4
Uttar Pradesh	1	1	0	1	1	4
Arunachal Pradesh	1	1	1	1	1	5
Assam	1	1	1	1	1	5
Bihar	1	1	1	1	1	5
Chhattisgarh	1	1	1	1	1	5
Manipur	1	1	1	1	1	5
Meghalaya	1	1	1	1	1	5
Sikkim	1	1	1	1	1	5

Source: Authors' calculations

Parameter-wise scores categorize the states based on their performance compared to the national average, with top-performing states labelled as front-runners (e.g., Gujarat, Kerala), followed by achievers (e.g., Delhi, Telangana), and aspirants (e.g., Nagaland, Mizoram). States that score higher than average are assigned a score of 0, and the others are assigned a score of 1. This approach ensures a nuanced understanding of renewable energy efforts, emphasizing state implementation effectiveness, and highlights leading states' roles in driving sustainable energy transitions.

Despite not excelling in every parameter, Maharashtra consistently performs above average across all metrics, boasting a score of 0/5. The state has enacted various policies and diligently seeks solutions to improve EE within its region. Substantial investments have been allocated to infrastructure, encompassing initiatives for electric vehicles, charging stations, and the implementation of LED lighting. Nevertheless, the state's substantial population and vast geographical expanse necessitate patience for these measures to have observable outcomes.

6. The Way Forward

Countries are rapidly moving towards clean energy and net-zero emissions by 2050 and beyond, with sustainable development emerging as a key consideration alongside traditional factors like energy availability, price, and security. In order to promote renewable energy transition, the national and state governments should collaborate, share knowledge, and jointly manage capital risks associated with the adoption of clean energy (NITI Aayog & RMI, 2020). Furthermore, governments should also document and disseminate best practices to facilitate peer-to-peer learning through EE scores. Healthy competition between states can drive improved energy affordability, security, and sustainability (IEA, 2021). The following section discusses district cooling as a method to mitigate climate change and its feasibility on a citywide scale.

6.1 District Cooling

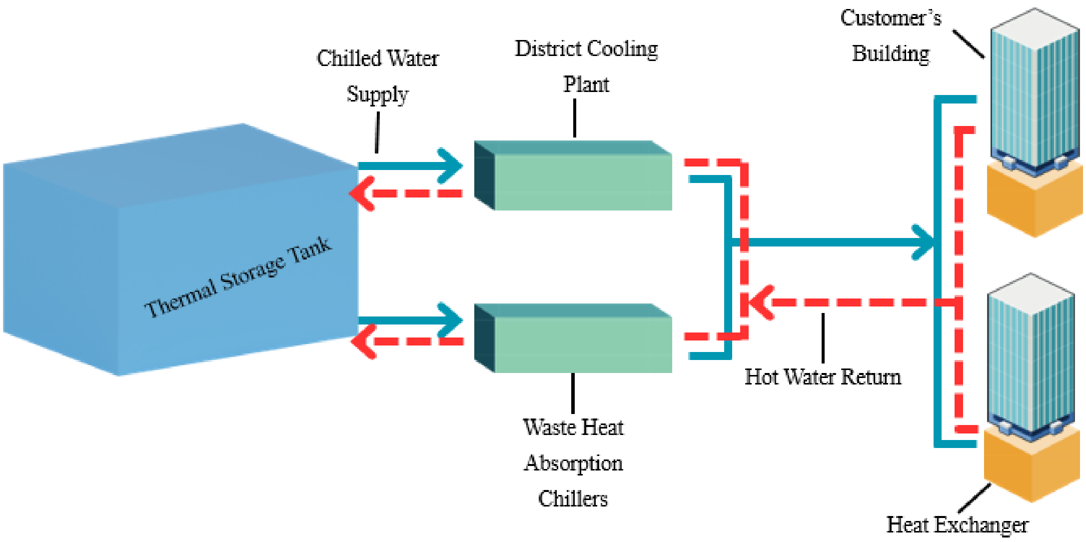

Figure 6. District cooling implementation road map
Source: National District Cooling Potential Study for India by Kumar et al. (2021).

District cooling is a centralized method whereby a single system provides chilled water or another cooling medium to several buildings or facilities spread across a given region or district. This system is painstakingly designed to efficiently meet the cooling needs of a group of buildings, offering a more sustainable alternative than the application of separate cooling systems within every single construction. A CDS works by using a central facility generating chilled water, which is then piped underground to the relevant buildings. The buildings use chilled water for air conditioning and cooling, then lets the heated water back to the central plant for re-cooling, thereby creating a closed-loop system. By means of centralizing the cooling process, CDSs help urban settings to lower carbon emissions, improve energy economy, and strengthen sustainability commitment (UNEP, 2015). The following Figure 6 explains the implementation roadmap for the CDS.

6.2 Select City-Wise Implementation of District Cooling

Table 6 lists the mandates and policies passed by the five cities of Pune, Rajkot, Thane, Coimbatore, and Bhopal, along with their respective policy formative integration status. Examining the degree of each city's activities in renewable energy adoption, EE measures, and other sustainability guidelines helps in assessing the readiness and progress towards deploying CDSs as a sustainable and efficient cooling solution for Indian cities.

Table 6. City-wise policies and initiatives

District Cooling and Trigeneration - Local Policy and Initiatives	Bhopal	Coimbatore	Pune	Rajkot	Thane
Smart City	Green	Green	Green	Green	Green
Solar City Program	Green	Green	Green	Green	Green
Baseline GHG Assessment	Red	Green	Green	Green	Green
Low GHG Plan / Target	Red	Yellow	Red	Green	Green
City-Wide Efficiency and Renewables Target	Green	Green	Green	Green	Green
Efficiency and Renewable Target by Sector	Red	Green	Yellow	Green	Green
Zonal Renewable Energy Targe	Red	Red	Green	Green	Green
Zonal Building Efficiency Target	Green	Red	Red	Red	Green
Mandates on SWH and/or PV by Sector	Red	Green	Green	Green	Green
Mandates on Centralised HVAC	Red	Green	Green	Green	Green
Green Building Policy	Red	Yellow	Green	Yellow	Yellow
Mandate on Water Re-use in Cooling	Red	Green	Red	Red	Red
Mandates on Building Certification	Yellow	Red	Green	Red	Red
FAR Bonus Linked to Certification	Red	Red	Green	Green	Red
Property Tax Rebate for SWH Installation	Red	Red	Green	Green	Green
Direct Investment in Energy Projects	Green	Green	Green	Green	Green
Public Buildings to Demonstrate	Green	Green	Green	Green	Green
Legend for the above data					
Existing Policy	Green				
Developing	Yellow				
Not Developed	Red				

Source: Authors' compilation

From Table 6, it can be seen that

1. Rajkot has established ambitious objectives across several sectors to foster sustainable growth and diminish GHG emissions, enhancing renewable energy utilization in residential and industrial domains.
2. Thane has established sector-specific objectives for implementing renewable energy and enhancements in EE throughout residential, municipal, commercial, and institutional sectors, intending to foster healthier and more sustainably built environments.
3. Coimbatore aims for a 10% decrease in energy usage over five years (2020-2025) by executing the EE and renewable energy strategies specified in its Solar City Master Plan. The city also considers implementing regulations for centralized heating, ventilation, and cooling systems in certain building types or sizes to enhance EE.
4. Bhopal is contemplating the provision of Floor Area Ratio (FAR) bonuses associated with building efficiency and sustainability standards to encourage developers and advance green building practices, potentially resulting in healthier urban environments.
5. Pune seeks to reduce energy consumption and GHG emissions through calculated actions, including energy audits, installing energy-efficient appliances, and introducing renewable energy systems throughout residential, commercial, and public sector buildings. Employing several projects, the city aims to increase the usage percentage of renewable energy by 50% by 2030. It has established sector-specific targets for EE and renewable energy deployment to support environmental sustainability and lower carbon emissions.

The local body of PMC, embodying the CDSs, could further establish the relationship between the clean energy initiatives and potential renewable energy on GDP Constant as a decentralized operating device that transitions from the conventional non-renewable energy sources to leveraging renewable energy through solar and hydro powers.

6.3 Recommendations for Pune City Based on Local Policies

The recommendations have been formulated to rectify the deficiencies in developed and underdeveloped policies concerning CDSs—with a reference case of Pune City in Maharashtra State of India. In accordance with the city's low GHG emission strategy, the recommendations focus on the necessity of incorporating energy-efficient technologies and renewable energy resources into CDSs to reduce carbon emissions. Moreover, performing lifecycle assessments will be crucial in measuring the carbon footprint of current systems and enabling focused interventions to diminish emissions further.

Establishing sector-specific targets for EE and renewable energy integration in CDSs is advisable to promote a customized approach to sustainability across different industries. Promoting the use of waste heat from industrial operations or renewable sources such as solar energy can substantially decrease dependence on fossil fuels, improving district cooling facilities' environmental efficacy. The Pune Municipal Corporation (PMC), which is the governing body for Pune City, will need to create tailored plans stressing infrastructure development, stakeholder involvement, policy formation, and capacity building. This strategy will help Pune's CDSs to be implemented effectively and promote the building of more environmentally friendly and energy-efficient metropolitan surroundings (Chen et al., 2021).

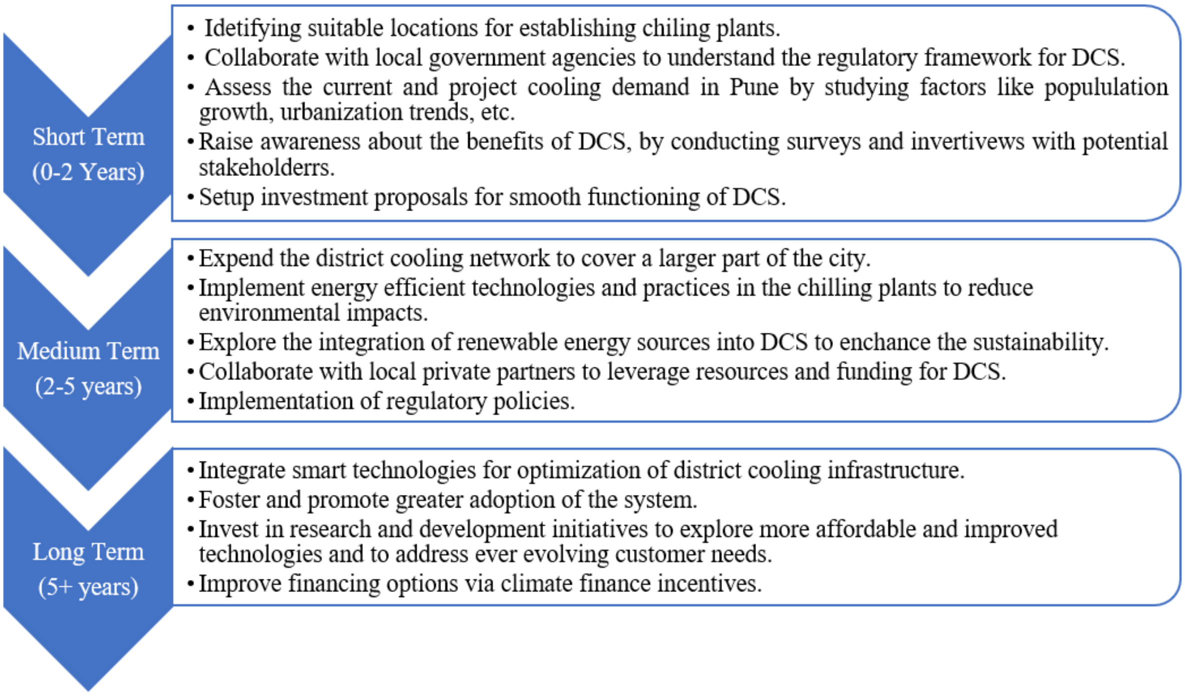

Figure 7. Recommendations for district cooling in Pune (2024 onwards)
Source: Authors' compilation

Referring to Figure 7, it is proposed that inclusion of CDSs in new construction and major redevelopment projects within designated zones should be mandated throughout Pune City in order to support the integration of district cooling infrastructure into urban development. Incentives such as expedited permitting and density bonuses aim to motivate developers to incorporate CDSs, thereby aligning with efficiency standards and contributing to the city's zonal efficiency targets. Further, mandating water reuse technologies in CDSs to minimize freshwater consumption and promote sustainable water management practices in Pune will go a long way in mitigating increasing temperatures. Providing technical support and financial incentives for implementing water-saving measures, such as closed-loop cooling systems or greywater recycling, can further facilitate district cooling adoption and usage of these technologies (TERI, 2020).

Pune has quite a lot of scope for CDSs, which are very relevant in the present-day context due to the increasing temperatures brought about by urbanization and vehicular pollution. However, the development of such a system is hampered by economic reasons. One of the critical aspects that impacts the economic viability of cooled distribution systems is the high initial investment costs of the system and related infrastructure. This investment is largely due to the requirements of building no-emissions cooling energy plants and installing energy conservation measures for cooling technologies and systems (TERI, 2020).

An attractive offering model could be one wherein the developers from the private sector and municipal authorities can share the costs of setting up CDSs in a public-private partnership (PPP) model (Gardiner, 2015). Green bonds could also be used for initial construction investment requirements. Other measures, including strategies to provide grants to assist in acquiring energy-efficient technologies and low market interest rates for loans, could increase the level of investment by the private sector. Moreover, planning for land use in new areas under development to accommodate CDSs should be emphasized further to improve the EE of cooling systems and their cost-effectiveness in urban cooling in the future. The integration of these funding approaches, together with a phased implementation strategy, would help improve the financial viability and applicability of CDSs in Pune (Eveloy & Ayou, 2019).

7. Conclusions

The research assesses how EE policies and climate change intersect at the local, national, and global levels, emphasizing Pune City, Maharashtra, in India. This study delineates the landscape of EE and renewable energy adoption in India, highlighting both areas for enhancement and strengths through a comprehensive analysis of various indicators, including GDP, renewable energy potential, electricity access, transmission and distribution losses, and clean energy initiatives. The article also stresses that it is essential to have coordinated efforts and that actions are required at all governmental levels. There is also an urgent need for a transition to sustainable energy, thereby reducing the impacts of climate change.

Policymakers must give EE and renewable energy projects top priority on their upcoming agendas in order to meet both national and international climate change targets. They ought to make use of state-of-the-art technologies and set up strong frameworks for regulation and oversight. Furthermore, a greater emphasis on grassroots-level initiatives and community involvement is necessary to promote local knowledge and the adoption of energy-efficient practices and technology. Increasing investments in clean energy infrastructure, enforcing stringent laws to reduce carbon emissions, offering grants and financial incentives for energy-efficient practices and technologies, and encouraging international cooperation to share resources and best practices are some alternative strategies for reducing climate change effects and increasing EE. In the light of climate change, developing countries like India may help create a resilient and sustainable future by adopting these alternative technologies and strategies and embracing a comprehensive, multi-tiered framework of governance, thus succeeding in achieving the SDG-7.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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