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IKI INTERNATIONAL CLIMATE INITIATIVE

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tabreed

District Cooling:
A Systemic Approach for Maharashtra's Energy Future

Kubernein Initiative

REVOLVE

This report is an initiative undertaken as a part of the Memorandum of Understanding signed between Tabreed India and Gesellschaft für Internationale Zusammenarbeit (GIZ)'s 'Energy Efficiency Cooling' programme, jointly implemented with the Bureau of Energy Efficiency (BEE), Ministry of Power, and funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) as part of the International Climate Initiative (IKI), to accelerate adoption of sustainable cooling practices.

Due to rising temperatures and the corresponding surge in air conditioner usage, projections indicate that by 2050, space cooling could be responsible for 45%[1] of peak energy demand in India. Drawing upon GIZ's proficiency in sustainable development strategies, notably its collaboration with BEE on District Cooling guidelines, and Tabreed's unrivalled experience in the industry, the partnership aims to promote widespread adoption of energy-efficient District Cooling systems to deliver on sustainable and holistic economic and human development in India.

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Foreword

Arijit Sengupta, Director, Bureau of Energy Efficiency, Ministry of Power, Government of India

At the Bureau of Energy Efficiency (BEE), we recognize district cooling as essential in addressing India's urban cooling challenges. Extreme heat in India, including Maharashtra, demands innovative solutions that balance cooling needs with energy efficiency. District cooling offers a strategic approach by reducing energy consumption and mitigating peak power demand.

Our mission at BEE is to **develop policies and strategies aiming to reduce the energy intensity of the Indian economy within the framework of the Energy Conservation Act, 2001.** This mission is pursued through the active participation of all stakeholders, promoting accelerated and sustained adoption of energy efficiency across all sectors. In collaboration with GIZ and Tabreed India, BEE is dedicated to advancing district cooling solutions. Our district cooling guidelines are crafted to evaluate the feasibility of these systems during the early planning stages of urban development. By bringing together key stakeholders, BEE strives to drive the widespread adoption of district cooling technologies, ensuring that states like Maharashtra can meet their cooling needs sustainably, support public health, and align with national energy conservation goals.

Nitin Jain, Programme Head, Energy Efficiency Programmes, Gesellschaft für Internationale Zusammenarbeit (GIZ) India

At GIZ, we see great potential in the integration of district cooling solutions in Maharashtra. This presents a critical step toward advancing energy efficiency and urban sustainability in India.

In India, we contribute to key initiatives under the Indo-German Partnership for Green and Sustainable Development. Through the 'Energy Efficiency Cooling' program, we collaborate with BEE and Tabreed India to enhance capacity, facilitate knowledge exchange and promote policy dialogue. This initiative directly contributes to the goals of the International Climate Initiative (IKI) by promoting climate-friendly technologies, improving energy efficiency, and supporting policy frameworks that enable sustainable cooling solutions. **By integrating these solutions into Maharashtra's urban planning, we aim to set a model for sustainable cooling that not only benefits India but also contributes to global resilience and sustainability.**

Sudheer Perla, Managing Director, Tabreed Asia

Tabreed is proud to have collaborated with BEE and GIZ to bring together eminent stakeholders for a round table discussion to chart out the course for District Cooling. The accompanying report highlights opportunities and recommends approaches for wider energy efficient cooling adoption that Maharashtra can consider. It offers insights and plans for both brownfield and greenfield developments that are key to Maharashtra's growth story, which will aid the State government in its plans for meeting its energy efficiency and sustainability goals.

Tabreed is already working with the Mahatma Phule Renewable Energy and Infrastructure Technology (MAHAPREIT) to bring District Cooling and District Energy technology to the Mumbai region, and looks forward to extend the support across the state in creating state-of-the-art, climate-smart, energy-efficient cooling systems that fulfils present and future needs.

Executive Summary

India stands at a critical juncture where on the one hand rising temperatures, urbanization, and growing energy demands are making Indian cities dangerously hot, affecting health, productivity, and economic stability. On the other hand, our aspiration for self-reliance in manufacturing through Make in India and the digital transformation that is affecting every aspect of our lives is all predicated on increasing availability of cooling. Currently unrecognized, India's energy transition in effect is simply our story of how we are meeting our growing demand for cooling as most energy generation capacity added through renewables over the past decade has gone largely towards meeting our increasing cooling demand. As this need rapidly accentuates over the coming years, whether we simply continue play catch-up through increasing our energy supply, or instead more holistically approach our energy transition to be one of an energy-cooling transition, is what will shape India's energy future, our response to climate change, urban resilience and indeed our approach for equitable economic growth.[4]

By 2038, India's cooling demand across buildings, cold chains, data centres, refrigeration, transport, and industries is expected to increase eightfold compared to 2018 levels. **Space cooling alone is projected to constitute 45% of peak energy demand by 2050, with air-conditioning penetration increasing from 8% to 40%.** A business-as-usual approach focused on incremental efficiency improvements will be inadequate. Instead, aggregating demand to adopt solutions such as District Cooling present a new response—an important step in the right direction, even if it does not provide all the answers or fundamentally change the question at hand.

District Cooling systems aggregate demand and centralize cooling production and distribution, offering up to **50% greater energy efficiency than traditional cooling solutions and reducing peak power demand by up to 40%**. By integrating with renewable energy sources, waste-to-energy plants, and sewage treatment facilities, District Cooling aligns with circular economy principles, minimizing resource wastage and environmental impact. The economic benefits are equally significant—lifecycle cost savings of up to 25%, reduced equipment needs, and optimized operations. Treating cooling as a central utility ensures equitable access to sustainable cooling solutions, making cities more resilient. However, District Cooling is not a silver bullet; rather, it is a practical and scalable intervention within a broader transformation that requires systemic shifts in how we produce, distribute, and consume energy.

India has historically approached sustainability through a holistic lens—deeply embedded in Indic traditions that emphasize harmony with nature and intergenerational responsibility. Traditional Indian architecture, for example, relied on passive cooling strategies that leveraged natural ventilation, shaded courtyards, and water bodies to regulate temperatures. Indigenous knowledge systems recognize the symbiotic relationship between communities and their ecosystems, demonstrating that sustainability is not a modern invention but a rediscovery of time-tested wisdom. Realigning modern economic and policy frameworks with these values is essential for fostering resilience and sustainability at scale.

Maharashtra, as one of India's most industrialized states, exemplifies the urgency for such a shift. **The industrial sector in the state recorded 58,856 MU (Million Units) of electricity consumption in 2022-23, which is a 10.3% increase from 2021-22.**[2] To support its economic growth sustainably, Maharashtra can leverage District Cooling in key sectors such as commercial and residential buildings, industries and manufacturing, IT parks and data centres, and cold chains. If District Cooling is incorporated into urban infrastructure planning aspects for all high building density locations such as Bandra-Kurla Complex, Dharavi, campus level at office parks like MindSpace Airoli, industrial mega-projects including Reliance Industrial Hub, Bidkin Industrial Area, warehousing hubs, and data centers, the state could attract **USD 1.5 Bn in investments whilst reducing power demand by approx. 1 GW and emissions by 80 million tonnes over its lifecycle.**

Policy mechanisms such as regulatory mandates and public-private partnerships will be critical in scaling District Cooling adoption. Furthermore, capacity-building initiatives and knowledge-sharing platforms can facilitate the integration of traditional wisdom with modern innovation, ensuring a sustainable and contextually relevant cooling transition.

Introduction - Innovative Cooling Solutions for India

In South Asia, it is estimated that **climate change induced heat stress could lead to around 12% loss of economic productivity**[3] **and 6% GDP loss annually. In 2024, India recorded**[4] **around 56 deaths and over 25,000 cases of heat stroke through April and May**. With nearly 75% of India's workforce[5] engaged in heat-exposed labour, exposure to extreme heat[6] is resulting in lower productivity due to the need for more frequent breaks, and at times a halt in work altogether.

As heat waves are becoming more frequent and intense, the need for cooling is rising. Higher[7] ambient temperatures, coupled with increased humidity, make both indoor and outdoor environments more difficult to endure. This is driving greater demand for cooling solutions across homes, workplaces, and critical sectors such as healthcare, food preservation, and transportation. Urbanization patterns are further compounding the problem – dense concretization, pollution, and declining tree cover are **intensifying the Urban Heat Island (UHI) effect, making cities significantly hotter than their surroundings and resulting in a direct measurable increase in cooling demand**[8] across residential and commercial buildings, cold-chain logistics, refrigeration, transport, and industries.

The space cooling sector alone is expected to grow **8 times in India by 2038 (compared to 2018 levels)** and air-conditioning penetration, which is currently at 8%, is expected to reach 40% by 2038. By 2070, under a high end emissions scenario (which is used to refer to a scenario with high fossil fuel led development), it is estimated India could experience a loss of 24.7% of GDP[9] due to climate change. Air conditioning and refrigeration are also projected to increase GHG emissions **90% above 2017 levels by 2050**,[10] perpetuating feedback loops for increased heat stress.

A business-as-usual response for more energy efficient solutions through standards and labelling, minimal incremental technology improvements and uneven market adoption will not be sufficient. Whole system approaches for demand aggregation through District Cooling and increased resource circularity addressing the energy-waste-water nexus through integrated District Energy systems have the potential to provide a sustainable way of meeting our cooling demand whilst addressing multiple other challenges cities face. The government of India recognises this in its plans and actions. The 2019 **India Cooling Action Plan (ICAP)**[11] includes District Cooling in the mix of solutions for the future. The **2023 District Cooling Guidelines launched by the Bureau of Energy Efficiency** provide a guide on seamless adoption of the technology, including roles and responsibilities of stakeholders, including state and city development authorities, developers and investors in unlocking District Cooling market potential for the Indian context. **The Department for Promotion of Industry and Internal Trade (DPIIT), Ministry of Commerce and Industry and the World Bank are also collaborating on 'Alleviating Heat stress by Enhancing production of Affordable cooling Devices (AHEAD)'**[12] to strengthen India's actions against intensifying heat waves via sustainable and affordable cooling solutions. In December 2024, a consultation workshop under the AHEAD program was organised with more than 100 stakeholders to formulate a tangible program for implementation by identifying pathways for meeting India's commitment to climate mitigation through domestic manufacturing of space cooling equipment, increasing access to cold chain, and promoting adoption of District Cooling technology.

Cooling, that was until recently considered a luxury, is fast becoming a vital part of India's critical infrastructure - like the power grid or banking. Innovative technologies that help create environment-friendly and resilient cooling infrastructure will be required to maintain economic growth, socio-political harmony, and productivity of human capital. While the government has already begun laying the framework, the adoption of new solutions and technologies will also require a **transformation of the market**[13]. This transformation can be achieved by bringing together diverse stakeholders, from state government ministries and bodies to the broader private sector ecosystem. This report seeks to introduce the concept of District Cooling, identify challenges, and present the opportunity for the uptake of District Cooling technology within the context of the state of Maharashtra.

The Case of Maharastra

Maharashtra occupies a pivotal role in India's development story: **it is the third largest state in terms of area, second most populous, third most urbanised, and contributes to 15.5% of India's industrial output**[14]. Industrial growth combined with increasing population, income-levels and urbanisation, leads to increase in energy demand, a large part of which continues to be met through fossil fuels in the state of Maharashtra, as across India. **The industrial sector in the state recorded 58,856 MU (Million Units) of electricity consumption in 2022-23, which is a 10.3% increase from 2021-22.**[15] Maharashtra's Greenhouse Gas (GHG) emissions grew at an estimated [16] 4.1% Compounded Annual Growth Rate (CAGR), from 2011-12 to 2021-2022[17] to reach 310 million tonne CO2 (MTCO2e), contributing to 10% of India's overall emissions.

GHG emissions are a direct contributor to global warming, and Maharashtra has begun to experience the consequences. In 2024, heat waves were reported across multiple districts and **Mumbai recorded its highest temperature of 39.7**[18] **degrees in a decade**. Recognizing these challenges, the state of Maharashtra has taken a proactive approach towards climate action through the Maharashtra State Adaptation Action Plan on Climate Change (MSAAPC) that aligns with the National Action Plan on Climate Change. In 2024, Mumbai launched a **Climate Budget – the first city to do so in India** – to enable better planning and resource allocation. At the city level, Mumbai has a Climate Action Plan (MCAP), and many other cities including Thane[19] and Pimpri-Chinchwad[20] have formulated Heat Action Plans wherein one of the objectives is to reduce heat stress, heat-related illnesses and risks by putting innovative cooling solutions[21] in place. Notably, in 2018, **Thane was also chosen by United Nations Environment Program (UNEP) as the first city in the country to pilot a District Cooling system**.[22]

In 2023, **Tabreed India signed an MoU with Mahatma Phule Renewable Energy and Infrastructure Technology (MAHAPREIT)**[23], a Government of Maharashtra undertaking, to bring District Cooling and District Energy technology to the Mumbai region. The partnership seeks to deploy sustainable cooling solutions in the state of Maharashtra in a holistic, systemic and circular manner; exploring integration of ancillary technologies including Sewage Treatment Plants (STPs), Waste to Energy plants (W2E), city gas networks, and renewable energy for greenfield and brownfield sites. Through the partnership, Tabreed and MAHAPREIT, for the targeted projects aim **to reduce grid electricity consumption by 50-70%, and replace all potable water with Treated Sewage Effluent (TSE), while reducing TSE usage by 30%**. Building on this, MAHAPREIT in January 2025 has launched a tender to empanel District Cooling service providers “to provide Cooling as a Service (CaaS) to meet consumers’ operational requirements across Maharashtra, with potential expansion into other states” [24].

Maharashtra’s Power Sector Vision 2030 notes the need to increase clean energy adoption[25] and recognises the benefits that innovative technologies bring to the table. This paves the way for future integrations of technologies such as District Cooling that support clean energy adoption and promote circular systems in the power sector.

What is District Cooling (DC) and Cooling as a Service (CaaS) Model?

The 2023 District Cooling Guidelines launched by the Bureau of Energy Efficiency, Ministry of Power defines **District Cooling as one single cooling network, distributing chilled water to a cluster of buildings as a self-sustaining service.**[26] This centralised system can meet the cooling needs of a large, densely occupied space, campus, or network of buildings, occupied by a single user (in airports, malls, hotels) or multiple users (in IT & manufacturing parks, integrated townships and other commercial hubs), through aggregating demand and leveraging diversity factors of varying cooling loads in multiple buildings in a cluster.

A centralized approach to cooling enables demand aggregation, significantly reducing the quantum of cooling equipment required, and **offering up to 25% lifecycle cost savings for customers.**

The Science of District Cooling

Efficient, consistent and sustainable cooling is provided to multiple buildings through a centralized District Cooling Plant that generates chilled water by using a series of key components, thus reducing the need for individual cooling equipment.

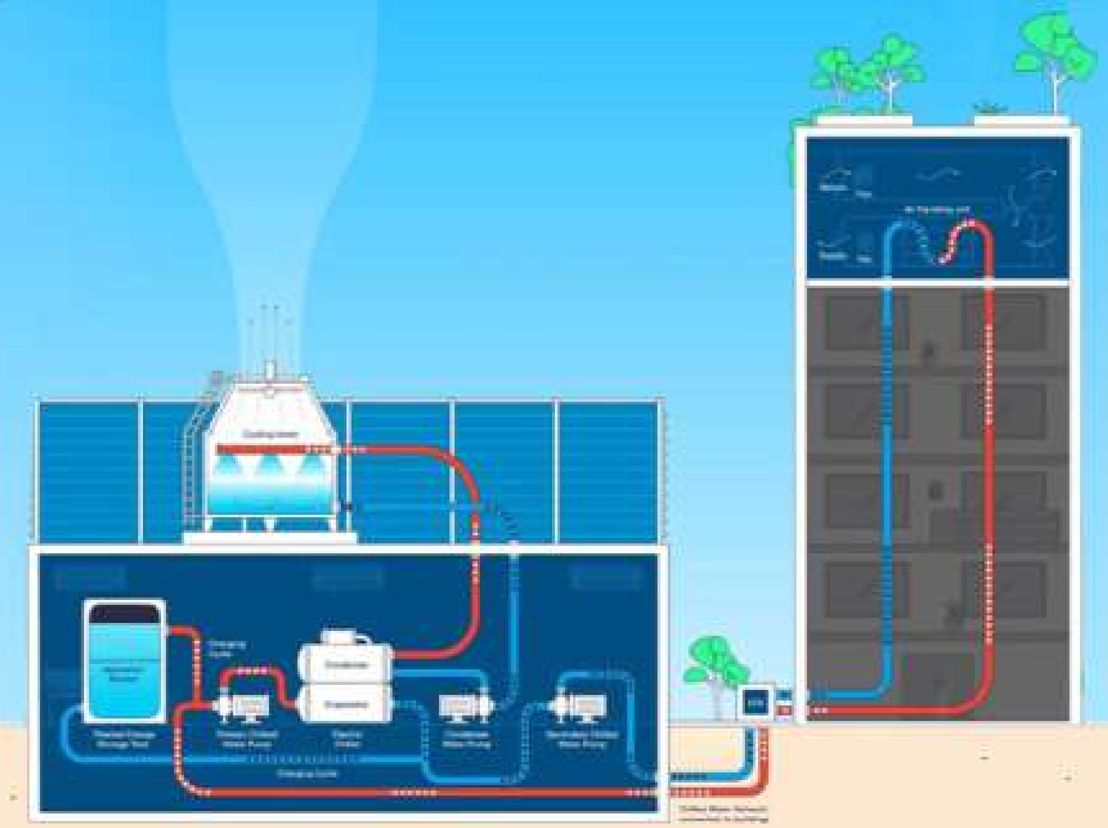
Chilling the Water in the Chiller: The process begins at the chiller. The chiller uses a refrigerant to cool water in the evaporator. The refrigerant absorbs heat from the water, reducing its temperature. The refrigerant then goes to the condenser, where it releases heat and gets ready for the next cycle.

Pumping Chilled Water to Buildings: Once the water is chilled, it is pumped through a series of insulated pipes (network) using Secondary Chilled Water Pumps. These pipes transport the cold water to various buildings while minimizing temperature loss.

Energy Transfer to Building Systems: The cold water arrives at each building's Energy Transfer Station (ETS) which comprises of plate type heat exchangers, pumps etc. The ETS connects the District Cooling network to the building's internal chilled water circuit (while isolating both the circuits) feeding HVAC systems (such as air handlers or fan coil units), which uses this chilled water to cool the air inside the building.

Return of Warmed Water to Central Plant: As the District Cooling network chilled water absorbs heat from the buildings via ETS, it warms up. This warm water is then returned to the District Cooling plant for re-chilling through a separate set of return pipes.

Heat Rejection in the Cooling Tower: In the District Cooling plant, the warm water is sent to the chiller for next cooling cycle while this heat is dispersed into the environment via cooling towers. This completes the cycle, allowing it to continue.



There are several innovative business models that aid the wider adoption of District Cooling in India. The **Cooling as a Service (CaaS) business model provides a pay-as-you-go solution that benefits customers** by eliminating the need for upfront investment. Similar to utilities like water, piped-gas, or electricity, consumers pay monthly bills for cooling based on usage, determined through meter readings. Under this model, the service provider owns, builds, and finances the cooling infrastructure while managing its operations and maintenance. **The public-private partnership (PPP) model is another widely used mechanism** of establishment of contractual frameworks to mitigate and share risks between stakeholders best equipped to address it. The table below provides key mitigants in a PPP contractual framework which can accelerate deployment of District Cooling systems through appropriate risk sharing mechanisms.

Key Highlights of a District Cooling Concession Structure under PPP model

Exclusivity: Exclusivity offered within the agreement structure for cooling services to key developments ensuring predictable demand.

Concession Term: DCS provider/Grantee offers an agreement term spanning 30 years, ensuring a time period long enough for recovery and for benefits to be demonstrated.

Flexibility and Scalability: Agreement should allow for future expansion (phased-in capacity) to meet rising demands, ensuring the infrastructure remains adaptable to the growth trajectory.

Revenue Model: With a two-part tariff structure,

o Fixed Demand Charge towards capital cost recovery: A step-down tariff structure agreed where initial loads will have a higher demand charge to recover pre-investment requirement for DC network and DCP. As plant expands when demand ramps up, overall tariffs are reduced. Indexation is pre-agreed

o Consumption charge towards recovery of utilities cost, chemicals, & O&M costs. Indexation based on a combination of WPI (commercial – electricity) and CPI (industrial workers).

Bulk-offtake and Demand Guarantees: The government/Grantor provides a guaranteed offtake for cooling services for each building and a long stop date for Phase 1 post which Grantor is obligated to start paying fixed charges, de-risking the project and ensuring a steady revenue stream from the outset.

Innovation for Capacity Under Utilization: Grantor allowed to sell to 3rd parties if any capacity remains un-utilized. Similarly, DCS provider allowed to sell capacity beyond agreed load basis a revenue sharing model between the Parties

Risk Allocation: The concession structure emphasizes performance-linked payments and includes provisions for penalties, ensuring the DCS provider delivers services efficiently.

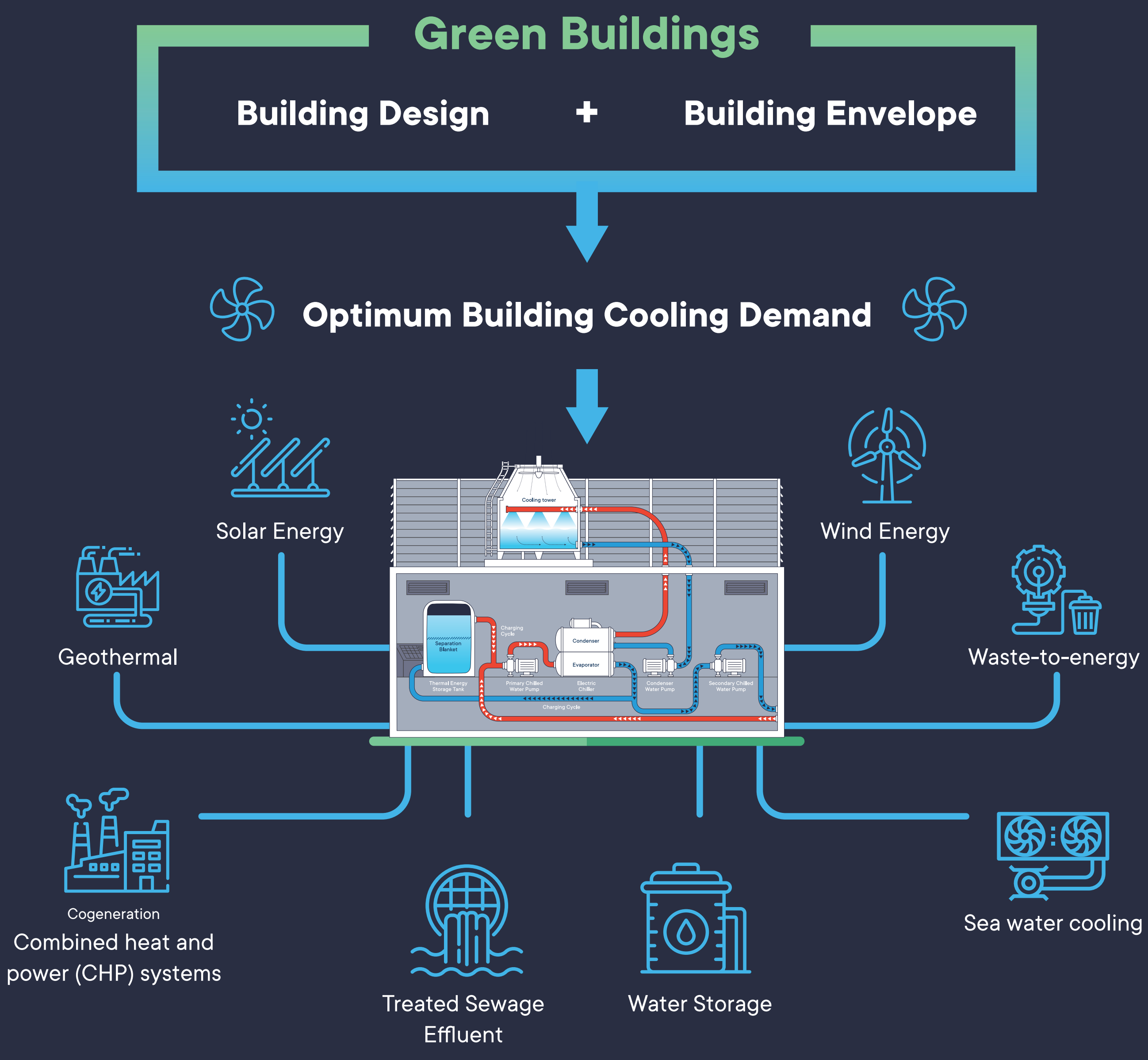
Comprehensive coverage for Force Majeure & Political Risk: The concession agreement protects the project from political or non-political events, ensuring that the project can operate smoothly without disruptions caused by external forces.

Over the past decade, the District Cooling model has been successfully adopted in several projects in Asian countries. In Singapore[27] for example, Changi Airport uses District Cooling technology; ST Ang Mo Kio Technopark[28], estimated to be operational by 2025, will have the country's largest District Cooling system; Marina Bay (central business district) has the world's largest underground District Cooling network wherein the private District Cooling service provider, Singapore Power, and the Singapore government have come together to invest in the central plant and the District Cooling network on a modular basis.

District Cooling systems have been taken up on a large scale in Indian projects as well. The **Government of Gujarat is implementing District Cooling to meet the air conditioning needs of Gujarat International Finance Tec-City or GIFT city,** reducing the mechanical load requirement for cooling from 270,000 RT to 180,000 refrigeration tonnes (RT). The District Cooling system is also integrated with Thermal Energy Storage (TES) tanks, which further optimizes power demand for cooling purposes from 240 MW to 135 MW. Another example of District Cooling for commercial buildings is in **DLF Cybercity in Gurugram, which is India's largest integrated business district.** The District Cooling system serves 10 buildings, with an air-conditioned area of more than 1.7 MN sqm. Additionally, **My Home Abhra in Hyderabad is 5-block residential** complex, whose cooling requirements are met by a centralised air conditioning plant. Equipped with a 3000 RTh TES system, the two-chiller plant supplies cooling to each apartment and common areas. The building residents' association owns, operates and maintains the DC System including the DCP and the distribution network. **A District Cooling system of 125,000 RT, Asia's biggest Public-Private Partnership (PPP) based concession**, has been planned for Hyderabad Pharma City, the world's largest bulk-drug industrial park being developed by Government of Telangana. The Andhra Pradesh Capital Region Development Authority (APCRDA), signed **India's first Public-Private Partnership concession with Tabreed in 2019 to develop a 20,000 RT District Cooling System** for the government complex area within the planned capital city of Amaravati, where Tabreed committed to designing the system to deliver 50% electricity demand reduction for cooling prestigious buildings like the High Court, and Secretariat amongst others. **One of the first Cooling as a Service models was made operational in 2023 at Gurugram's Intellion Park** through a strategic alliance between Tata Realty and Infrastructure Limited, and Tabreed India.

Benefits of District Cooling: Enabling a Systems' Approach for Circularity

As mentioned earlier, in a District Cooling scheme, demand is aggregated centrally to be then met by a central plant that produces chilled water, circulated through a network of pre-insulated pipes to multiple buildings in a cluster. Depending on the alternatives or baseline being compared against, **District Cooling can be up to 50% more energy efficient**[29]**, and can reduce peak power demand by up to 40%**; even more when combined with thermal energy storage solutions.



District Cooling can eliminate the leakage of refrigerants through preventive measures, early detection, and contain any leakages leading to minimal impact on the environment. Furthermore, the system can support and promote the use of new-generation green refrigerants, which have a far lower global warming potential than the prevalent refrigerants used, thus further reducing greenhouse gas emissions from harmful refrigerant use, in line with India's commitments under the Kigali Amendment to the Montreal Protocol. The placement of equipment away from buildings **reduces vibration and noise, leading to a more pleasant outdoor environment and improved air quality**. District Cooling also **mitigates formation of urban heat islands** by preventing heat rejection into the surrounding atmosphere, and instead dissipating the heat into treated water or natural water sources such as rivers, seas or lakes. These micro-climate feedback loops would otherwise further increase the demand for conventional air-conditioning.

District Cooling's biggest advantage is in the way it lends itself for **integration with a range of technologies to enable a systems' approach for a circular economy**[30] that minimizes waste and promotes sustainable use of natural resources through smarter product design, longer use, and recycling. When integrated with systems such as City Gas Distribution Plants (CGD), Waste to Energy Plants (W2E), traditional power plants, Liquified Natural Gas (LNG) Regassification Terminals and Sewage Treatment Plants (STP), **District Cooling can improve resource efficiency to provide broad access, minimize costs and reduce environmental impact.**

Improving Water Efficiency

District Cooling can help reduce the dependency on potable water sources through the use of **Treated Sewage Effluent (TSE) from STPs** as well as from natural sources (where available) such as lakes, rivers, or oceans without affecting aquatic life. This is significant for a state like Maharashtra where water scarcity is a growing concern; several districts were declared drought hit in 2023 following a deficient monsoon[31], and reservoirs were at **23.04%[32] capacity in 2024 (a drop from 32% in 2023).**

One of the recommendations of Maharashtra's State Water Policy[33], launched in 2019, is supplementing the existing water sources with treated waste water to meet the gap caused by water scarcity. The integration with District **Cooling can increase the commercial viability of STPs that remain underutilized despite the growing demand for water in India**. Although India's STP capacity has seen substantial increase in the last few years, there is a significant gap in the use of treated wastewater, which leads to underuse. Currently, only **28% of waste water[34] from urban centers (20,236 MLD)** is treated for re-use, whereas the rest is discharged into water bodies.

The use of treated water for cooling systems has been successful in several states, as can be seen across commercial developments with captive cooling plants including RMZ's One Paramount in Chennai, Tata Realty's Intellion Park in Gurugram, TCS Olympus in Mumbai, and Prestige Shantiniketan in Bengaluru amongst many others. The only consideration to be kept in mind while utilizing treated water for District Cooling is the quality of water to ensure it doesn't affect the longevity of cooling equipment. Adequate treatment and usage of TSE water also helps address challenges around blowdown into rivers that deteriorates the quality of water.

Renewable Power & Thermal Energy Storage

In line with nationwide net zero targets, Maharashtra aims to procure **50% of its energy from non-traditional sources by 2030**[35]. The Maharashtra State Renewable Energy Policy 2020[36] has set an ambitious target[37] of achieving total solar installed capacity of 12,930 MW by 2025, which includes a target[38] of 2,000 MW for grid connected rooftop solar projects. The current solar installed capacity stood at 3,836 MW as of March 2024[39], highlighting the need for accelerated efforts to bridge the gap and meet the target. District Cooling can free up building rooftop space, traditionally occupied by cooling towers in captive cooling plants or outdoor units in conventional air conditioning systems, which can then be used to install rooftop solar. The renewable energy thus produced on site can be used to power the District Cooling system. Any excess production of renewable energy can be stored in thermal energy storage (TES) tanks to address concerns around variability in renewable power generation and demand.

Currently, no state in India has a comprehensive strategy for storing green energy and ensuring round-the-clock energy supply. Some progress has been made in battery energy storage systems (BESS): Maharashtra State Electricity Distribution Co. Ltd (MSEDCL)[40] launched a Battery Energy Storage Systems (BESS) tender[41] in 2024 to set up standalone BESS pilot projects of 300 MW/ 600 MWh connected to the state grid. However, BESS continues to face challenges in terms of scalability, commercial viability, and also disposal of batteries which currently doesn't get as much attention as it merits. In comparison, **Thermal Energy Storage (TES) is a time-tested technology that is an integral part[42] of District Cooling systems.** TES integration with District Cooling enables buildings to reduce mechanical load requirement and thus the associated fixed power demand for cooling, **freeing up the grid's capacity for other uses; demand side management to smoothen the power demand curve** by shaving the peaks through use of chilled water stored in TES tanks during these peak hours, which are observed primarily due to a burgeoning demand for cooling; and serve as partial back-up in crunch-times or during power outage.

TES can also support decarbonization of the residential cooling demand which is projected to become one of the largest contributors to cooling demand in the near future. Since residential buildings are usually situated in densely populated areas, TES needs to be such that it uses minimal space. In efforts to test this out, a Phase-Change Material (PCM) based-TES tank is being piloted at Plaksha University in Mohali, Punjab, to meet night-time cooling demand of residential or hostel buildings in the campus. To minimize the grid reliance, the tanks are proposed to be charged with solar energy during the day and discharged at night to address the issue of renewable energy's supply variability.

Alternate Energy Sources

District Cooling could also enable substitution or supplementation of grid-power with alternate sources such as aforementioned renewable energy or combined with waste to energy plants or natural gas to further minimise, and in certain cases even eliminate, dependence on traditional electricity sources.

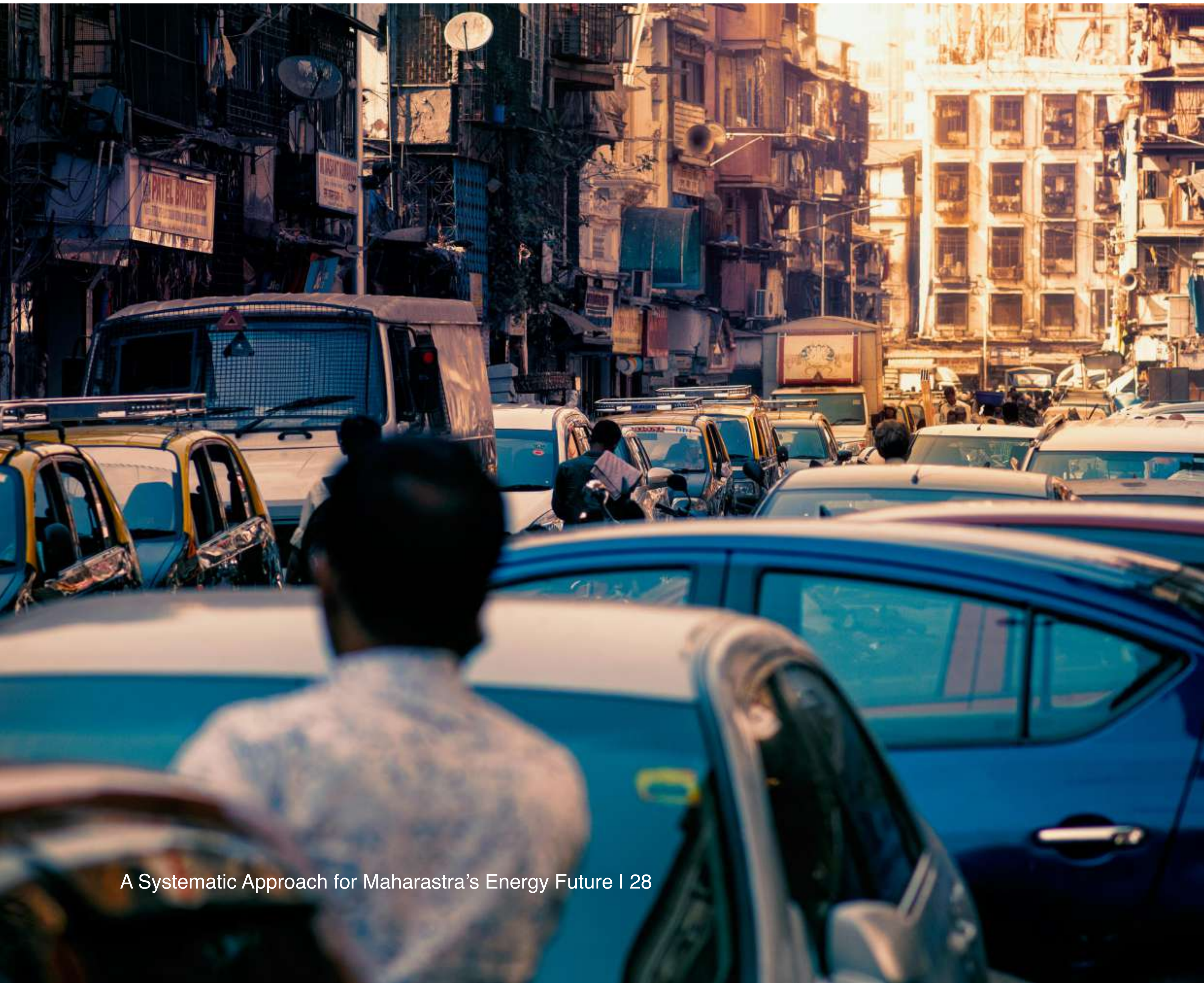
It is estimated that 70-80% energy produced in Waste-to Energy plants in the process of electricity generation is wasted. This waste heat can be recovered or utilized using absorption chillers to power the District Cooling system, increasing the viability of Waste-to Energy plants. Taking it one step further, the District Cooling plant could provide cooling for Waste-to Energy or power plant, creating a circular loop. In 2015, under its Comprehensive Policy[43] for Grid-Connected Power Projects based on new and renewable (nonconventional) energy sources, **Maharashtra has set a target of 200 MW of industrial waste-based power projects capacity.** As of September 2022[44], the state had an installed capacity of 48 MW of Waste to Energy (Urban/Industrial) plants. A number of plants under implementation/ development in the state include Nashik[45], Mumbai[46], Pimpri-Chinchwad[47], Sangli, Dhule[48], etc.

City gas distribution (CGD) operators can also improve their viability; **District Cooling plants can use gas as an alternate source of fuel to provide anchor demand to make CGD operations more viable.** Furthermore, by leveraging gas as an alternate fuel, District Cooling plants can eliminate the need for grid power, partially, and diesel gensets for power back-up, completely.

Sectoral Analysis in Maharastra: Opportunity for District Cooling

This chapter highlights below the key sectors where there is large market opportunity for adoption of District Cooling. To exemplify the benefits of the technology within the sectors, a study of some of the most prominent brownfield and greenfield establishments in Maharashtra has been undertaken. The developments that are currently in operation (brownfield) and those that are in the process of being built (greenfield) offer different but significant opportunities for energy efficiency through adoption of the technology. For **brownfield developments**, retrofitting end of life cooling equipment with high-efficiency equipment such as chillers, cooling towers, and pumps can significantly reduce energy and water consumption. On the other hand, **greenfield developments** provide an opportunity to integrate energy-efficient systems during the design and planning stages, reducing the need for large mechanical systems and minimizing grid energy demand from the outset.

These examples bring out the stark contrast to the business-as-usual approach, highlighting the environmental and financial costs that may otherwise come to the state. **Maharashtra is a high growth state with increasing industrial and commercial space cooling requirements.** The steps that the state takes in the next few years from a regulatory standpoint can change the trajectory of development followed by the state.

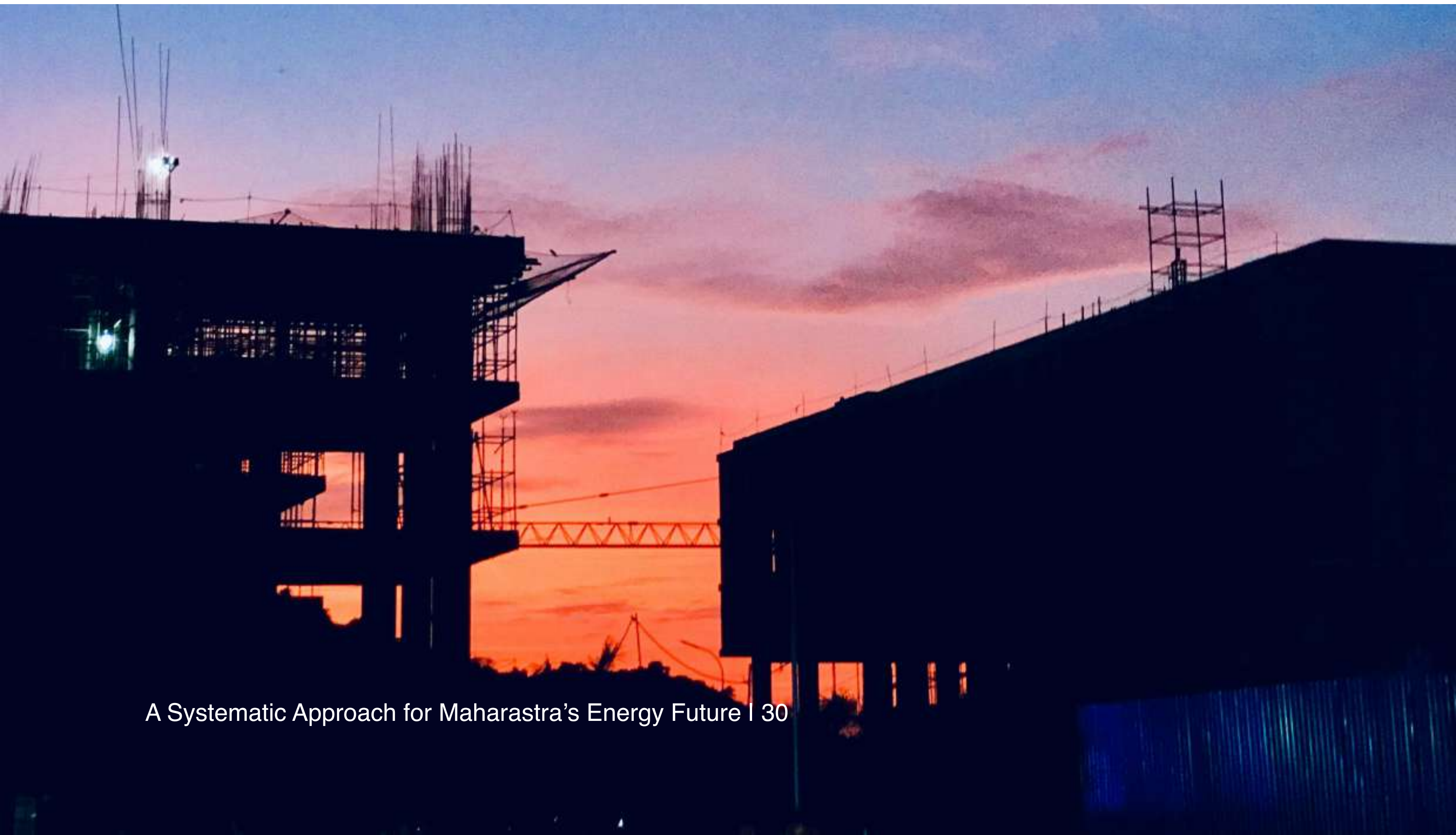


1. Space Cooling: Commercial & Residential Building Infrastructure

The building sector in India, comprising of commercial, retail, hospitality, educational institutions, and hospitals, is **responsible for[49] 33% of total electricity consumption, of[50] which 57% is towards cooling requirements.** In 2022- 23, Maharashtra's[51] residential electricity consumption was 32.8 TWh, which is 20% of the state's total electricity consumption, second only to Uttar Pradesh. Room air-conditioners (window/split ACs) and non-refrigerant-based cooling systems such as fans and air-coolers form the largest pool of cooling technologies used in residential buildings. On the other hand, space cooling in commercial and retail buildings is more reliant on chiller systems, packaged direct expansion (DX) systems, and variable refrigerant flow (VRF) systems. The estimated growth in installed chiller base in India is projected to rise from 5.7 MN RT in 2018 to 38.1 MN RT in 2038[52]. Accordingly, the commercial sector has the highest potential of adopting District Cooling to maximize energy savings.

Maharashtra Energy Development Agency (MEDA) is the state designated agency (SDA) to coordinate, regulate and enforce the Energy Conservation Act within the state of Maharashtra, and has energy efficiency (EE) programs[53] across sectors. Integration of District Cooling will align with MEDA's Strategic Energy Conservation Plan[54], which aims for sustainable energy supply through balancing of supply and demand, with maximum resource efficiency. Industries that are part of MEDA's Save Energy Programme[55] ,that provides financial assistance for carrying out detailed energy audits in small and medium enterprises would also greatly benefit. Under the Mumbai Climate Action Plan (MCAP)[56], **Energy and Buildings is one of the priority areas with a goal of having high efficiency chillers in 80% commercial buildings by 2050.**

In this section, a few developments have been detailed as potential case studies for adoption of District Cooling. However, there are innumerable projects, existing or upcoming, which can benefit significantly, thus contributing to Maharashtra's climate action plan. Some of these include Goel Ganga Integrated IT Township, planned by Hines; Thane Cluster Development Scheme.



Case Study: Brownfield Developments in Mumbai

Tabreed estimates **the chiller market size for existing brownfield developments (commercial buildings and campuses, malls, hotels, hospitals, etc.) in Mumbai to be 350,000-400,000 RT, spread over 130-140 million square feet.** To understand and exemplify the benefits of District Cooling, a study of some of the largest and most prominent existing commercial establishments in Mumbai was undertaken. The data set for the purpose of the assessment includes commercial buildings, malls, campuses, hospitals, hotels across the central and peripheral regions of the city, having a gross leasable area of more than half a million square feet. Several buildings and campuses under consideration have received green building certifications and other accolades.

A closer look at some of them, as seen in the table below, demonstrates that by leveraging principles of District Cooling, **the total installed capacity can be optimized from 219,000 RT to 167,500 RT** across commercial and retail use cases due to diversity benefits, alongside **a 90-100 MW (40%) reduction in power demand** through use of professionally operated and managed energy efficient equipment.

Existing Commercial and Retail Space Cooling Demand	GLA (msf)	Installed Capacity (RT)		Power Demand (kW)		Water Consumption (KLD)	
		Business as Usual (BAU)	District Cooling System (DCS)	Business as Usual (BAU)	District Cooling System (DCS)	Business as Usual (BAU)	District Cooling System (DCS)
Office Campus	10	29,505	20,063	26,555	15,048	2,425	1,374
Mall	10	41,716	35,459	50,059	30,140	6,488	7,659
Business Park	23	80,857	54,983	72,771	41,237	5,593	3,766
Standalone Building	9	33,019	28,066	39,623	23,856	1,357	1,922
Hotel	9	29,160	24,786	34,991	21,068	4,535	5,354
Hospital	1	4,919	4,181	5,903	3,554	765	903
Total	64	2,19,176	1,67,538	2,29,903	1,34,903	21,163	20,978

While the savings demonstrated above are noteworthy and can be achieved through multiple, central cooling plants at campus level, the aggregation of such systems to supply cooling at a wider scale through a true District Cooling system or a merchant District Cooling system has a greater multiplier effect through the diversity benefits offered.

However, integrating a District Cooling system into a built environment presents challenges. Retrofitting requires adapting to existing infrastructure, which can be complex and costly. Space constraints may limit the ability to install an adequately sized system, making large-scale implementation difficult. Additionally, the lack of detailed utility maps and schematics can lead to disruptions in construction, including roadworks, pipes installation, and temporary shutdowns. **The absence of formal recognition of cooling as a utility further complicates obtaining the necessary right-of-way and permits**. On the private sector side, businesses that have already invested in individual cooling infrastructure may require innovative business models and financial incentives to transition to District Cooling. This is not to mention the operational challenges that arise from the need to coordinate multiple stakeholders, including building owners, tenants, and municipal authorities.

The following case study demonstrates how a merchant District Cooling model can be adopted for brownfield developments, addressing some of the challenges highlighted above.

Case Study: BKC Area, Mumbai (Brownfield)

The Bandra Kurla Complex (BKC) is a central business district (CBD) in the city of Mumbai, and amongst many other marquee buildings, hosts the National Stock Exchange (NSE), Securities and Exchange Board of India (SEBI), the Diamond Bourse (world's largest diamond trading hub), the Consulates of United States of America, United Kingdom, Australia and France, and 5-star hotels, clubs, hospitals and staff quarters.

It is a prominent upscale commercial hub which commands some of the highest property rates in the country. According to Mumbai Metropolitan Region Development Authority (MMRDA), **the complex is the first of a series of "growth centres"[57] created to "arrest further concentration" of offices and commercial activities in eastern parts of Mumbai.** It has aided in decongesting the central business district in South Mumbai while seeding new areas of planned commercial real estate in the metropolitan region. A list of a few prominent buildings in BKC along with their cooling loads have been mentioned below:

Developments	Area (msft)	Estimated Peak Cooling Load (RT)
One BKC	1.5	5,000
Sofitel	0.4	1,100
Trident	0.5	1,800
Jio World Centre	8.5	25,000
U.S. Consulate General Mumbai	0.5	1,600
NSE	0.2	1,300
Wockhardt Towers	0.2	500
Godrej	0.6	3,200
NABARD	0.5	1,700
IBM India Private Limited, IDFC	0.5	1,600
SEBI	0.2	700
Bharat Diamond Bourse	2	7,500
The Capital	1	4,000
Kotak Towers	0.4	1,000
NSDL Bhawan	0.1	300
SIDBI	0.1	300
ICICI	0.6	1,800
Bank of Baroda	0.2	600
PNB	0.2	600
Income Tax Office (Kotliye Bhawan)	0.3	900
SBI	0.4	2,100
IDBI/SEBI	0.3	1,000
Parinee Crescenzo	0.9	3,100
First International Financial Centre (TCG)	0.7	2,400
Laxmi Tower	0.4	1,400
Platina	0.4	1,500
Total	**22**	**72,000**

Given the high cooling loads and proximity of the buildings, **there is a significant opportunity to aggregate and optimize cooling demand through a merchant District Cooling system.** This opportunity is particularly well-timed as many buildings' cooling equipment is aging and may soon require replacements; and in cases where the equipment is relatively new and in good shape, it can be reused within the District Cooling plants through smart technical design interventions.

With the buildings having varying end-uses, leveraging diversity benefits, **the installed mechanical load of the area can be reduced by 40%, from 72,000 RTs to 44,000 RT.** The diversified cooling demand of the area can be met through two District Cooling plants of 17,000 RT (DCP 1) and 32,000 RT (DCP 2) capacity (including thermal energy storage of 2,500 RTs each).

Through the use of large industrial grade energy efficient equipment, power demand of the system can be reduced by 50%, resulting in savings in power bills and corresponding savings in associated emissions of ~25,000 tCO2e. Additional savings can be attributed to better O&M due to a centralized, professional team ensuring the asset is operated in line with the design intent, while keeping in mind asset longevity and lifecycle costs. The results of such aggregation and consolidation are promising, as summarized below.

- **40% (28,000 RT) reduction in installed mechanical capacity.**
- **45-50% (30 MW) reduction in power demand** and associated infra requirements vis-à-vis stand-alone systems through integration of TES, reduced mechanical cooling load and better efficiency which frees up grid capacity.
- **15-20% + improvement in electrical efficiency** from 0.90 kWh per RTh to 0.75 kWh per RTh resulting in lower electricity bills.
- **15-20% (1,000 KLD) reduction in annual water demand** for cooling.
- Annual CO_2 emission reduction of 25,000 tonnes (17%).

Parameters	Unit	Business as Usual (BAU)	District Cooling System (DCS)
Installed Mechanical Load	RT	72,000	44,000
Thermal Storage	RT	-	5,000
Power Load	MW	65	35
Annual Power Consumed	Million kWh	165	135
Annual Water Consumed	Kilo-litre per day	5,900	4,900

The business model can be structured under a Cooling as a Service (CaaS) approach, where the District Cooling provider acquires existing captive cooling plants from individual buildings through an **upfront purchase consideration,** while eliminating the need for future capital investments in cooling infrastructure. To facilitate implementation, **the municipality can allocate dedicated utility plots** within the designated area for setting up the District Cooling system. The transition would be executed in a phased manner, ensuring minimal disruption to occupants. Over time, as buildings are integrated into the system, their existing cooling infrastructure would be gradually decommissioned, with cooling requirements efficiently met through two interconnected District Cooling plants.

Even when space constraints limit the feasibility of a fully centralized District Cooling system, **an alternative approach can be adopted by interconnecting the cooling systems of larger identified campuses** to serve the cooling needs of smaller campuses in the vicinity. This distributed model retains the advantages of diversity benefits and optimized cooling loads while making efficient use of available infrastructure.

Additionally, **thermal energy storage tanks combined with CNG sourced from the Mahanagar Gas Station in BKC can act as a supplemental power source,** ensuring system resilience and eliminating the need for diesel generators during power outages. This not only enhances energy security but also contributes to **lower emissions and improved air quality compared to traditional diesel-based backup solutions.**

After exemplifying the operating model for a merchant District Cooling system for a brownfield site and significant savings it can bring about in terms of mechanical cooling capacity, power demand, electricity consumed, this section continues with case studies which illustrate the benefits of adopting District Cooling in other existing operational developments as well as upcoming greenfield developments.

Case Study: Dharavi

Dharavi, spread across 600 acres, is one of Asia's largest slums, home to over a million people[58]. Known for its thriving informal economy, which includes pottery, leatherwork, garment production, and recycling, **Dharavi stands as an economic powerhouse in the heart of Mumbai.** Yet, it remains plagued by challenges such as poor infrastructure, overcrowding, and inadequate access to essential services. After years of delays, the Dharavi redevelopment project[59] - awarded to the Adani Group in 2022 at an estimated cost of INR 20,000 crore - represents a critical opportunity to transform the lives of its residents while addressing broader urban challenges. The plan envisions free housing for eligible residents, affordable housing under the Pradhan Mantri Awas Yojana, across a development footprint of 296 acres with commercial spaces (10% of the area) and open areas like Mahim Nature Park and the Koliwadas.

While the project offers a pathway to improved housing and urban infrastructure, the essential aspect of thermal comfort is a critical and growing necessity in Mumbai's increasingly hot and humid climate. **Dharavi's staggering population density of 354,167 people per square kilometre exacerbates challenges such as heat stress[60], poor air quality, and the urban heat island effect,** directly impacting residents' health and productivity. In such conditions, access to cooling is a necessity. Post-redevelopment, cooling demand in Dharavi is estimated to reach approximately 83,500 RT, assuming an average requirement of 1.5 RT for each 350 sq. ft. housing unit. Without a planned approach, this demand could be met through ad-hoc installations of unitary air conditioning systems, leading to significant energy inefficiencies, grid stress, and higher operational costs for residents. However, **integrating District Cooling into the redevelopment offers a far more sustainable and effective solution, reducing the required cooling capacity to just 64,000 RT due to its inherent efficiencies.**

District Cooling not only addresses the immediate need for thermal comfort but also has **the potential to tackle several interconnected challenges that Dharavi faces.** By centralizing the cooling infrastructure, it significantly reduces energy consumption, lowering greenhouse gas emissions and alleviating the pressure on Mumbai's electricity grid during peak demand. Additionally, thermal energy storage systems, particularly in open spaces, could store cooling energy during off-peak hours and distribute it during peak demand, further optimizing energy use and reducing operational costs.

Particulars	Units	Business as Usual (BAU)	District Cooling System (DCS)
Peak Cooling Demand	RT	83,500	
Installed Cooling Load (Mechanical)	RT	83,500	59,000
Thermal Energy Storage (TES)	RT	-	5,000
Power Load	MW	115	45
System Efficiency	ikW/RT	1.4	0.75
Annual Power Consumed	Million kWh	140	75
Water Consumption	Kilo-litre per day	-	2,800
Annual Utility Cost Savings	INR Cr	~100	
Annual CO2 Emission Savings	Tonnes	65,000	

District Cooling can integrate seamlessly with other sustainable technologies to create a circular urban ecosystem and address several connected urban challenges. For instance, waste generated from households and industries in Dharavi can be processed in decentralized waste-to-energy plants, converting organic waste into biogas or other forms of usable energy. This energy could then be used to supplement the operation of District Cooling systems, creating a self-sustaining loop. Similarly, treated wastewater from on-site sewage treatment plants could be reused in cooling towers, reducing the dependency on freshwater resources and addressing the pressing issue of water scarcity in Mumbai. Such synergies would not only enhance the efficiency of the cooling infrastructure but also contribute to broader sustainability goals, making Dharavi a model for integrated urban development.

To ensure inclusivity and prevent exploitation, cooling services for residential users could be delivered under a Cooling-as-a-Service (CaaS) model, where residents do not bear upfront capital costs but pay a nominal, usage-based fee or are provided cooling entirely free for a baseline consumption. The government could facilitate initial capital investments through grants or low-interest loans from development finance institutions or international organizations that support climate-resilient urban infrastructure projects. Each household could receive free cooling up to a fixed monthly limit, sufficient for basic thermal comfort, with additional usage billed at affordable rates. This structure would encourage energy conservation while ensuring equitable access to cooling.

Case Study: Mindspace Airoli, Navi Mumbai (Brownfield)

Mindspace Airoli is one of the largest business parks in the Mumbai Region with a total land area of 50 acres and a total leasable area of 5.2 million sq ft. Strategically located near Airoli Railway Station, **the IT Park has transformed commercial office space in the Thane-Belapur road micro market.** The park provides high quality infrastructure and amenities including in-house power.

The existing cooling systems in Mindspace Airoli East and West consists of multiple standalone plants that are a mix of air- and water-cooled chillers, adding up to total peak cooling demand of 21,000-22,000 RT.

While District Cooling or campus-level captive cooling plants were not considered earlier, **the aging cooling assets (over 10-12 years) and the company's ESG commitments provide an opportunity to significantly improve the design and energy efficiency of the cooling system,** and thus make it a prime example of retrofitting a large brownfield campus with District Cooling. The most feasible approach could be to set up two District Cooling plants in Airoli East (with mechanical chiller capacity of 8,000 RT and TES of 1,000 RT) and Airoli West (with mechanical chiller capacity of 6,000 RT and TES of 1,000 RT), respectively, to avoid roadblocks/diversions to lay the underground network across the busy Thane-Belapur Road. Interconnection opportunities for connecting the two plants can be thereafter sought to improve system resilience and for performance optimization. The benefits from adopting District Cooling through a Cooling-as-a-Service (CAAS) model are outlined below:

- **30-35% (7,000 RT) reduction in installed mechanical capacity and space use** in both the campuses.

- **50% (10 MW) reduction in power demand** and associated infra requirements vis-à-vis stand-alone systems through integration of TES, reduced mechanical cooling load and better efficiency which frees up grid capacity.

- **25% + improvement in electrical efficiency** across campuses from 1.00 kWh per RTh to 0.75 kWh per RTh resulting in lower electricity bills.

- **15-20% (300 KLD) reduction in annual water demand** for cooling.

- **Cost savings of 30-35% on account of improved efficiency of operations** through a one-point centralized O&M team (excluding power).

Particulars	Units	Business as Usual (BAU)	District Cooling System (DCS)
Peak Cooling Demand	RT	21,000	
Installed Cooling Load (Mechanical)	RT	21,000	14,000
Thermal Energy Storage (TES)	RT	-	2,000
Power Load	MW	20	10
System Efficiency	ikW/RT	1	0.75
Annual Power Consumed	Million kWh	55	40
Water Consumption	Kilo-litre per day	1,800	1,500
Annual Utility Cost Savings	INR Cr	15	
Annual CO2 Emission Savings	Tonnes	12,000-13,000	
Capex	INR Cr	210	230

One key advantage of adopting CAAS for Mindspace Airoli Business Park would be the transfer of development, design, financing and execution risks. A private investment and development partner can commit to a long-term concession and undertake necessary investment in cooling infrastructure and distribution network to provide uninterrupted cooling services to end users in a brownfield marquee development such as this.

Other, often unaccounted, benefits include consistent and reliable cooling service due to systems being operated and maintained by professionals with specialized expertise. With round-the-clock service availability, any potential disruptions can be promptly addressed, minimizing downtime and inconvenience for users. This, in addition to suitable replacement/refurbishment capital expenses incurred by the utility operator at regular intervals, ensures asset longevity and a far lower lifecycle cost than expended through the business-as-usual approach.

Case Study: Mixed-Use Greenfield Development in Navi Mumbai

This greenfield project in Navi Mumbai, Maharashtra is a unique and ambitious mixed-use urban development project, where the developer intends to build **a "campus-themed IT Park" bringing together a space with perfect harmony for work, leisure and wellness**. Planned over 47.5 acres, the project will consist of commercial buildings, along with dedicated spaces for educational institutions and retail zones. With an overall built-up area of over 9.5 million square feet, the project, once completed, will be Navi Mumbai's largest IT Park.

To aid the broader vision of improving economic competitiveness and environmental sustainability which goes beyond stand-alone green building design, the developer could consider the adoption of District Cooling Systems (DCS) as a part of the masterplan. With over 50% of energy demand at the campus in Navi Mumbai likely to be for air-conditioning, with adoption of DCS, the project can set new sustainable, environmental, and cost-efficient benchmarks for a master plan of this nature.

The peak cooling demand at the development is anticipated to be 25,000 RT. Based on the size of the project, an optimal planning strategy is to consider a single central chilled water production plant that may include a thermal energy storage system (TES) and chilled water distribution network that runs in parallel to other common infrastructure up to the perimeter of each building in the premises. Capacity deployment can be planned in a modular fashion on the basis of demand ramp-up and completion of buildings within the master plan to ensure there are minimal pre-investments made.

Commercial implications of this District Cooling strategy are listed below:

- **30% (7,500 RT) lower mechanical load enabled** from aggregation of demand.
- Together with lower installed capacity, more efficient technology selection and thermal storage, **peak energy demand for the entire project can be reduced by up to 10 MW.**
- **Lower annual electricity and water consumption costs:** based on design and system efficiencies, resultant power consumption viz-a-viz standalone systems is 17% lower.
- **Freed-up basement and rooftop space of more than 18,000 sqft,** allowing more flexibility in building design, improved building aesthetics and increased saleable area.
- **Lower GHG emissions** (annual GHG emission savings of ~9,000 tonnes along with zero refrigerant leakages) released in the environment.
- **Life-cycle cost savings:** All the aforesaid benefits of a District Cooling system for the developer and end-users alike viz. no capital outlay, lower installed capacity, lower electricity and water bills for air-conditioning supply, reduction in electric load, increased energy efficiency and lower O&M costs shall provide 20-30% savings in lifetime cooling costs.

Particulars	Units	Business as Usual (BAU)	District Cooling System (DCS)
Peak Cooling Demand	RT	25,000	
Installed Cooling Load (Mechanical)	RT	25,000	17,500
Thermal Energy Storage (TES)	RT	-	2,500
Power Load	MW	25	15
System Efficiency	ikW/RT	0.9	0.75
Annual Power Consumed	Million kWh	55	45
Water Consumption	Kilo-litre per day	2,000	1,700
Annual Utility Cost Savings	INR Cr	15-20	
Annual CO2 Emission Savings	Tonnes	8,000-10,000	
Capex	INR Cr	245	285

Furthermore, it is understood that a residential complex is being planned in the vicinity of the IT Park, the cooling requirements of which can be met through the same DCP (for the commercial IT park) with no additional capacity requirement at the primary side due to the varying usage patterns.

A common DCS does imply pre-investment into additional piping and networks to connect each residential building with DCS on the primary (high) side and installation of fan coil units (FCU) on the secondary (low) side. **However, commercially, these pre-investments are more than paid-off by the savings in electrical infrastructure that would have been required if each household were to set-up its own DX unit.**

Residential Sector	District Cooling with FCUs (low-side)	Standalone Cooling/ DX or split units
Peak Cooling Demand	4,500 RT	
Associated Installed Capacity	3,500 RT	4,500 RT
Estimated Electricity Load (indoor + outdoor)	2.9 MW	6.75 MW
Reduction in Electricity Load	3.85 MW or >55%	--

Furthermore, **significant savings can be expected in electricity costs for the households**, vis-à-vis a traditional approach of widow/split units, due to improved efficiency from industrial grade chillers and a much lower installed load to cater to the cooling requirements of residential blocks. **Mahanagar Gas Station, which is less than a km away from the campus, can serve as a supplemental power source** for the District Cooling system to eliminate the need for diesel generators to power cooling systems during power outage.

2. Space and Process Cooling: Industries and Manufacturing Facilities

Maharashtra is a leader in manufacturing and contributes 15.5%[61] to India's industrial output, and 15.7% to India's exports - second[62] only to Gujarat. Gems & Jewellery (22.84%), Engineering (11.39%), Electronics and Electrical Components (17.30%) are the largest contributors. As of March 2024, the state[63] has 882 mega projects approved with an investment value of INR 7,74,577 crore which will help generate employment for 8.44 lakh people. Under the Micro and Small Enterprises-Cluster Development Programme (MSE-CDP),[64] Maharashtra State Industrial Cluster Development Programme (MSI-CDP)[65], and Scheme of Funds for Regeneration of Traditional Industries (SFURTI),[66] numerous industrial clusters have been operationalised and approved for development. The Delhi-Mumbai Industrial Corridor (DMIC)[67] will further boost industrial development and connectivity in the state. Which in turn will lead to both an increase in cooling needs, as well as technologies that meet these needs efficiently.

Cooling is a critical requirement across different industrial sectors in Maharashtra such as chemicals, food processing, pharmaceuticals, textiles, amongst others. Industries such as pharmaceuticals, textiles, and food processing are particularly reliant on precise temperature control to maintain product quality and operational efficiency. Similarly, the pharmaceutical sector needs rigorous climate control to ensure the stability of medical products. The textile and garment industries also have high cooling requirements to control humidity and prevent damage to fabrics and machinery. According to industry reports, approximately 30-50% of the total energy consumption in these sectors can be attributed to cooling needs.

Maharashtra's 2019 Industrial policy[68 & 69] lays emphasis on green industrialisation, with provision of **Green Industrialization** Assistance for measures **to promote sustainability such as conserve water, energy and environment** alongside economic growth. District Cooling offers a means to not only meet the growing cooling needs of these multiple industries, but also to do so in a sustainable way that aids in reducing carbon emissions, minimising wastage of natural resources, and ensures sustainable development.

This section details upcoming industrial hubs developments as potential case studies to illustrate how District Cooling could bring significant savings and reduce the carbon footprint of a sector which is generally considered hard to abate.

Case Study: Reliance Industrial Hub at Navi Mumbai (Greenfield)

Reliance Industries Ltd. (RIL) is set to build a **global economic hub in Navi Mumbai over an area of 5,000 acres** of sub-leased land from the Maharashtra government. The implementation Special Purpose Vehicle (SPV) is jointly held by City and Industrial Development Corporation of Maharashtra (CIDCO), the government planning agency, and Reliance Industries.

The project forms part of the state's plan to decongest Mumbai and create parallel industrial hubs in Navi Mumbai and Panvel by upgrading infrastructure and providing facilities such as affordable housing and improved connectivity. RIL's industrial and economic hub will provide both physical as well as digital infrastructure to encourage corporations to set up offices and factories. Given the sheer size and scale of the Hub, incorporation of District Cooling can further raise Reliance Industrial Hub's green accolades, fitting seamlessly into the Hub's vision for sustainable and smart growth for environmentally conscious development.

By aggregating cooling demand, District Cooling reduces mechanical load and power demand from the grid. It further boosts energy efficiency, lowers emissions, and ensures reliable service, maximizing uptime. A 120,000 RT District Cooling system can be set up, served through 3 interconnected DCPs of 36,000 RT each, including a Thermal Energy Storage system of 4,000 RT for each of the 3 DCPs. The capacity can be deployed in phases, with initial capacity being deployed for greenfield units coming up in the near future.

- **35%-40% (~70,000 RT) lower mechanical load** enabled from aggregation of campus demand.
- **55%-60% (120 MW) savings in power demand** and associated infra requirements vis-à-vis stand-alone systems through integration of TES, reduced mechanical cooling load and better efficiency which frees up grid capacity.
- **30% lower energy consumption**, given DCS average electricity efficiency of 0.75 kW/RT as compared to 1.10 kW/RT for stand-alone, conventional cooling systems through use of large, industrial grade water cooled, centrifugal chillers

Particulars	Units	Business as Usual (BAU)	District Cooling System (DCS)
Peak Cooling Demand	RT	1,80,000	
Installed Cooling Load (Mechanical)	RT	1,80,000	108,000
Thermal Energy Storage (TES)	RT	-	12,000 (4,000 RTs X 3 TES)
Power Load	MW	200	80
System Efficiency	ikW/RT	1.1	0.75
Annual Power Consumed	Million kWh	495	340
Water Consumption	Kilo-litre per day	10,350	12,350
Annual Utility Cost Savings	INR Cr	~200	
Annual CO2 Emission Savings	Tonnes	1,50,000	
Capex	INR Cr	1,800	1,700

In close coordination with CIDCO and the municipality, dedicated utility plots will have to be identified, preferably near electrical sub-stations, for setting up DCPs. **An enabling policy framework can give a huge impetus to the District Cooling scheme coming to fruition in the Hub.** Policies as elaborated in subsequent sections can require industrial units to mandatorily connect to District Cooling according to a pre-defined rate card. Further, under a PPP model, for risk sharing purposes, while the District Cooling provider sets up the plant, CIDCO can take the onus of laying the network which forms a substantial portion of the pre-investment required, especially in cases of uncertain demand uptake. District Cooling systems also open the possibilities for integrating other energy supply systems including utilizing waste heat emitted through industrial processes to operate and power the cooling system

Case Study: Bidkin Industrial Area, Kubhephal, Ladgaon (Greenfield)

The Aurangabad Industrial City (AURIC) was inaugurated in 2019[70] as **the first industrial integrated smart city of India under the Government of India's flagship Smart Cities Mission** (spread over the Shendra and Bidkin areas near Aurangabad). It was a part of the Delhi–Mumbai Industrial Corridor Project (DMIC), planned as an industrial zone across six states between India's capital, Delhi, and its financial hub, Mumbai.

While the project faced delays, in September 2024 it has been re-launched as Bidkin Industrial Area (BIA). Spanning 7,855-acres, it has been announced as a part of the central government's "Make in India, Make for the World" programme. **The industrial area is expected to attract INR 56,200 crore in investments and create over 30,000 jobs.**

It is situated 20 kilometers south of Chhatrapati Sambhaji Nagar, better known as Aurangabad, for a total project cost of INR 6,414 crores across three phases. The Maharashtra Industrial Township Limited (MITL), a Special Purpose Vehicle (SPV) formed with a 51:49 partnership between Maharashtra Industrial Development Corporation (MIDC) and National Industrial Corridor Development and Implementation Trust (NICDIT), has driven this ambitious project to develop industrial and mixed-use plots in the area to attract more skilled businesses and also promote industrial development. Currently, the project has attracted investments from companies like Ather Energy (100 acres), Lubrizol (120 acres), Toyota-Kirloskar (850 acres), and JSW Green Mobility (500 acres).

The Bidkin Industrial Area can incorporate District Cooling for techno-commercial and environmental benefits and savings. **Industries are generally categorized as a "hard to abate" sector,** and hence any scope to minimize carbon footprint associated with the sector should be fully exploited. District Cooling can help reduce the burden on the grid by reducing mechanical load and associated power demand and accordingly support savings in power and water costs. As with the previous case study, waste heat from the manufacturing process can power the District Cooling system, and neighbouring waterbodies can serve as heat rejection sinks.

Since industrial development is a key driver for job creation and economic growth, green and sustainable industrial development ensures that these benefits are achieved in a way that is inclusive, equitable, and environmentally friendly. **Below is a brief overview of how a District Cooling system can prove to be more advantageous when compared to a conventional cooling system.** 5 interconnected District Cooling plants can be proposed, with a combined installed mechanical capacity of 1,02,500 RT. The District Cooling plants can be supplemented by thermal energy storage tanks (TES) to further optimize power load.

Particulars	Units	Business as Usual (BAU)	District Cooling System (DCS)
Peak Cooling Demand	RT	1,70,000	
Installed Cooling Load (Mechanical)	RT	1,70,000	1,02,500
Thermal Energy Storage (TES)	RT	-	12,500
Power Load	MW	185	75
System Efficiency	ikW/RT	1.1	0.75
Annual Power Consumed	Million kWh	470	320
Water Consumption	Kilo-litre per day	9,800	11,600
Annual Utility Cost Savings	INR Cr	195	
Annual CO2 Emission Savings	Tonnes	1,37,000	
Capex	INR Cr	1,700	1,650

As seen in the table above, while the capex may be higher for a District Cooling system due to significant civil and infrastructural works, including laying of piping and network, even without considering environmental benefits, the savings on utility and O&M in District Cooling will pay back many times over. Furthermore, the cooling requirements of the residential areas in the vicinity can be met through the same District Cooling system for free or at subsidized rates, with no additional capacity requirement due to the varying usage patterns.

Other Opportunities

- Beyond the detailed case studies above, several major infrastructure and industrial projects in Maharashtra present strong potential for District Cooling adoption. Integrating energy-efficient and sustainable cooling solutions into these developments can enhance operational efficiency, reduce environmental impact, and support Maharashtra's long-term climate and energy goals. The Gem & Jewellery Export Promotion Council (GJEPC) and the Government of Maharashtra signed an MoU at the World Economic Forum 2024 to develop **India's first and largest Jewellery Park in Navi Mumbai, spanning 25 acres in the Mahape Industrial Area**. Given the high cooling requirements of manufacturing and precision-based industries, District Cooling can provide a cost-effective, reliable, and low-carbon cooling solution for this specialized industrial cluster.

- A fully developed industrial zone near Mumbai and JNPT port, **Taloja Industrial Area** hosts key industries such as SARK Chemical Industries, Scottish Chemical Industries, and Exide Industries Ltd. **Developed by MIDC, the area is set for a transformative infrastructure upgrade under a smart industrial city pilot project, making this an opportune moment to integrate District Cooling into its master plan.** Doing so could enhance energy efficiency, reduce peak electricity demand, and improve air quality, supporting Maharashtra's vision for sustainable industrial growth.

- Located in Palghar district, **Dahanu is rapidly evolving into a major industrial zone,** benefiting from its proximity to key infrastructure projects. While industrial expansion is crucial, preserving the region's coastal ecosystem and agricultural heritage is equally important. District Cooling offers a sustainable alternative to conventional cooling, reducing energy and water consumption while ensuring that environmental conservation remains a priority in Dahanu's industrial transformation.

3. IT and Data Centres

The rapid rise of Artificial Intelligence (AI) powered technologies, has led to a surge in demand for data storage and processing, with the energy demand by data centres quickly outstripping the supply. **By 2034[71], the annual global energy consumption by data centres is expected to top 1,580 terawatt-hours, which is almost equal to India's total usage.** The interlinking of AI with daily tasks, is set to register a still higher demand for data centres.

Maharashtra dominates India's data centre landscape, accounting for over 60% of the country's total data centre capacity. As of 2024[72], India hosted over 130 operational data centres with a combined IT load capacity of more than 1,200 MW, spread across 10-15 million square feet of space. The sector is anticipated to grow at a CAGR of 15%, with total capacity expected to rise to 6,690 MW by 2030[73]. **Mumbai city represents 40-45% of India's total data centre capacity and is known as the "Data Center Capital of India"** due to its connectivity, access to a skilled workforce, and proximity to major undersea cable landing stations.

Rapid growth of data centres present significant challenges, particularly concerning increased energy consumption. **Cooling systems account for around 40%[74] of a data centre's total energy usage, excluding IT equipment**. Additionally, data centres are classified by the Uptime Institute's tier system[75], which evaluates operational uptime. As new Tier III and Tier IV facilities emerge in Maharashtra, with uptime requirements of 99.982% and 99.995% respectively, redundancies in both power and cooling systems will be critical to ensure uninterrupted operations and prevent downtime. The challenge lies in meeting the rising energy and cooling demands of data centres sustainably while maintaining uptime requirements.

The Maharashtra government has progressive policies such as the IT and ITES Policy[76], released in 2023, which designate IT services as "essential services," and includes data centres under the Essential Services Maintenance Act. To ensure environmental sustainability, **the Green Integrated Data Centre Parks initiative aims to create 1.5 GW of capacity that is powered by 100% renewable energy, and promote eco-friendly practices in the sector.** One such practice can be the adoption of District Cooling in data centres in place of conventional cooling. District Cooling systems can reduce the need for individual building level equipment, energy consumption, operational costs and environmental impacts. In the gamut of solutions available with District Cooling, waste heat from data centres can be utilized to supply cooling, creating a mutually beneficial and environmentally friendly setup; phase change material-based thermal storage tanks, which occupy far lesser space, can be used for improved efficiency as well as for back-up in case of power failure; multiple power sources including CNG can further support reduction in equipment for back-up.

In Singapore for example, at the **JTC Data Center Park,** District Cooling is implemented through a centralized chilled water plant supplying energy-efficient cooling to all connected data centres. The government of Singapore also provides significant support to encourage adoption, including grants from the Economic Development Board (EDB) to offset the capital costs of integrating District Cooling infrastructure. Data centres benefit from reduced power tariffs for using District Cooling, and carbon tax rebates reward facilities for achieving emission reductions. The government of Singapore invests in developing the pipeline network through agencies like the Urban Redevelopment Authority (URA), ensuring reliable and scalable connections. By eliminating the need for individual chillers, the system reduces energy consumption and operational costs while offering uninterrupted, flexible cooling—a model that aligns with Singapore's sustainability goals and its push for green industrial development.

Planning for data centre clusters in Maharashtra should prioritize comprehensive, multi-facility cooling solutions to avoid duplication of investments and siloed approaches. Below, some policy recommendations/amendments to Maharashtra's existing IT/ITeS Policy 2023 are provided to incentivize adoption of District Cooling.

Additionally, some potential case studies are listed to illustrate how District Cooling can be incorporated in data centres, which is fast emerging as a sector likely to account for significant amounts of power and water demand.

Case Study: Green Integrated Data Center Park, Mumbai and Navi Mumbai (Greenfield)

The Government of Maharashtra has proposed to build 1.5 GW capacity of data centre parks in and around Mumbai, all completely powered by clean and renewable energy sources. The state is aiming to attract investments worth INR 1.60 lakh crore (~US$ 20 billion) for the project that will see the development of three facilities of 500 MW each.

The Green Integrated Data Center Park is an ambitious digital infrastructure project that mandates the use of 100% green energy for core data centre activities. The project will also get uninterrupted water supply at a "reasonable tariff". The facilities and incentives will only be given when promoters invest at least INR 10,000 crores and use 100% clean energy.

For a 500 MW data centre, 5 District Cooling systems of 34,500 RTs could be considered:

Particulars	Units	Business as Usual (BAU)	District Cooling System (DCS)
Peak Cooling Demand	RT	1,72,500	
Installed Cooling Load (Mechanical)	RT	1,72,500	1,57,500
Thermal Energy Storage (TES)	RT		15,000
Power Load	MW	240	120
System Efficiency	ikW/RT	1.4	0.75
Annual Power Consumed	Million kWh	2,110	1,130
Water Consumption	Kilo-litre per day		12,400
Annual Utility Cost Savings	INR Cr	950	
Annual CO2 Emission Savings	Tonnes	8,96,000	
Capex	INR Cr	1,860	2,530

Several other technical design elements should be kept in mind to optimize plant performance:

- Assuming that the data centre's total capacity of 500 MW is distributed/ divided between 10 buildings of 50 MW each, **there will be a requirement for energy transfer stations in each building to cater to varying temperature needs of the buildings.** ETSs are critical for regulating and distributing chilled water, ensuring the right temperature is supplied based on the operational requirements of each building. They also enhance energy efficiency by managing demand variations across the network and reducing energy losses.

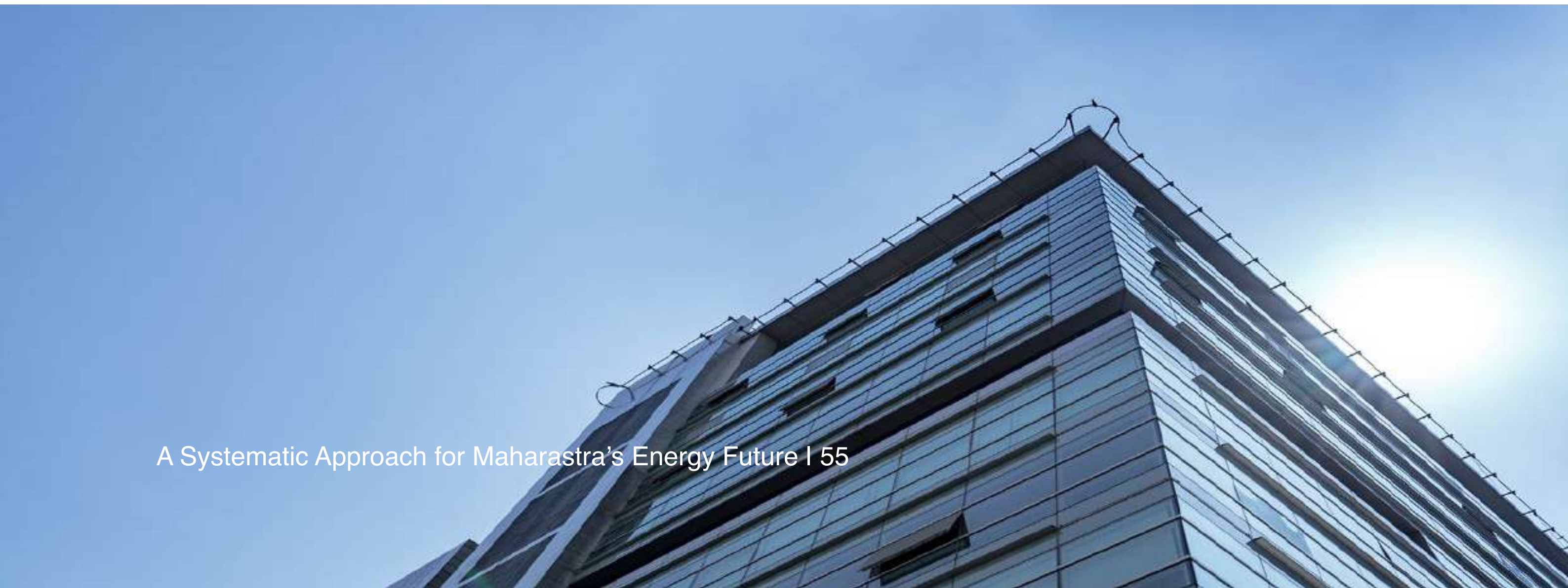
- Furthermore, it is preferable to have **separate networks for all the data centres** to adapt to differing temperature requirements while ensuring energy efficiency as well as for added resiliency in an event of failure.

- A **TES system (~15,000 RT) is recommended for backup cooling mechanism** ensuring uninterrupted cooling and to avoid the lag between power failure and switching on the gen-sets. A short outage span of even 5 mins can have exponential repercussions and damage equipment. The TES system can use stored energy to supply chilled water to maintain data centre temperatures during restoration time.

- **Water cooled chillers (0.75 kWh/RT)** can be used in the plant instead of the usually employed air-cooled chillers (1.40 kWh/RT), which are more energy intensive and have a larger footprint, requiring substantial open space either on the ground or terrace.

- **A rooftop solar system can potentially meet upto 20-30% of the building's electricity requirements,** cutting energy expenses while also promoting sustainability.

- Additionally, **a central District Cooling system will reduce operations and maintenance** as compared to individual cooling systems which employ separate teams for operations and maintenance.



Case Study: Colt and CapitaLand Data Center, Mumbai (Brownfield + Greenfield)

RMZ, a leading India-based real estate developer and Colt Data Center Services, a company headquartered in London, have formed a 50:50 joint venture to **invest up to $1.7 billion (over INR 14,300 crores) into India's data centre market.** The JV aims to build data centres with a combined capacity of 250 MW in India, starting with projects located in Navi Mumbai and Chennai, with a third location to be added later.

At less than half a kilometre distance from the Colt Data Center, is an upcoming 108 MW CapitaLand Data Center on a 6.6 acre-site. CapitaLand is expanding its footprint in the data centre sector across key Indian cities, to cater to the growing demand for information technology solutions and data consumption in India.

While the energy consumption of data centres is significant, the benefits of the services offered and the economic activity supported by data centre services are many times larger. As such, **there is an urgent need to decarbonize the sector as much and as fast as possible, using sustainable cooling especially through District Cooling as one of the levers.**

Given their **proximity and high cooling demand**, both data centres present an opportunity for **a shared District Cooling System (DCS)** that can enhance sustainability, reduce energy costs, and optimize cooling infrastructure. A common District Cooling system of 84,000 RTs (comprising of 3 plants of 28,000 RTs each) could be considered, with an investment potential of INR 1,200 crores for the

Optimized Power Demand and Grid Efficiency

- **50-55% (65 MW) reduction in peak power demand and infrastructure requirements** compared to stand-alone cooling systems, freeing up grid capacity.
- **15-20% energy savings through the integration of Thermal Energy Storage (TES)**, allowing load shifting and enhanced efficiency.

Lower Energy and Operational Costs

- **45-50% lower energy consumption,** with DCS efficiency of 0.75 kW/RT versus 1.40 kW/RT for conventional systems.
- **Resultant 40-45%% savings in annual utility costs.**

Significant Carbon Savings

- **Annual CO_2 emission reduction of 4,36,000 tonnes.**

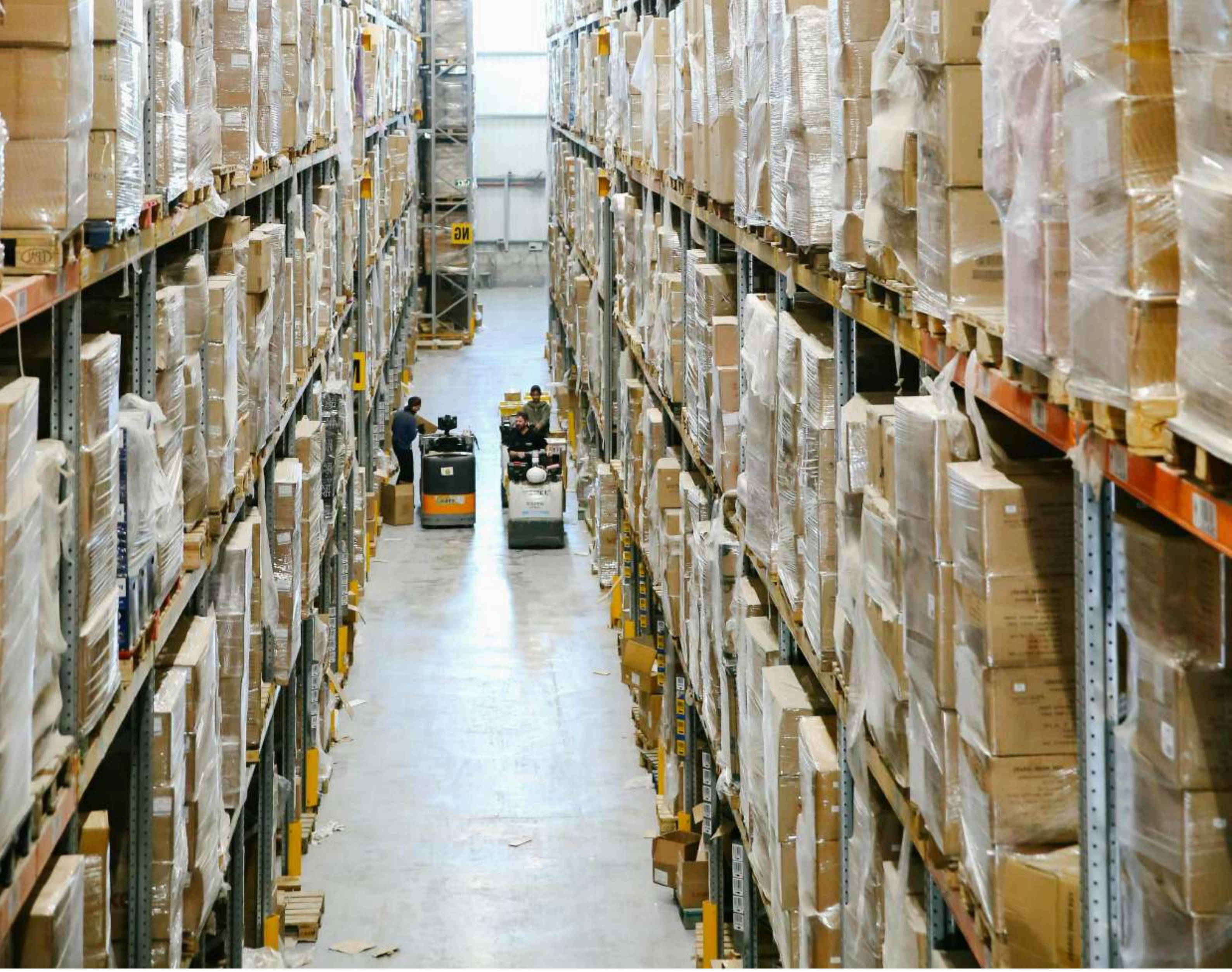
Particulars	Units	Business as Usual (BAU)	District Cooling System (DCS)
Peak Cooling Demand	RT	84,000	
Installed Cooling Load (Mechanical)	RT	84,000	76,500
Thermal Energy Storage (TES)	RT	-	7,500 (2500*3)
Power Load	MW	120	55
System Efficiency	ikW/RT	1.4	0.75
Annual Power Consumed	Million kWh	1,030	550
Water Consumption	Kilo-litre per day	-	6,050
Annual Utility Cost Savings	INR Cr	465	
Annual CO2 Emission Savings	Tonnes	4,36,000	
Capex	INR Cr	900	1,200

To meet the redundancy requirements of hyperscalers, District Cooling could serve as the primary cooling system, with in-building cooling equipment retained for backup. This approach enhances **scalability and reliability** by ensuring uninterrupted cooling through a centralized system with built-in redundancies. It also enables **integration with cleaner energy sources**, such as natural gas or renewables, further reducing carbon emissions. Additionally, **water sustainability** can be improved by replacing potable water with treated sewage effluent (TSE).

4. Warehouses and Cold Chains

According to the India Cooling Action Plan, agricultural cold chain is critically under-developed in India, especially for agricultural packhouses, refrigerated transport and logistics. The lack of availability of cold-chain is estimated to lead to an average of 15-20% loss[77] of food in India. This amounts to about **50% of all post-harvest food loss in the country.** Even as India faces high malnutrition and hunger, it wastes 80 million tonnes[78] of food at retail and consumer levels, which is only second to China in the world. **The reason behind this wastage is lack of cooling and refrigeration[79] infrastructure.** As most producers are small farmers, they do not have easy access to these facilities. An increase in heat due to changing climate and weather patterns is worsening the problem. Moreover, farmers today receive less than half the wholesale price for their produce and for perishable goods. Increasing access to cold chain infrastructure can help reduce food loss, expand market connectivity, protect the quality and safety of food, increase farmers' revenues and improve the resilience of farmers and the rural communities in which they are located.

Agriculture and allied activities (such as dairy, animal husbandry and fisheries) are of significant economic importance to Maharashtra; contributing INR 3,61,268[80] crores (11.36%) to the state's income in FY 22-23. Maharashtra has a coastline of 720 km, with 1.12 lakh sq km area suitable for marine fishing. Some of the major maritime districts[81] include Thane, Palghar, Mumbai city, Mumbai suburban, Raigad, Ratnagiri and Sindhudurg. The state ranked[82] 7th, with close to 5% share in India's fisheries production. The growth of fisheries brings with it **the need for increased cooling, both for supporting infrastructure like cold storage and processing plants like food processing industries.**



The Maharashtra Logistics Policy 2024[83] identifies cold storages as a required facility in Large Logistics Parks. The state has a cold storage capacity of 1.03 MTPA . Cold storage Hubs in Maharashtra contribute a significant portion to the pan-India demand for warehousing; **in the first 9 months of 2024[84] Pune and the Mumbai Metropolitan Region (MMR) contributed 50% of the Grade A/A+ warehousing demand pan-India.**

As storage facilities steadily increase in Maharashtra, a sustainable approach to meeting cooling requirements is key for the state's developmental plans. While this is a more nuanced segment, wherein applicability of District Cooling needs to be assessed on a case-by-case basis, the technology offers pathways in which this can be done without harming the environment, and ensuring food and economic security for the people of Maharashtra and India.

Case Study: Greenfield & Brownfield Cold Storage Facilities in Maharashtra region

A defining feature of cold storage facility is their ability to meet diverse temperature-controlled storage needs. These facilities **integrate multi-temperature storage capabilities** within a single park to ensure an unbroken cold chain, critical for temperature-sensitive products as follows:

- **Freezing Zones (-40°C to -20°C):** For products like frozen seafood, meat, and ice cream.
- **Chilled Zones (+2°C to +8°C):** For perishable goods such as dairy, pre-cooked foods, and fresh produce.
- **Ambient Zones (+15°C to +25°C):** For non-perishable items like dried fruit, cereals, canned fruits, canned meat and canned vegetables.

There are several clusters for cold storage in Maharashtra including Nashik, Ahmednagar, Solapur, Nagpur and Jalgaon, hosting multiple parks to cater to precise cooling requirements across freezing, chilled, and ambient storage zones. At present, these parks likely rely on standalone cooling systems, including air-cooled chillers and DX units. While these systems address immediate cooling needs, they are energy-intensive, expensive to maintain, and difficult to scale efficiently to meet future requirements.

Given these challenges, the cold storage facilities could adopt alternate strategies to optimize cooling operations across its parks. As is the case usually, if the various parks are situated in close proximity to each other, the **first strategy could involve transitioning to a centralized District Cooling system,** which would serve multiple parks from a single central plant. The plant would distribute chilled water via an insulated underground pipe network, significantly reducing energy consumption through optimized chiller performance and load-sharing mechanisms, given varying demands and occupancy levels through the year. For freezing storage requirements, **the chilled water provided through the District Cooling system can be utilized in the condenser line of their refrigeration equipment,** thereby improving the efficiency of the system by up to 25–30% compared to standalone systems, while ensuring scalable capacity to meet the growing cooling demands of future facilities. The central plant could incorporate advanced technologies such as thermal energy storage to store cooling energy during off-peak hours and deploy renewable energy sources or treated wastewater for cooling towers to further enhance sustainability. By outsourcing the management of the centralized system to a specialized cooling services provider under a Cooling as a Service (CaaS) model, such facilities could offload operational complexities while ensuring long-term service reliability. The service provider would also assume responsibility for future capital investments, alleviating the financial burden of infrastructure upgrades or replacements.

If a centralized cooling system is not immediately feasible, the standalone cold storage facilities could pursue **a second strategy focused on targeted retrofits and operational improvements for its existing standalone systems.** Retrofitting current systems with advanced components such as variable-speed compressors, water cooled condenser and electronic expansion valves could improve energy efficiency by 10-15%. Introducing IoT-enabled energy monitoring and predictive maintenance tools could further optimize system performance and reduce downtime. Additionally, creating a centralized maintenance team to oversee all cooling operations across the facilities would standardize practices and improve overall reliability. These targeted interventions, while less transformative than a centralized District Cooling system, could be implemented incrementally, providing immediate energy and cost savings without requiring significant upfront capital investment.

For cold storage operations, the choice can be between these two strategies depending on both immediate priorities and long-term objectives. By adopting one or both approaches, the sector can enhance the efficiency and sustainability of its cooling operations, ensuring reliable services for its tenants.

Other Opportunities

In addition to the cold chain facilities, other potential projects including warehouses requiring cooling could also benefit from incorporation of District Cooling systems as listed below:

- **Mahindra Logistics** has announced the construction of a new warehousing facility in Phaltan, near Pune, to augment its capabilities and meet the rising demand. Spread over an area of 25 acres, through this warehouse, Mahindra Logistics will manage inbound logistics for the manufacturing and distribution solutions of its clients in automotive and manufacturing sectors located in the region, providing enhanced reach and service levels. If a CAAS model is adopted, the facility can benefit from significantly **reduced installed mechanical capacity and power demand** and associated infra requirements vis-à-vis stand-alone systems.

- Morgan Stanley Real Estate Investing (MSREI), the private real estate investment management arm of Morgan Stanley, has entered into a strategic partnership with Prakhhyat Group, a leading developer with a portfolio exceeding 10 million sq. ft. of industrial and logistics projects, for a warehousing development named **One K-Square in Bhiwandi, Mumbai, one of India's most prominent logistics hubs.** Spread across 0.7 million sq. ft., One K-Square will cater to diverse sectors, including e-commerce, third-party logistics (3PL), fast-moving consumer goods (FMCG), and fast-moving consumer durables (FMCD). One K-Square is strategically located in proximity to **K Square Logistics Park,** Prakhhyat Group's flagship development with a total footprint of 4 million sq. ft. The combined scale of these two developments, totaling nearly 5 million sq. ft., creates an ideal environment to implement a District Cooling system to optimize cooling efficiency while minimizing environmental impact.

5. Policy and Regulatory Frameworks for Adoption of District Cooling

As with the introduction of any new technology, a policy and regulatory push is required for wider acceptance and adoption. Similar tools have been successful leveraged towards adoption of electric vehicles, renewable energy, and will be essential for adoption of District Cooling. Some policy and regulatory suggestions that could aid Maharashtra in the process of integrating District Cooling in its development and planning process have been given below.

Zoning:

Zoning to earmark high building density areas in the city masterplan and mandatory pre-feasibility studies where District Cooling systems will yield socio-economic benefits. Pre-feasibility studies should evaluate the economic, environmental, and operational benefits of District Cooling, as well as analyze potential synergies to promote circular economy through integrating common effluent treatment plants, waste-to-energy plants, gas distribution networks, and renewable power generation. Mandatory pre-feasibility studies will encourage developers to consider efficient, sustainable cooling options from the outset. A similar approach has been adopted in Singapore, where Green Mark certification mandates such evaluations for new developments.

Pre-feasibility studies must be prioritized in cooling intensive sectors such as:

- New industrial and infrastructure development projects such as the Delhi-Mumbai Industrial Corridor (DMIC)[85], which is expected to create an economic backbone that links the national capital (Delhi) with India's financial hub (Mumbai).
- New data centre projects with a built-up area greater than 20,000 sq. m.
- Cold storage- Maharashtra has envisioned a comprehensive development plan for warehousing and cold storages specially to address concerns around food wastage. Based on the Logistics Masterplan of Maharashtra, logistics zones have already been established through a hub and spoke model which facilitate district level collection and distribution of goods. Designating these zones as cooling-intensive clusters will help focus efforts and streamline the adoption of District Cooling.
- Mining industry- As a leading industrial state, Maharashtra has reserves[86] of iron ore, bauxite, manganese, limestone and calcium, amongst others. It also has excessive reliance on coal based thermal power plants, and is India's sixth-largest coal producing state. The mining industry remains heat-intensive and the development of cooling systems at these sites is a sector that has potential for growth.

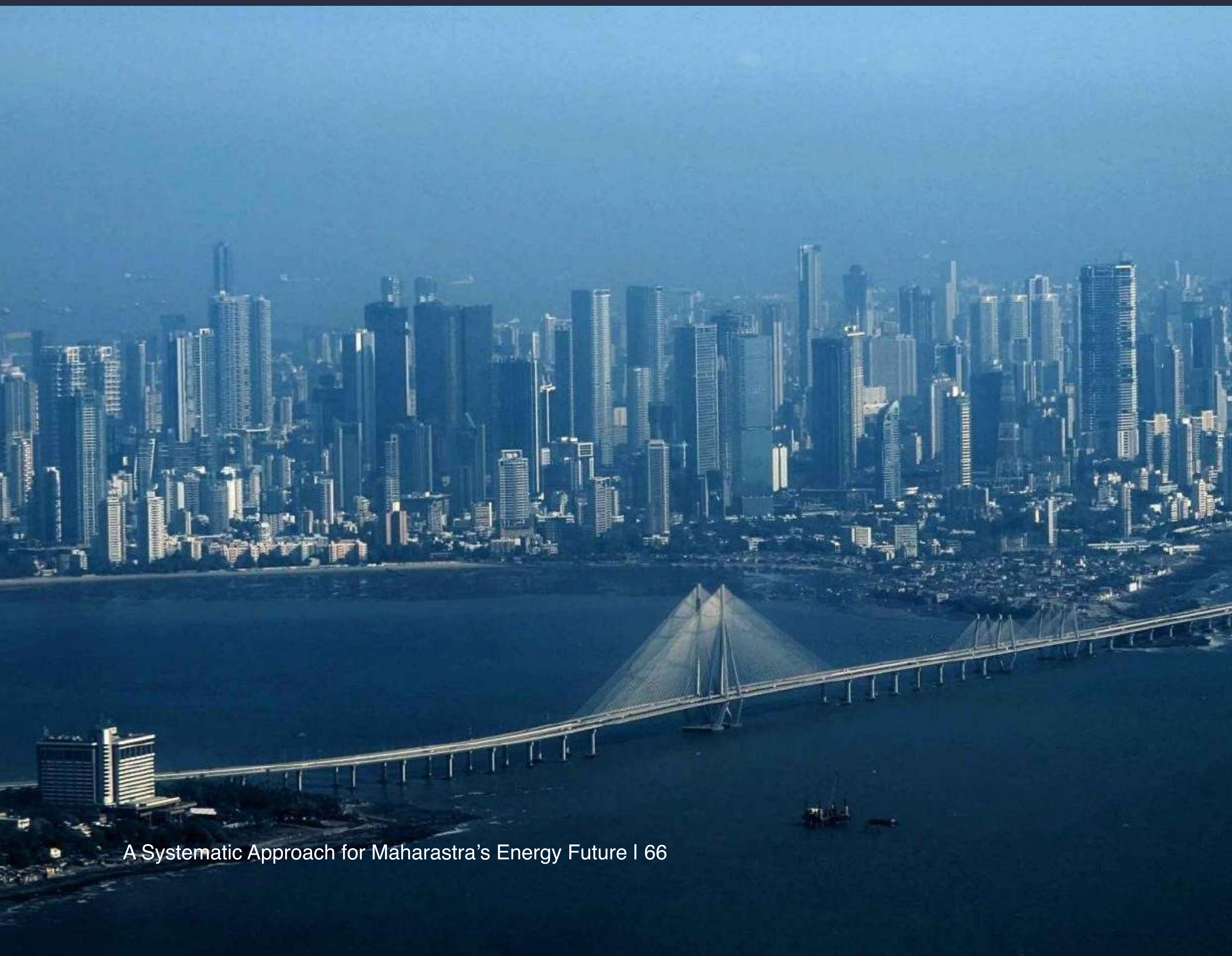
Mandating:

Policy measures to mandate adoption of District Cooling in cooling-intensive clusters identified through pre-feasibility studies such as:

- Planned industrial and logistics/warehouse clusters: For example, the Hyderabad Pharma City in Telangana incorporated District Cooling into its masterplan after a feasibility study was conducted, and to ensure compliance, District Cooling was mandated as part of the land allotment strategy. The nodal body provided educational materials to allottees on its advantages, such as reduced power bills, lower lifecycle costs, and alignment with climate commitments.

- Data centers located in government designated data centre parks: District Cooling can meet the primary cooling requirements of the parks, while redundant equipment can be maintained at the building level for emergency situations. This mandate ensures the sustainability of cooling infrastructure while addressing redundancy requirements.

A transparent rate card may also be made available, detailing the cost of cooling services in the same manner as other utilities like water and electricity. A **dedicated governance model** should be established through, for instance, a District Cooling Tariff Committee for grievance redressal and adjustments to charges. Mandating adoption of District Cooling will facilitate the state's target to reduce the cost of logistics and carbon footprint through the promotion of green initiatives.



Fiscal Incentives:

- Cost reimbursement of up to 25% of retrofitting cost could be given to IT and ITeS units to implement the energy efficiency equipment. This incentive can be higher in value for those units which connect with DCS.
- IT buildings integrating DCS can be made eligible for a 20% additional Floor Space Index (FSI) for the built-up area serviced by the DCS. This additional FSI will act as a significant incentive, optimizing land use and rewarding developers for adopting sustainable cooling solutions.
- Data centers utilizing DCS for at least 50% of their cooling demand could be incentivized with additional fiscal benefits including an additional power subsidy for electricity used by DCS systems or reduced water tariff/blowdown obligations. Additional corporate tax incentives can be introduced, proportional to the carbon savings achieved through DCS adoption.

Licensing:

A licensing regime can be adopted to ensure provision of cooling by technically and financially competent private sector players, based on a stringent pre-agreed criterion of nomination including adherence to the latest technology standards, innovative solutions, and flexibility in infrastructure development.

Easier Permitting Regimes:

Developments that meet the requirements for District Cooling adoption, and choose to sign up, can have a prioritized, fast-track approval process. MIDC can support the development of core DCS infrastructure in data center parks, industrial or even IT parks, including chilled water pipelines and distribution networks. This measure can then address the high upfront costs often associated with DCS adoption and mirrors the approach taken in Qatar's Lusail City, where centralized cooling infrastructure has been supported by government incentives.

Social Mandate:

District Cooling systems set up in proximity to housing and commercial establishments of vulnerable communities can have a social mandate to ensure District Cooling piping network expands to these areas to provide subsidized or free thermal comfort.

6. Way Forward

Large-scale adoption of District Cooling will require several changes in the ecosystem. As cooling increasingly becomes a part of the requirements to maintain a basic standard of living, it would be beneficial to advance its positioning as a public utility good. Recognizing **cooling as an essential utility** will facilitate the development of centralized District Cooling systems, and supporting infrastructure, which can provide energy-efficient and cost-effective cooling solutions across built environment. To reach this awareness, **greater information and knowledge sharing** about cooling alternatives, such as District Cooling, will be required at larger citizen level, government, and private sector. Engagement with local government bodies to understand regional differences, hurdles and suitability, can assist to devise programs for large-scale implementation at city or village levels. The hope is that this document will serve as a starting point to build this awareness and opportunity for District Cooling in Maharashtra.

Bureau of Energy Efficiency
Ministry of Power, Govt. of India

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

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About Tabreed India

Tabreed India Private Limited is a wholly owned subsidiary of Tabreed Asia Central Cooling Company — a 75/25 joint venture between National Central Cooling Company PJSC (Tabreed UAE) and the International Finance Corporation (IFC).

Since inception Tabreed has partnered with State governments and organisations to deliver District Cooling solutions, while also leveraging India's innovative technology ecosystem. In 2019, Tabreed was awarded India's first public-private partnership (PPP) concession for providing 20,000 RT of District Cooling services to the Amaravati Government Complex. In 2023, Tabreed secured a landmark 32-year concession to develop Asia's largest PPP District Cooling project for 125,000 RT at Hyderabad Pharma City, and partnered with Tata Realty to deliver 6,600 RT through the Cooling as a Service (CaaS) model to their premium commercial campus in Gurugram. In 2024, Tabreed expanded its innovation portfolio by collaborating with Plaksha University under the IFC TechEmerge program to pilot phase-change based thermal storage for energy-efficient night-time cooling. Additionally, it is actively working with IIT Jammu to establish cooling test beds for advanced research. Leveraging its world-class design, engineering, and operational expertise, Tabreed India is committed to building local capabilities while seamlessly implementing global best practices to drive sustainable cooling solutions across the country.

About Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH is a German federal enterprise with worldwide operations. GIZ supports the German Government in the field of international cooperation for sustainable development. The current thematic areas of GIZ in India are – Energy, Environment, Climate Change and Biodiversity, Sustainable Urban Development and Sustainable Economic Development. The Federal Ministry for Economic Cooperation and Development (BMZ), the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), as well as the Federal Ministry for Economic Affairs and Climate Action (BMWK), are the main commissioning parties of GIZ in India. Other clients include Indian public sector clients, the European Union and foundations. The Government of India has launched numerous important initiatives to address the country's economic, environmental and social challenges, and GIZ is contributing to some of the most significant ones under the umbrella of the Indo-German Partnership for Green and Sustainable Development.

About Bureau of Energy Efficiency (BEE)

The Government of India has set up Bureau of Energy Efficiency (BEE), under the Ministry of Power (MoP), on 1st March 2002 under the provision of the Energy Conservation Act, 2001. The mission of Bureau of Energy Efficiency is to assist in developing policies and strategies with a thrust on self-regulation and market principles with the primary objective of reducing energy intensity of the Indian economy within the overall framework of the Energy Conservation Act, 2001. This will be achieved with active participation of all stakeholders, resulting into accelerated and sustained adoption of energy efficiency in all sectors. The BEE coordinates with designated consumers (DCs), designated agencies, and other organizations and recognizes, identifies, and utilizes the existing resources and infrastructure, in performing the functions assigned to it under the EC Act. BEE launched DCS guidelines to give impetus to sustainable cooling in India.

References:

1. Ministry of Environment, Forest & Climate Change. 2019. "India Cooling Action Plan." Ministry of Environment, Forest & Climate Change. https://ozonecell.nic.in/wp-content/uploads/2019/03/INDIA-COOLING-ACTION-PLAN-e-circulation-version080319.pdf.

2. Directorate of Economics and Statistics, Planning Department, Govt. of Maharashtra. n.d. "Economic Survey of Maharashtra 2023-24." Govt. of Maharashtra, Mumbai. https://maitri.maharashtra.gov.in/wp-content/uploads/pdf/2023-24.pdf.

3. Tim Fox, Dr, Dr Leyla Sayin, Professor Toby Peters, Centre for Sustainable Cooling, and Dr Jeanne d'Arc Mujawamariya. 2023. "The Hot Reality: Living in a +50°C World." Making the Case for Cooling as Critical Infrastructure. https://www.sustainablecooling.org/wp-content/uploads/2023/11/Hot-Reality-Living-in-a-50C-World.pdf

4. Livemint. 2024. "Heatwave: 56 Heat-related Deaths, 25,000 Heatstroke Cases Reported in India From March to May." Mint, June 3, 2024. https://www.livemint.com/news/india/heatwave-56-related-deaths-reported-in-india-from-march-to-may-25-000-heat-stroke-cases-odisha-20-deaths-in-may-11717401959354.html.

5. World Bank,. n.d. "Climate Investment Opportunities in India's Cooling Sector." World Bank. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099920011222212474/p15743300f4cc10380b9f6051f8e7ed1147.

6. Shagun. 2024. "ILO Flags Risk of Excessive Heat to 2.4 Billion Workers Globally; Indian Workers Among Those at High Risk." Down to Earth. April 23, 2024. https://www.downtoearth.org.in/climate-change/ilo-flags-risk-of-excessive-heat-to-2-4-billion-workers-globally-indian-workers-among-those-at-high-risk-95750#:~:text=In%20a%20country%20like%20India%2C%20where%2090%20per%20cent%20of,given%20their%20frequent%20exposure%20to.

7. "Chapter 2: Impacts and Costs of Climate Inaction for Asia and the Pacific." 2024. In ASIA–PACIFIC CLIMATE REPORT 2024 CATALYZING FINANCE AND POLICY SOLUTIONS. Asian Development Bank. https://www.adb.org/sites/default/files/publication/1008086/ap-climate-report-2024-chapter2.pdf.

8. Ministry of Environment, Forest & Climate Change. 2019. "India Cooling Action Plan." Ministry of Environment, Forest & Climate Change. https://ozonecell.nic.in/wp-content/uploads/2019/03/INDIA-COOLING-ACTION-PLAN-e-circulation-version080319.pdf.

9. "Chapter 2: Impacts and Costs of Climate Inaction for Asia and the Pacific." 2024. In ASIA–PACIFIC CLIMATE REPORT 2024 CATALYZING FINANCE AND POLICY SOLUTIONS. Asian Development Bank.
https://www.adb.org/sites/default/files/publication/1008086/ap-climate-report-2024-chapter2.pdf.

10. United Nations Environment Programme and International Energy Agency. 2020. "Cooling Emissions and Policy Synthesis Report: Benefits of Cooling Efficiency and the Kigali Amendment." UNEP, Nairobi and IEA, Paris. https://wedocs.unep.org/bitstream/handle/20.500.11822/33094/CoolRep.pdf.

11. Ministry of Environment, Forest & Climate Change. 2019. "India Cooling Action Plan." Ministry of Environment, Forest & Climate Change. https://ozonecell.nic.in/wp-content/uploads/2019/03/INDIA-COOLING-ACTION-PLAN-e-circulation-version080319.pdf.
"District Cooling Guidelines." 2023. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. https://beeindia.gov.in/sites/default/files/publications/files/DC%20Guidelines_e-circulation%20version_Launched%20dated%2022%20July%2023_0.pdf.

12. "DPIIT in Alliance With World Bank Hosts "Alleviating Heat Stress by Enhancing Production of Affordable Cooling Devices (AHEAD)" Consultation Workshop." n.d. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1987912#:~:text=The%20Department%20for%20Promotion%20of,stress%20by%20Enhancing%20production%20of.

13. Tim Fox, Dr, Dr Leyla Sayin, Professor Toby Peters, Centre for Sustainable Cooling, and Dr Jeanne d'Arc Mujawamariya. 2023. "The Hot Reality: Living in a +50°C World." Making the Case for Cooling as Critical Infrastructure. https://www.sustainablecooling.org/wp-content/uploads/2023/11/Hot-Reality-Living-in-a-50C-World.pdf

14. "Fact Sheet." n.d. MAHARASHTRA INDUSTRY, TRADE AND INVESTMENT FACILITATION (MAITRI). https://maitri.maharashtra.gov.in/explore-maharashtra/fact-sheet/.

15. Directorate of Economics and Statistics, Planning Department, Govt. of Maharashtra. n.d. "Economic Survey of Maharashtra 2023-24." Govt. of Maharashtra, Mumbai. https://maitri.maharashtra.gov.in/wp-content/uploads/pdf/2023-24.pdf.

16. Bhushan, Chandra, and Srestha Banerjee. 2024. "Just Energy Transition in Maharashtra: An Opportunity for Green Growth and Green Jobs." International Forum for Environment, Sustainability and Technology (IFOREST), New Delhi, India. https://iforest.global/research/just-energy-transition-in-maharashtra-an-opportunity-for-green-growth-and-green-jobs-request-download-copy/.

17. "MAHARASHTRA GHG EMISSION PROFILE 2021-22." n.d. https://iforest.global/wp-content/uploads/2024/02/Maharashtra-GHG-Profile.pdf.

18. The Hindu Bureau. 2024. "Mumbai Records the Maximum Temperature in Last 10 Years." The Hindu. April 17, 2024. https://www.thehindu.com/news/cities/mumbai/mumbai-records-the-maximum-temperature-in-last-10-years/article68072206.ece.

19. TMC and CEEW. 2023. "Heat Action Plan for Thane City 2024." Thane Municipal Corporation, Thane; and New Delhi: Council on Energy, Environment and Water (CEEW). https://www.ceew.in/sites/default/files/how-can-thane-implement-heat-action-plans-to-tackle-heatwaves-risks.pdf.

20. "Heat Action Plan Pimpri-Chinchwad Municipal Corporation." 2024. Pimpri-Chinchwad Municipal Corporation, Government of Maharashtra and Department of Environmental Architecture & Landscape Architecture BNCA. https://www.pcmcindia.gov.in/marathi/pdf/Heat-Action-Plan.pdf.

21. TMC and CEEW. 2023. "Heat Action Plan for Thane City 2024." Thane Municipal Corporation, Thane; and New Delhi: Council on Energy, Environment and Water (CEEW). https://www.ceew.in/sites/default/files/how-can-thane-implement-heat-action-plans-to-tackle-heatwaves-risks.pdf.

22. "District Energy in Cities Initiative – UNEP-CCC." n.d. UNEP-CCC. https://unepccc.org/publications/district-energy-in-cities-initiative-4/.

23. "Pre Bid Notice and 1st Extension to RFQ for Empanelment of Agencies for Cooling as as Services CAAS Provider in MAHARASHTRA and Other States." n.d. https://mahapreit.in/notice/pre-bid-caas.

24. "RFQ for Empanelment of Agencies for Cooling as a Services CaaS Provider in Maharashtra and Other States." n.d. https://mahapreit.in/tender/rfq-caas-provider-.

25. "Power Sector Vision 2030." n.d. https://mahaurja.com/meda/data/other/Maharashtra%20Power%20Sector%20Vision%202030.pdf.

26. "District Cooling Guidelines" 2023. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. https://beeindia.gov.in/sites/default/files/publications/files/DC%20Guidelines_e-circulation%20version_Launched%20dated%2022%20July%2023_0.pdf.

27. “District Cooling System | SP Group. n.d. https://www.spgroup.com.sg/sustainable-energy-solutions/district-cooling-and-heating.

28. Civera, David. 2022. “Breakthrough: Singapore’s Largest Industrial District Cooling System at ST’S AMK TechnoPark, 1st Industrial Project for SP Group.” ST Life.Augmented Blog (blog). June 1, 2022. https://blog.st.com/district-cooling-system/.

29. Realty Plus Magazine. 2023. “DISTRICT COOLING FOR DECARBONIZING REAL ESTATE SECTOR,” January 9, 2023. https://www.rprealtyplus.com/interviews/district-cooling-for-decarbonizing-real-estate-sector-109083.html.

30. “What Is Circular Economy and Why Does It Matter?” 2022. UNDP Climate Promise. November 16, 2022. https://climatepromise.undp.org/news-and-stories/what-is-circular-economy-and-how-it-helps-fight-climate-change.

31. Madaan, Neha. 2024. “Post-2023 Monsoon, Groundwater Crisis Deepens in Maharashtra; Situation Acute in 16 Districts.” The Times of India, January 7, 2024. https://timesofindia.indiatimes.com/city/pune/post-2023-monsoon-groundwater-crisis-deepens-in-maharashtra-situation-acute-in-16-districts/articleshow/106605338.cms.

32. Express News Service. 2024. “Water Storage Down to 23% in 2,994 Dams in Maharashtra.” The Indian Express, May 28, 2024. https://indianexpress.com/article/cities/mumbai/water-storage-down-dams-maharashtra-9357590/.

33. Government of Maharashtra. 2019. “Maharashtra State Water Policy.” https://mwrra.maharashtra.gov.in/en/wp-content/uploads/sites/2/2022/09/State-Water-Policy-2019.pdf.

34. Bassi, Nitin, Saiba Gupta, and Kartikey Chaturvedi. 2023. “Reuse of Treated Wastewater in India: Market Potential and Pointers for Strengthening Governance.” New Delhi: Council on Energy, Environment and Water. https://www.ceew.in/sites/default/files/scaling-wastewater-reuse-treatment-and-management-india.pdf.

35. The Economic Times. 2024. “Maharashtra to Meet 50 Pc of Energy Needs From Non-traditional Sources by 2030: Fadnavis,” October 7, 2024. https://economictimes.indiatimes.com/news/india/maharashtra-to-meet-50-pc-of-energy-needs-from-non-traditional-sources-by-2030-fadnavis/articleshow/114007579.cms?from=mdr.

36. “Non-Conventional Energy Generation Policy-2020.” n.d. Government of Maharashtra. https://www.mahaurja.com/meda/data/other/Policy2020GridAndOffGrid.pdf.

37. GoM. n.d. “FAQ / Solar.” https://www.mahaurja.com/meda/data/off_grid_solar/FAQ-Solar.pdf.

38. “Target Under Non-Conventional Energy Generation Policy-2020, Integrated Policy of the State for Part I On-Grid New & Renewable (Non-conventional) Energy Generation Projects-2020 and Part II- Integrated Policy of the State for Off-Grid New & Renewable (Non-conventional) Energy Generation Projects-2020.” 2020. Government of Maharashtra. https://www.mahaurja.com/meda/data/grid_solar_power/Re%20Policy%202020%20Target.pdf.

39. Directorate of Economics and Statistics, Planning Department, Govt. of Maharashtra. n.d. “Economic Survey of Maharashtra 2023-24.” Govt. of Maharashtra, Mumbai. https://maitri.maharashtra.gov.in/wp-content/uploads/pdf/2023-24.pdf.

40. Maisch, Marija. 2024. “India’s Maharashtra State Launches 300MW/600 MWh Standalone Battery Storage Tender - Energy Storage.” Energy Storage. August 21, 2024. https://www.ess-news.com/2024/08/21/indias-maharashtra-state-launches-300mw-600-mwh-standalone-battery-storage-tender/.

41. “Request for Selection (RfS) Document for Setting up of Pilot Projects of 300 MW/ 600 MWh Standalone Battery Energy Storage Systems in Maharashtra Under Tariff-Based Global Competitive Bidding.” 2024. Maharashtra State Electricity Distribution Co. Ltd. (MSEDCL). https://www.mahadiscom.in/supplier/wp-content/uploads/2024/08/2.-RfS-for-setting-up-300-MW-BESS.pdf.

42. “Thermal Storage, District Energy.” n.d. District Energy. https://www.districtenergy.com/services/how-it-works/thermal-storage/#:~:text=Thermal%20storage%20refers%20to%20a,to%20customers%20during%20the%20day.

43. Government of Maharashtra. 2015. “Comprehensive Policy for Grid-connected Power Projects Based on New and Renewable (Non-conventional) Energy Sources - 2015.” Government of Maharashtra.https://www.mahaurja.com/meda/data/grid_waste_to_energy/state%20policy/RE%20Policy-2015_English%20Version.pdf.

44. “Case No. 06 of 2023 Petition of Maharashtra Energy Development Agency under Section 86(1)(e) seeking appropriate directions to Distribution Licensees to meet 50% of total Renewable Purchase Obligation (RPO) requirement by purchase of energy from Renewable Sources within the State as per amendment dated 30 June 2022 in Renewable Energy Generation Policy 2020 issued by Government of Maharashtra.” n.d. https://merc.gov.in/wp-content/uploads/2023/12/Final-Order-6-of-2023.pdf.

45. “Indian City Becomes Waste to Energy Model.” n.d. Internationale Klimaschutzinitiative (IKI). https://www.international-climate-initiative.com/en/iki-media/news/indian_city_becomes_waste_to_energy_model/.

46. Acharya, Pratip. 2024. “Mumbai’s Waste to Electricity Plant Will Be Able to Generate 17 Million Units of Power a Year, Know More About It.” The Indian Express, February 23, 2024. https://indianexpress.com/article/cities/mumbai/mumbai-waste-to-electricity-plant-able-to-generate-17-million-units-of-power-9177098/.

47. More, Manoj Dattatrye. 2023. “PCMC’s Waste-to-energy Plant to End Issue of Dry Waste Disposal.” The Indian Express, July 30, 2023. https://indianexpress.com/article/cities/pune/pcmc-pune-waste-to-energy-plant-pollution-complaints-dry-waste-disposal-8867095/.

48. “LOK SABHA UNSTARRED QUESTION NO. 3040 ANSWERED ON 16.12.2021: WASTE TO ENERGY PLANTS.” n.d. https://sansad.in/getFile/loksabhaquestions/annex/177/AU3040.pdf?source=pqals.

49. Department of Science, Technology and Environment, Puducherry Climate Change Cell. 2022. “Energy Benchmarking Guidelines for Climate Proofing Buildings in U.T. of Puducherry.” https://dste.py.gov.in/PCCC/pdf/Reports/Energy%20Benchmark%20Report.pdf.

50. Kumar, Satish, Sneha Sachar, Sandeep Kachhawa, Akash Goenka, Saikiran Kasamsetty, and Gerry George. 2018. “Demand Analysis of Cooling by Sector in India in 2027.” Alliance for an Energy Efficient Economy. https://aeee.in/wp-content/uploads/2020/09/2018-Demand-Analysis-for-Cooling-by-Sector-in-India-in-2027-v2.pdf.

51. “INDIA ENERGY SCENARIO FOR THE YEAR 2023-24.” 2024. Bureau of Energy Efficiency. https://beeindia.gov.in/sites/default/files/BEE_India_Energy_Scenario_Report-2024_web_version-rev2.pdf.

52. “Market Assessment Report for Chillers in India - CLASP.” 2023. CLASP. August 29, 2023. https://www.clasp.ngo/research/all/market-assessment-report-on-chillers-in-india/.

53. “Maharashtra - AEEE State EE Index.” 2023. AEEE State EE Index - State Index. May 29, 2023. https://stateenergyefficiencyindex.in/factsheet-page-2022/maharashtra/.

54. MEDA. n.d. “Overview of the Strategic Energy Conservation Plan.” https://mahaurja.com/meda/data/energy_conservation/SAPlan.pdf.

55. “Save Energy Program (Financial Assistance for Carrying Out Detailed Energy Audit).” n.d. Maharashtra Energy Development Agency (MEDA). https://www.mahaurja.com/meda/data/energy_conservation/SaveEnerProg.PDF.

56. “Mumbai Climate Action Plan 2022.” 2022. Brihanmumbai Municipal Corporation. https://ghhin.org/wp-content/uploads/Mumbai-Climate-Action-Plan-2022.pdf.

57. “Bandra Kurla Complex | Mumbai Metropolitan Region Development Authority.” n.d. https://mmrda.maharashtra.gov.in/planning/badra-kurla-complex/overview#:~:text=Development%20of%20Bandra%20Kurla%20Complex,in%20the%20Bandra%2DKurla%20Complex.

58. “Dharavi Slum | India Cine Hub.” n.d. https://indiacinehub.gov.in/location/dharavi-slum#:~:text=Dharavi%20slum%20is%20one%20of,multi%2Dethnic%20and%20diverse%20settlement.

59. Thakkar, Mehul R. 2024. “Dharavi Redevelopment Project: Survey Work for 25,000 Tenements Completed, 60,000 Dwellings Numbered so Far.” Hindustan Times, November 28, 2024. https://www.hindustantimes.com/real-estate/dharavi-redevelopment-project-survey-work-for-25-000-tenements-completed-60-000-dwellings-numbered-so-far-101732790768320.html.

60. Eeshanpriya M S 2020 “Inside Dharavi: India’s largest slum and a major Covid hotspot.” Hindustan Times, April 30, 2020. https://www.hindustantimes.com/india-news/inside-dharavi-india-s-largest-slum-and-a-major-covid-hotspot/story-ZbX5VOngcJlmsK9F4ohBvM.html

61. “Fact Sheet.” n.d. MAHARASHTRA INDUSTRY, TRADE AND INVESTMENT FACILITATION (MAITRI). https://maitri.maharashtra.gov.in/explore-maharashtra/fact-sheet/.

62. Briefing, India. 2024. “India’s State-wise Merchandise Exports in FY 2023-24.” India Briefing News. August 6, 2024. https://www.india-briefing.com/news/indias-fy-2023-24-state-wise-merchandise-export-performance-33691.html/.

63. Directorate of Economics and Statistics, Planning Department, Govt. of Maharashtra. n.d. “Economic Survey of Maharashtra 2023-24.” Govt. of Maharashtra, Mumbai. https://maitri.maharashtra.gov.in/wp-content/uploads/pdf/2023-24.pdf.

64. “Investor’s Guide Directorate of Industries, Government of Maharashtra.” n.d. http://di.maharashtra.gov.in/_layouts/15/doistaticsite/English/investors_guide_mse_cdp.html.

65. “Maharashtra State Industrial-Cluster Development Programme (MSI-CDP).” n.d. http://di.maharashtra.gov.in/_layouts/15/doistaticsite/English/investors_guide_msi_cdp.html.

66. Directorate of Economics and Statistics, Planning Department, Govt. of Maharashtra. n.d. “Economic Survey of Maharashtra 2023-24.” Govt. of Maharashtra, Mumbai. https://maitri.maharashtra.gov.in/wp-content/uploads/pdf/2023-24.pdf.

67. “Delhi-Mumbai Industrial Corridor (DMIC).” n.d. National Industrial Corridor Development Programme. https://www.nicdc.in/index.php/delhi-mumbai-industrial-corridor-dmic.html.

68. “Maharashtra Industrial Policy 2019.” 2019. Government of Maharashtra. https://www.midcindia.org/wp-content/uploads/2021/09/Maharashtra-Industrial-Policy-2019.pdf.

69. Maharashtra’s 2019 Industrial Policy has identified a total of fourteen priority thrust sectors - Electrical Vehicles (Manufacturing, Infrastructure and Servicing), Aerospace and Defence Manufacturing, Industry 4.0 (Artificial Intelligence, 3D Printing, Internet of Things and Robotics, Nanotechnology, among others), Promotion of Integrated Data Centre Parks (IDCP), Textile Machinery Manufacturing, Biotechnology and Medical and Diagnostic Devices, Agro & Food Processing (Secondary and Tertiary Food Processing units), Information Technology (IT) & IT Enabled Services (ITeS), Electronic System Design & Manufacturing (ESDM) and Semiconductor Fabrication (FAB), Logistics & Warehousing, Green Energy/ Bio Fuel Production, Sports and Gym Equipment Manufacturing, Nuclear Power plant equipment manufacturing, Mineral/Forest based Industries.

70. Banerjee, Shoumojit. 2019. “PM Inaugurates First Greenfield Industrial Smart City in Aurangabad.” The Hindu. September 7, 2019. https://www.thehindu.com/news/national/other-states/pm-inaugurates-first-greenfield-industrial-smart-city-in-aurangabad/article29364348.ece.

71. “AI Is Already Wreaking Havoc on Global Power Systems.” 2024. Bloomberg. June 21, 2024. https://www.bloomberg.com/graphics/2024-ai-data-centers-power-grids/.

72. MarkNtel Advisors. n.d. “India Data Center Market Size, Share, Trend & Growth Report 2030.” MarkNtel Advisors. https://www.marknteladvisors.com/research-library/india-data-center-market.html#:~:text=The%20country%20hosts%20over%20130,of%20capacity%20have%20been%20announced.

73. “India Data Center Market Size | Mordor Intelligence.” n.d. https://www.mordorintelligence.com/industry-reports/india-data-center-market?utm_source=chatgpt.com.

74. Corporation, Boyd. 2024. “Energy Consumption in Data Centers: Air Versus Liquid Cooling.” Boyd | Trusted Innovation (blog). October 3, 2024. https://www.boydcorp.com/blog/energy-consumption-in-data-centers-air-versus-liquid-cooling.html?utm_source=chatgpt.com.

75. “Tier Classification System.” n.d. Uptime Institute. https://uptimeinstitute.com/tiers?utm_source=chatgpt.com.

76. Government of Maharashtra. 2023. “New Information Technology and Information Technology Enabled Services Policy of the State of Maharashtra -2023.” https://maitri.mahaonline.gov.in/pdf/IT%20Policy%202023.pdf.

77. “India - Cool Coalition.” 2023. Cool Coalition. January 20, 2023. https://coolcoalition.org/pilot-projects/india/.

78. Bloomberg. 2024. “India Heat Waves Linked to Climate Change Cause Massive Food Waste.” Www.Business-Standard.Com, May 24, 2024. https://www.business-standard.com/india-news/india-heat-waves-linked-to-climate-change-cause-massive-food-waste-124052400069_1.html.

79. Parija, Pratik. 2024. “Rotten Bananas in a Scorching India Expose Climate’s Food Cost.” Bloomberg UK. May 24, 2024. https://www.bloomberg.com/news/features/2024-05-24/india-heat-waves-linked-to-climate-change-cause-massive-food-waste?cmpid=BBD081524_GREENDAILY&utm_medium=email&utm_source=newsletter&utm_term=240815&utm_campaign=greendaily.

80. Directorate of Economics and Statistics, Planning Department, Govt. of Maharashtra. n.d. “Economic Survey of Maharashtra 2023-24.” Govt. of Maharashtra, Mumbai. https://maitri.maharashtra.gov.in/wp-content/uploads/pdf/2023-24.pdf.

81. ‘Maharashtra fisheries have a wide scope for regional economic development that underlines the need for the Aqua Chamber of Commerce.’” n.d. Agro Spectrum India. https://agrospectrumindia.com/2023/05/01/maharashtra-fisheries-have-a-wide-scope-for-regional-economic-development-that-underlines-the-need-for-the-aqua-chamber-of-commerce.html.

82. Ministry of Fisheries, Animal Husbandry & Dairying. 2023. “Fisheries sector plays a significant role in Indian economy.” Press Information Bureau (PIB). May 16, 2023. https://pib.gov.in/PressReleasePage.aspx?PRID=1924524.

83. Industries Department, Government of Maharashtra. 2024. “LOGISTICS POLICY- 2024: Maharashtra Connecting Bharat Rashtra.” Government of Maharashtra. https://maitri.mahaonline.gov.in/PDF/Maharashtra%20Logistics%20Policy%202024-%20English.pdf.

84. “India’s Best Real Estate Data Analytics, Market Research | CRE Matrix.” 2025. January 27, 2025. https://www.crematrix.com/#downloadReport=MjQ0.

85. Briefing, India. 2025. “Top India Manufacturing Locations and Industrial Clusters.” India Briefing News. January 27, 2025. https://www.india-briefing.com/news/india-manufacturing-locations-industries-34990.html/.

86. “Mineral Resources of Maharashtra.” n.d. Directorate of Geology and Mining, Govt. Of Maharashtra, Nagpur. https://mahadgm.gov.in/index.php/Contentpage/index/26/.