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SG GREEN

SINGAPORE GREEN BUILDING COUNCIL

BUILDING GREENER DATA CENTRES FOR A SUSTAINABLE DIGITAL FUTURE

SGBC MEMBERSHIP

SINGAPORE GREEN BUILDING COUNCIL MEMBER

The Singapore Green Building Council (SGBC) enables sustainability across the building and construction value chain, championing capability development and innovative solutions that support industry transformation through Membership, Certification and Outreach. Together with a growing network of Member organisations united by a commitment to green building and sustainability, SGBC drives impactful change to the built environment.

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MESSAGE FROM THE EDITORIAL TEAM

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Can something as foundational to the digital economy as the data centre also become a model of sustainability?

This central question informs the latest issue of the SG Green magazine. Data centres have long operated in the background, quietly powering the platforms and services that define modern life. But today, they are recognised not only as mission-critical infrastructure but also as significant consumers of energy and water. In Singapore's resource-constrained context, this places them at the intersection of two national imperatives: maintaining digital competitiveness and meeting ambitious climate targets.

This issue examines that intersection from multiple angles. Our contributors explore how the sector is moving beyond incremental efficiency gains toward systemic change - rethinking not only how data centres are cooled and powered, but how they interact with the grids, communities, and ecosystems around them.

The Energy Studies Institute (ESI) states that constraints on energy, water, and carbon intensity are reshaping the business case for data centres. Operators who invest in measurable performance and system integration, they suggest, will turn regulatory pressure into strategic advantage. Cundall challenges us to look beyond the illusions that can obscure true progress—fixation on single metrics like PUE, overbuilt redundancy disguised as resilience, and carbon accounting that masks rather than reveals. The path forward requires an ecosystemic view spanning energy, technology, finance, and policy.

We also showcase innovation closer to home. Ngee Ann Polytechnic's Centre for Environmental Sustainability introduces Spraying Jet Impingement technology - a liquid cooling solution developed in Singapore that achieves immersion-level efficiency without the infrastructure cost.

What emerges from these pages is a clear picture: the data centre sector in Singapore is moving toward a higher-quality, more disciplined growth model. Constraints on energy, water, and carbon are raising the bar for entry, but they are also rewarding operators who invest in credibility, adaptability, and contribution to broader system outcomes.

As one of our contributors notes: sustainability in data centres should be viewed not as an external obligation, but as a strategic lever. Facilities that align commercial objectives with disciplined management of energy, water, and carbon are better positioned to manage risk, secure capital, and remain competitive in an increasingly resource-constrained operating environment.

We hope this issue informs your own journey, whether you are an operator, a designer, a policymaker, or simply someone who believes that the digital future must also be a sustainable one.

Yours Sincerely,
SG Green Editorial Team


Sheraton Centre
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BUILDING TOMORROW: WHY DECARBONISATION IS THE NEXT FRONTIER FOR SINGAPORE'S BUILT ENVIRONMENT

Singapore's new decarbonisation technology roadmap identifies nearly 70 strategies to meet our carbon targets. For building owners, the message is clear: start with solutions ready for adoption today.

Building Tomorrow: Why Decarbonisation is the Next Frontier for Singapore's Built Environment

The building sector accounts for almost 40 percent of global CO_2 emissions. This roadmap responds to that shift by adopting a whole life carbon approach, covering upfront, use-stage, operational, and end-of-life emissions.

Our progress towards the ambitious "80-80-80 in 2030[1]" goals of the Singapore Green Building Masterplan tells a compelling story of what can be achieved when vision meets execution. As of March 2026, approximately 66 percent of our buildings' gross floor area has been greened, while close to 33 percent of new developments achieved Super Low Energy certification. Our best-in-class buildings have delivered 72 percent improvement in energy efficiency compared to 2005 levels. These achievements demonstrate the sector's continued commitment to sustainability.

Yet as we celebrate these successes, I believe we must acknowledge an uncomfortable truth: incremental improvements in operational efficiency, while important, will not be sufficient to meet the scale of the climate challenge ahead. The next bound lies in decarbonisation through the reduction of whole life carbon emissions.

This shift represents more than just another target to achieve. It requires us to fundamentally reimagine how we design, construct, and operate our buildings. We must look beyond the operational phase to examine the embodied carbon in our materials, the carbon intensity of our construction processes, and the entire lifecycle impact of our built environment.

The Built Environment Decarbonisation Technology Roadmap that we have launched at the Urban Solutions and Sustainability Research & Innovation Congress (USS R&I Congress) on 5 February 2026 reflects this new reality. Developed by BCA and SGBC with strong industry engagement, the roadmap identifies about 70 high-impact technologies and strategies, prioritised to guide near-term deployment and longer-term R&D.

Rather than simply providing another set of guidelines, this roadmap serves as a strategic compass for navigating the complex landscape of decarbonisation technologies. It identifies specific innovation areas for research development, while also highlighting technologies ready for immediate adoption. For example, adopting alternative and

[1]80-80-80 by 2030: The first "80" is greening 80% of Singapore's buildings by 2030, second "80" is to have 80% of our new developments by GFA to be Super Low Energy (SLE) buildings from 2030, third "80" is achieving 80% improvement in energy efficiency for best-in-class green buildings by 2030.

next-generation cooling solutions such as hybrid cooling, passive displacement cooling systems reducing reliance on energy-intensive conventional air-conditioning systems. On the embodied carbon reduction front, the roadmap emphasises early and integrated action across the project lifecycle such as minimising a building's total carbon footprint by building less and light and implement efficient construction technologies that minimise waste.

What excites me most about this roadmap is its potential to accelerate our progress towards the remaining targets of our Green Building Masterplan. Achieving 80 percent Super Low Energy certification for new developments by 2030 and reaching 80 percent energy efficiency improvements for our best buildings, are ambitious goals that will require the kind of technological innovation this roadmap promotes. More importantly, these achievements will position Singapore to meet our 2050 net-zero commitment.

However, the success of this roadmap depends entirely on collective action. No single entity, whether government, developer, consultant, or technology provider, can drive this transformation alone. The roadmap is fundamentally a call to action for our entire ecosystem. It challenges developers to rethink their project specifications, encourages consultants to explore new design methodologies, and invites researchers to focus their efforts on the most impactful innovations.

I believe Singapore's built environment sector has consistently demonstrated its ability to lead by example. Our track record in green building adoption, our willingness to embrace new technologies, and our collaborative approach to industry challenges position us uniquely to pioneer decarbonisation at scale. The question is not whether we can achieve these goals, but how quickly we can mobilise the collective will to make them reality.

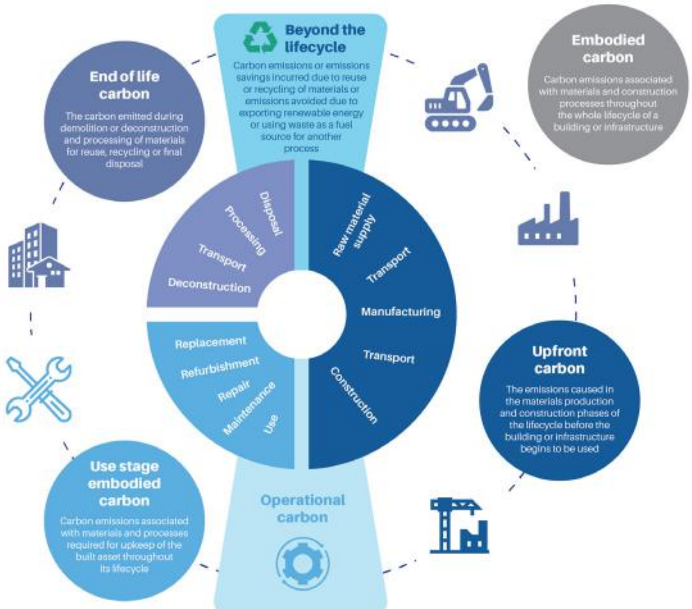
The roadmap that we have developed together with SGBC is more than a technical document. It is a blueprint for ensuring that Singapore's built environment remains at the forefront of global sustainability efforts. The time for incremental change has passed. The future demands bold action, and I am confident that our sector is ready to answer that call.

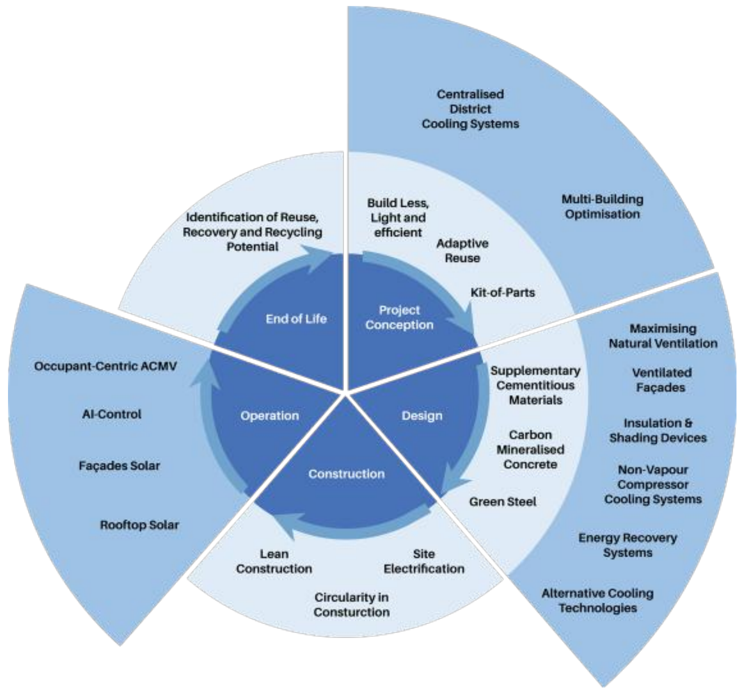
Foreword by:
Mr. Tan Chee Kiat
Deputy CEO for Industry Development
Building and Construction Authority (BCA)

ABOUT THE ROADMAP

Developed jointly by the Building and Construction Authority (BCA) and the Singapore Green Building Council (SGBC) with support from the Agency for Science, Technology and Research (A*STAR), the Built Environment Decarbonisation Technology Roadmap represents the culmination of extensive engagement with over 100 industry stakeholders since January 2025 and was officially rolled out on 5 February 2026.

The roadmap adopts a whole-life carbon approach, addressing both operational carbon-emissions from building operations-and embodied carbon-emissions from materials, construction, maintenance, and end-of-life processes. While the document identifies nearly 70 technologies across both categories, it also provides clear guidance on which solutions are ready for adoption in the near term.





UNDERSTANDING QUICK WINS

Quick wins refer to technologies that are commercially available, having achieved Technology Readiness Level (TRL) 7 to 9, demonstrate significant carbon reduction potential, and are ready for immediate deployment in the Singapore market. These are not conceptual innovations or pilot-stage developments - they are proven solutions supported by local case studies and established supply chains.

For building owners, consultants, and contractors navigating the complex landscape of decarbonisation, these quick wins offer low-risk, high-impact entry points.

OPERATIONAL CARBON: ADDRESSING THE LARGEST CONTRIBUTOR

Air-conditioning and mechanical ventilation (ACMV) systems account for 40 to 60 percent of a building's total energy consumption in Singapore's tropical climate. Reducing this demand represents the single most impactful intervention for operational carbon reduction.

Hybrid cooling systems combine elevated air temperatures - typically 24°C to 27°C - with increased air movement from fans, reducing cooling load while maintaining occupant comfort. Kajima's office at 55 Market Street demonstrated a 36 percent reduction in daily ACMV energy consumption through hybrid cooling. The Technical Reference for Hybrid Cooling Systems (TR 141:2025) is now available to guide industry adoption, and hybrid cooling also directly supports the Go 25 national movement for sustainable cooling.

Energy recovery ventilators (ERVs) capture cooling energy from exhaust air to pre-cool incoming fresh air. DBS Newton Green implemented an ERV system featuring graphene heat exchangers achieving over 75 percent heat exchange efficiency, substantially reducing the cooling and dehumidification load associated with fresh air ventilation.

Smart building controls represent another readily accessible intervention. Occupant-centric ACMV optimisation utilising model predictive control (MPC) can deliver more than 20 percent energy savings compared to conventional building automation systems. NRGSense Technologies, an NTU spin-off, has deployed MPC solutions at PSA Tuas Terminal Maintenance Base and Jurong Town Hall, demonstrating both energy savings and improved occupant comfort.

For building owners seeking even simpler measures, high-efficiency EC fans, brushless DC pumps, and IE5 ultra-premium efficiency motors serve as drop-in replacements that improve system efficiency with attractive payback periods.

EMBODIED CARBON: THE RISING PRIORITY

As the roadmap notes, drawing on World Green Building Council research, for super low-energy and net-zero energy buildings, embodied carbon can constitute up to 100 percent of the building's carbon footprint.

Supplementary cementitious materials (SCMs) such as Ground Granulated Blast-furnace Slag (GGBS) can replace 50 to 80 percent of Ordinary Portland Cement (OPC) in concrete mixes, substantially reducing embodied carbon with minimal cost premium and no compromise to structural integrity. These materials are commercially available and already utilised in projects across Singapore.

Carbon mineralised concrete advances this approach further by injecting captured carbon dioxide into the concrete during mixing, permanently sequestering the CO_2 while enhancing compressive strength. The Geneo development at Singapore Science Park employed carbon mineralised concrete for 44 percent of its total concrete volume, achieving a 28 percent reduction in embodied carbon emissions-equivalent to 3,400 tonnes of CO_2e saved.

For non-structural applications, recycled concrete aggregate (RCA) is readily available and can replace virgin aggregates, reducing both carbon emissions and demand for imported materials. Singapore currently recycles an estimated 90 percent of construction and demolition waste, though much of this is presently used for backfill rather than high-value applications.

DESIGN DECISIONS: LOCKING IN CARBON SAVINGS

Perhaps the most powerful quick win requires no technology acquisition-only a deliberate shift in design philosophy.

Carbon avoidance through adaptive reuse preserves existing structures and avoids the substantial upfront carbon emissions associated with new construction. Singapore Land Tower's recent asset enhancement exercise preserved the existing structure and avoided over 50 percent of embodied carbon emissions compared to redevelopment.

Reuse of existing foundations offers comparable savings. CapitaSky, the redevelopment of the former CPF building, achieved 100 percent reuse of existing bored piles, saving 8,400 tonnes of concrete and reducing carbon emissions by 37 percent.

For new construction, lean design principles optimise structural systems to utilise material only where necessary, reducing embodied carbon without compromising performance or safety.

ENABLING WIDESPREAD ADOPTION

The quick wins put forward in the roadmap achieve maximum effectiveness when supported by appropriate tools and frameworks.

The Singapore Building Carbon Calculator (SBCC) enables project teams to quantify embodied carbon emissions using localised datasets, supporting informed material selection and design decisions. Developed by BCA, JTC, SGBC, and NUS-ESI, the SBCC is freely available and increasingly referenced in Green Mark submissions.

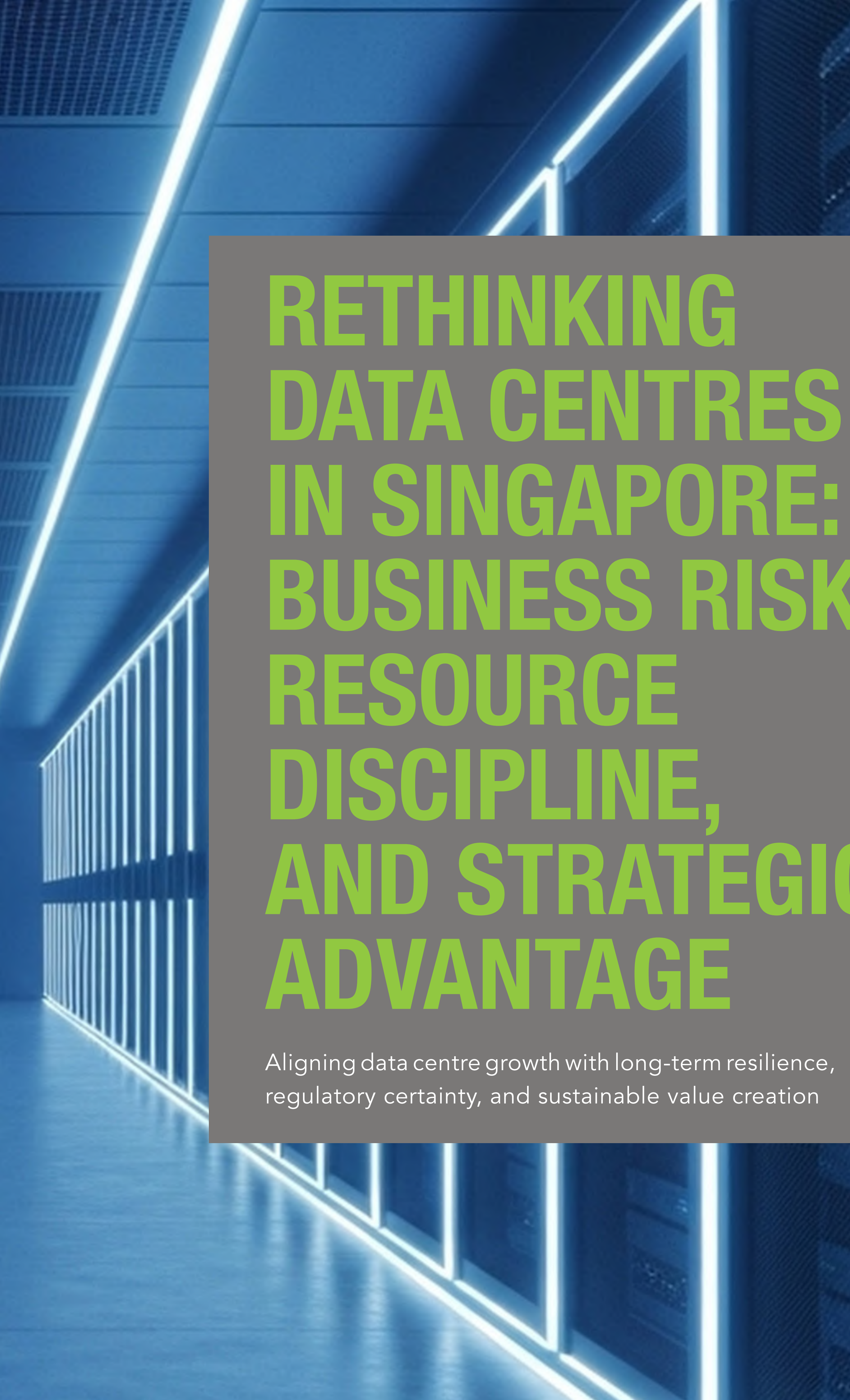
The Singapore Green Building Product (SGBP) Certification Scheme provides a reliable reference for specifiers, with tiered tick ratings that differentiate products based on environmental performance. For concrete and steel, two of the largest contributors to embodied carbon, SGBP certification offers a straightforward mechanism for verifying lower-carbon options. The newly launched market-wide carbon benchmark for concrete launched by the Climate Group and CapitaLand Development on 26 February 2026 further enables industry players to identify and select lower-carbon concrete, accelerating decarbonisation and strengthening supply chain cohesion in reducing material emissions.

A CALL TO ACTION

Singapore's 2035 emissions target represents an ambitious yet achievable goal. The Built Environment Decarbonisation Technology Roadmap provides the strategic blueprint. Responsibility now rests with building owners, consultants, contractors, and suppliers to translate this guidance into action.

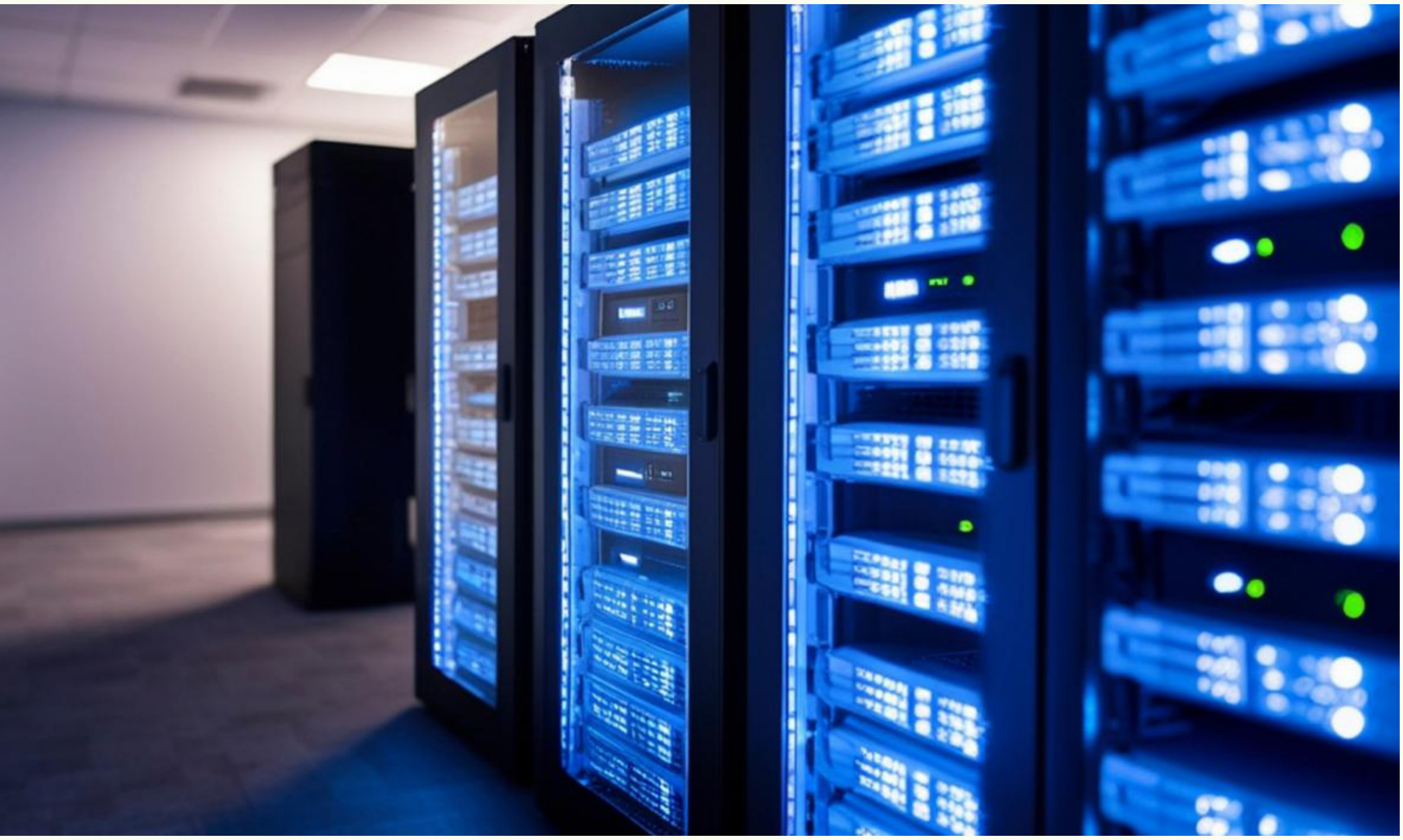
The quick wins are documented. The technologies are validated. The case studies are local. The question is no longer whether to decarbonise, but rather how expeditiously the sector can implement the solutions already at hand.

Download the Roadmap here.



RETHINKING DATA CENTRES IN SINGAPORE: BUSINESS RISK, RESOURCE DISCIPLINE, AND STRATEGIC ADVANTAGE

Aligning data centre growth with long-term resilience, regulatory certainty, and sustainable value creation



DATA CENTRES AS STRATEGIC BUSINESS INFRASTRUCTURE

Data centres have become mission-critical assets in the modern economy, underpinning digital platforms, financial systems, artificial intelligence, and enterprise operations across sectors. As demand for digital services accelerates, the sector is increasingly shaped by constraints rather than abundance. In cities with limited land, finite energy capacity, and growing water stress, data centre development is no longer a straightforward function of capital or technical capability. Instead, it has become a question of how growth can be aligned with long-term resilience, regulatory certainty, and sustainable value creation.

Three structural trends are reshaping the operating landscape. First, AI and accelerated compute are driving step-changes in rack power density, shifting cooling from an incremental optimisation challenge to a fundamental design constraint, and pushing the industry toward liquid-based heat removal at the chip and rack level. Second, the binding constraint for expansion is increasingly system capacity rather than capital alone, encompassing power availability, grid connection timelines, and carbon intensity. Third, the sustainability lens is broadening from a narrow focus on facility efficiency toward multi-metric performance, including water dependency and verifiable carbon outcomes, reinforced by rising expectations for disclosure and assurance.

Singapore's experience reflects this broader global inflection point. The earlier pause on new data centre approvals was not simply a reactionary measure, but a recognition that conventional expansion models were no longer viable within existing resource limits. The subsequent reopening of the sector through a selective and performance-led framework marks a more mature phase of development. The second data centre call for application, launched by the Infocomm Media Development Authority (IMDA) in 2025 reinforces this shift by prioritising efficiency, carbon performance, and system contribution over headline capacity. For businesses, this signals a structural change in market access conditions where performance, rather than scale alone, determines long-term viability.

PERFORMANCE-LED GROWTH AND REGULATORY CERTAINTY

From a commercial perspective, this recalibration reduces long-term regulatory and transition risk. Data centre assets are capital-intensive and long-lived, with design decisions locking in operating profiles for decades. Facilities that meet higher performance thresholds upfront are less exposed to future policy tightening, costly retrofits, or operational disruption. In this context, sustainability performance is no longer an external compliance issue but a core component of asset risk management and value preservation.

In line with IMDA frameworks and the Green Mark for Data Centres scheme, performance is increasingly assessed using established efficiency indicators such as Power Usage Effectiveness (PUE) and Water Usage Effectiveness (WUE). PUE remains the primary indicator used to assess overall energy efficiency and infrastructure effectiveness. However, PUE alone no longer provides a complete representation of sustainability performance. WUE is increasingly recognised as an important indicator of cooling system design and water dependency, while Carbon Usage Effectiveness (CUE) provides a more direct linkage between operational efficiency and actual carbon emissions by accounting for both energy consumption and grid emission factors.

For business decision-makers, these indicators offer a clearer basis for comparing proposals, assessing long-term operating risk, and evaluating alignment with evolving regulatory, financing, and customer expectations.

WATER UTILISATION AS AN EMERGING BUSINESS RISK

While PUE has historically dominated data centre efficiency discussions, water utilisation is emerging as a critical and under-examined business risk. Cooling systems account for the majority of operational resource use in data centres, and design choices often involve trade-offs between electricity consumption and water demand. In Singapore's water-constrained environment, these trade-offs have direct implications for operational resilience, regulatory exposure, and long-term cost volatility.

As reflected in Green Mark Data Centre requirements, sustainable design increasingly calls for balanced optimisation across energy efficiency, water efficiency, and carbon performance rather than the pursuit of any single metric in isolation. Cooling strategies that achieve low PUE through water-intensive approaches may introduce vulnerabilities over the asset lifecycle, particularly as water resilience becomes a more prominent policy and planning consideration. In hot and humid climates, where economisation headroom is constrained by wet-bulb temperatures, this operational "tropical penalty" makes such trade-offs more acute, pushing operators to treat electricity use, water reliance, and resilience as a coupled system rather than independent variables.

Accordingly, data centre strategies that consider PUE and WUE together, complemented where appropriate by internal tracking of carbon outcomes, are better positioned to manage long-term operational and resource risk, while supporting business continuity in the face of tightening environmental constraints.

FROM ISOLATED FACILITIES TO INTEGRATED SYSTEMS

Another important shift is the move away from treating data centres as isolated facilities toward viewing them as integrated components of broader infrastructure systems. Increasingly, the question is not only how efficiently a facility operates internally, but how well it interacts with surrounding energy, cooling, and industrial ecosystems.

A practical near-term opportunity lies in accelerating the transition to liquid-assisted architectures, including direct-to-chip liquid cooling and hybrid air–liquid designs, supported by fit-for-purpose secondary loops, containment strategies, and maintainability standards. Over the longer term, immersion cooling remains a potential pathway for selected workloads, although mainstream adoption will depend on resolving operational issues such as serviceability, fluid management, materials compatibility, and ecosystem readiness.

The recent Memorandum of Understanding between the National University of Singapore (NUS) and JTC Corporation exemplifies this system-level direction. The partnership explores AI-influenced data centre infrastructure to optimise energy and water use, alongside the integration of low-carbon energy solutions such as solar, hydrogen, biofuels, and fuel cells through smart microgrids and virtual power plants. It also focuses on innovations in cooling systems, power distribution, energy storage, and circular energy practices that materially lower emissions. Conceptually, the decarbonisation pathway will increasingly involve a stack of low-carbon electrons and/or molecules, paired with flexible demand, storage, and digital controls, enabling data centres to function as grid-aligned participants rather than passive loads.

Jurong Island is positioned as a testbed for emerging technologies, bringing together academia, startups, and global technology providers to accelerate development, validate solutions at scale, and shape future industry standards. The collaboration also includes talent development initiatives, supporting specialised training, internships, and skills development to build long-term capability in sustainable digital and industrial infrastructure. For businesses, such system-level integration reduces long-term retrofit risk, enhances operational flexibility, and unlocks efficiency gains that cannot be achieved through standalone facility optimisation.

OPERATIONAL PERFORMANCE OVER DESIGN INTENT

Operational performance is becoming increasingly important relative to design intent. Regulators, financiers, and customers are placing greater emphasis on in-use outcomes rather than theoretical or nameplate efficiency, reflecting growing recognition that actual performance over the asset lifecycle ultimately determines environmental impact, operating cost, and compliance risk.

Digital tools such as real-time monitoring, advanced analytics, and AI-enabled optimisation allow operators to manage energy and cooling dynamically in response to changing loads and external conditions. From a business standpoint, ongoing monitoring and reporting aligned with IMDA expectations and Green Mark post-certification requirements, supported by internal tracking of carbon outcomes where relevant, strengthen cost control, compliance assurance, and performance transparency. For liquid-cooled deployments, this should extend to coolant-side temperature, flow, and pressure monitoring, supported by robust leak detection and maintenance protocols.

Facilities that can demonstrate stable and verifiable performance across assessed indicators are better positioned to secure long-term customers and financing, particularly as sustainability disclosures and assurance requirements become more rigorous.

CAPABILITY AND EXECUTION AS DIFFERENTIATORS

Delivering balanced performance across energy, water, and carbon dimensions requires more than capital investment or technology deployment. It depends on access to talent capable of integrating engineering, digital systems, sustainability, and operations. As data centres become more complex and interconnected, execution capability becomes a key differentiator between operators.

Singapore's emphasis on partnerships between industry, research institutions, and infrastructure agencies helps address this challenge by supporting capability development while reducing the risks associated with deploying new solutions at scale. For businesses, participation in such ecosystems

strengthens organisational learning and improves readiness for evolving regulatory and performance expectations.

TURNING CONSTRAINTS INTO A STRATEGIC ADVANTAGE

Taken together, these developments indicate that Singapore's data centre sector is moving toward a higher-quality and more disciplined growth model. Constraints on energy, water, and carbon intensity undoubtedly raise the bar for entry, but they also reward operators that invest in measurable performance, system integration, and long-term resilience. Rather than competing on scale alone, the market is shifting toward competition on credibility, adaptability, and contribution to broader system outcomes.

For business leaders, sustainability in data centres should therefore be viewed not as an external obligation, but as a strategic lever. Facilities that align commercial objectives with disciplined management of PUE and WUE, complemented by transparent carbon outcome tracking, are better positioned to manage risk, secure capital, and remain competitive in an increasingly resource-constrained operating environment.

The way forward is therefore pragmatic: design and operate for verifiable multi-metric outcomes rather than single-metric optimisation; treat cooling as a first-order strategic constraint in an AI-driven era by accelerating liquid-capable architectures while managing water dependency and maintainability; and build system-level partnerships that integrate energy, cooling, and digital controls to unlock resilience and decarbonisation pathways that no standalone facility can access.

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THE ILLUSION CENTRE

Rethinking Power, Redundancy, and Carbon in Data Centres

Each of us today carries an obligation to respond to the climate crisis. How we meet that obligation is entirely up to us-not the planet-and depends on the integrity, ambition, momentum, and effectiveness of our strategies. Some approaches, though well-intentioned, do not deliver the speed or scale required for meaningful climate mitigation and adaptation. Others rely on illusions: low- to medium-impact technical fixes, short-term sustainability credentialism, clever accounting, and selective metrics that paint a reassuring picture while quietly slowing progress and shrinking impact.

Few sectors exemplify these contradictions as glaringly as the ballooning data centre industry.

Data centres present a profound paradox-one that reveals a fundamental incompatibility with the natural world. Modern civilisation cannot function without them; they are the axis around which our digital economy rotates. And yet, they are among the fastest-growing drivers of global energy demand, a demand our world is already struggling to meet sustainably. Beyond energy, these facilities are water-guzzlers and waste factories.

So how do we resolve this paradox? The first step is to identify and dismantle the illusions these digital fortresses offer us.

UNDERSTANDING THE ILLUSIONS

The Power Illusion

"We are green because we have a low PUE."

Power Usage Effectiveness (PUE) has become the industry's calling card. But how often do we ask where the power actually comes from? Or what type of energy is being used? Annualised or averaged PUE figures can mask systemic inefficiencies, underutilisation, and wasted energy at partial loads. A fixation on efficiency metrics, without a system-level understanding of energy sourcing and consumption, creates a dangerously incomplete picture.

To move forward, operators and the wider data centre ecosystem must go beyond PUE and embrace system-level approaches to energy use, accounting for source, timing, and real-world grid impacts.

The Redundancy Illusion

"We are green because we have a low PUE."

Redundancy is not inherently virtuous. And redundancy does not equal resiliency. Is redundancy right-sized and aligned with workload criticality? Or does overbuilt redundancy (over-redundancy) conceal outsized energy, fiscal, and embodied carbon footprints from duplicated structure, equipment, and hardware? Resilience should never be an excuse for overprovisioning, which can lock in both capital inefficiency and long-term carbon debt.

The Carbon Illusion

"We are green because we are operationally efficient."

Operational efficiency alone does not equate to climate responsibility. Has efficiency been assessed against scope 2 emissions from grid electricity? Has scope 3 been meaningfully considered? Absent a whole-life carbon perspective, "green" data centres compromise their ecological status.

WHO HOLDS THE LEVERS?

Breaking these illusions requires recognising where control truly lies. For data centre developers and operators, solutions can emerge across three types of levers:

- High-control levers: capital allocation, design decisions, sustainability planning
- Context-based levers: site characteristics such as climate, infrastructure, and local constraints; facility characteristics such as size, legacy systems, age, massing, form
- Limited-control levers: grid energy mix, regulation, policy, market structures, sustainable finance instruments

Success depends on maximising high-control levers while proactively shaping the limited-control ones through advocacy, market signalling, and collaboration with policymakers, regulators, and financiers.

This becomes especially urgent when we consider industry trajectory. By 2029, hyperscalers are expected to command an even larger share of global critical IT load (Synergy Research Group, n.d.). For the sector to decarbonise as a whole, strategies within the limited-control bucket must evolve rapidly. Policymakers, banks, and regulators will need to work alongside operators and developers to ensure that deep decarbonisation is achievable at scale, across the value chain.

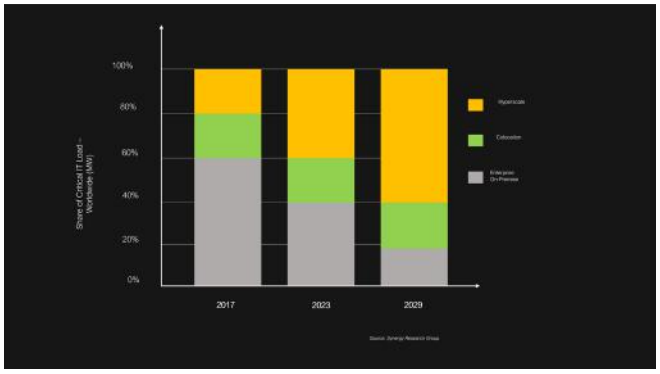

Figure 1. Share of Critical IT Load by 2029 (Synergy Research Group, n.d.)

With the stakes clear, we can now examine how operators and developers can unravel each illusion in practice.

BREAKING THE POWER ILLUSION

The most persistent issue here is energy sourcing. What energy is being used, and where is it coming from?

Renewable energy is the lynchpin. But globally, we face a serious shortfall. At COP28 in 2023, 120 countries pledged to triple global renewable capacity to around 11.2 TW by 2030. Meeting that target would have required annual growth of at least 16.1 percent from 2022 onward. Both 2023 and 2024 fell short, meaning renewable deployment must now accelerate even faster (IRENA, Renewable Energy Statistics 2025).

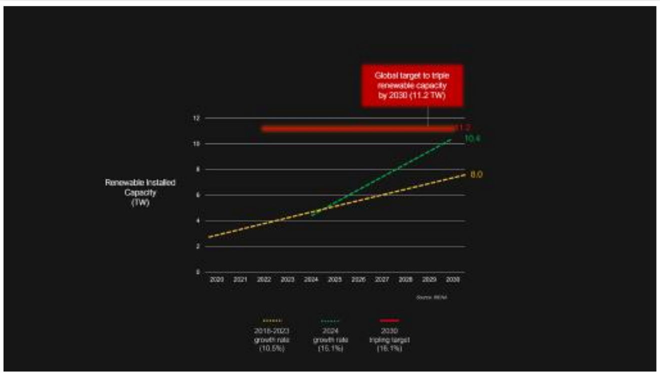

Figure 2. Renewable Installed Capacity Trends (IRENA, Renewable Energy Statistics, 2025)

This shortfall is not merely technical, it is structural. Clean energy infrastructure is not scaling because demand signals are insufficient. Grids need credible, locational demand to justify investment, and data centre operators are singularly positioned to provide it.

Consider a data centre in Singapore. When this data centre matches its annual electricity consumption with renewable energy certificates (RECs) or offshore Power Purchase Agreements (PPAs), it may appear carbon-free on paper. But in reality, the local Singapore grid (where the data centre operates) is predominantly gas-powered and will still burn fossil fuels, especially at night when solar is unavailable; so the data centre is still physically using fossil electricity. This creates a mismatch between carbon accounting and actual decarbonisation because the demand signal goes to a foreign grid (like Australia), not the local grid balancing area. The Singapore grid operator sees no difference in real-time demand or supply-and so there is no additional pressure to decarbonise grid mix.

Hourly carbon-free energy (CFE) matching crucially alters this dynamic. By reporting and procuring clean energy on an hourly basis within the local grid, operators must align consumption with real, local clean generation. What this does is create tangible demand for local renewables, giving utilities and developers a reason to build them. Unlike annual matching, CFE reporting cannot be achieved through accounting alone: it requires physical decarbonisation.

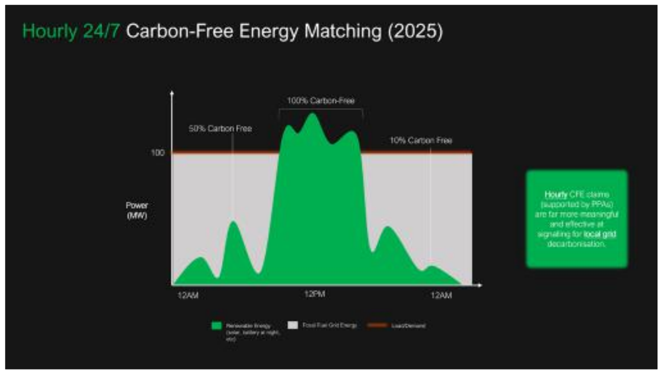

Figure 3a. Hourly 24/7 Carbon-Free Energy Matching (2025)

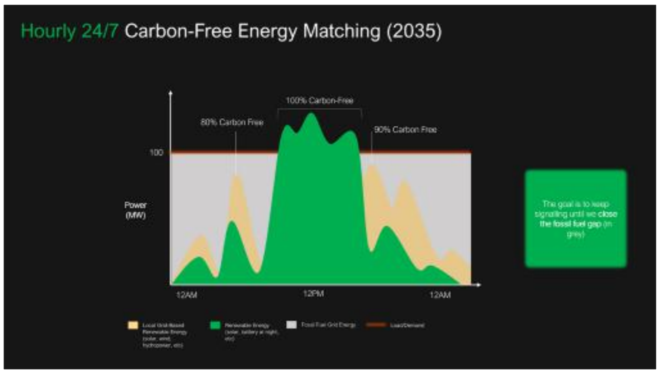

Figure 3b. Hourly 24/7 Carbon-Free Energy Matching (2035)

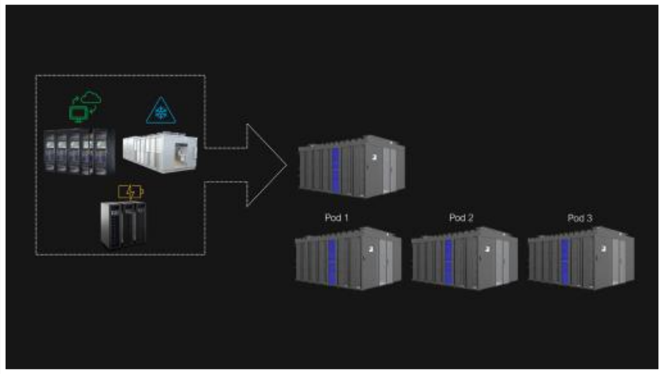

Figure 4. Modularity (Illustration)

When paired with complementary strategies (such as demand response, dynamic load management, renewables-focused business planning, and strategic site selection), hourly CFE can become a powerful lever for system-level change.

At the facility level, problems are compounded by PUE-driven efficiency illusions. Data centres are rarely fully utilised, yet they are designed for peak load. According to Uptime Institute's Global Data Centre Survey 2024, 25percent of facilities operate below 40 percent utilisation (Uptime Institute Global Data Center Survey 2024 et al., 2024). The result is oversized infrastructure running inefficiently for most of its life, a problem that leads directly to the next illusion.

BREAKING THE REDUNDANCY ILLUSION

Why do we build idle infrastructure in the first place? Redundancy is critical for data centres, but how much redundancy do we actually need?

This is where data centre investors must pay attention. Over-redundancy bleeds money in two ways. First, it wastes capital on overbuilt infrastructure. Second, it wastes energy through the knock-on effect of idle servers (they still draw power), which in turn wastes operational money.

Technical, design-led efforts like strategic modularity and phased build-out offer a compelling alternative. By right-sizing redundancy within modular pods and expanding infrastructure in line with demand, facilities can operate closer to optimal efficiency curves. Utilisation improves, energy waste declines, and resilience is maintained without excess.

Tenants also play a crucial role. Honest, well-considered load forecasting enables designers and operators to implement scalable, modular solutions, though this depends on ownership structures and the degree of control operators hold.

Critically, redundancy must be addressed as part of an integrated strategy. Partial-load PUE analysis, high-efficiency systems, virtualisation, and modular design achieve far more together than in isolation. And the embodied carbon implications of redundancy lead us directly to the final illusion.

BREAKING THE CARBON ILLUSION

Carbon is often marginalised in data centre conversations. We need to remind ourselves why carbon matters. Climate science is clear: carbon budgets are finite. For a 1.5°C pathway, humanity has already emitted roughly 2,600 $GtCO_2$ since 1850. From 2025 onward, we have approximately 130 $GtCO_2$ remaining. At current emission rates of around 40 $GtCO_2$ per year, that budget will be exhausted within three to four years (Forster et al, 2025). We do not want this to happen.

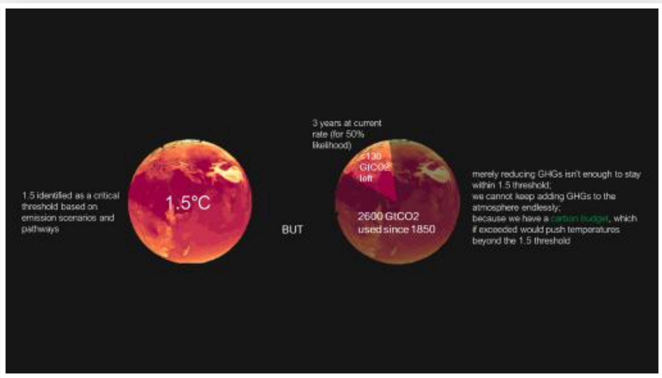

Figure 5. 1.5C Carbon Budget Scenario

Now, as the grid/energy supply becomes cleaner, the relative importance of embodied carbon increases. Supply chain emissions—from materials, manufacturing, transport, and equipment—are conservatively at least double operational emissions. This makes whole-life carbon thinking non-negotiable.

Circularity must be embedded from the outset, before design even begins. This requires infrastructure, policy, and market mechanisms that support circular outcomes across the entire lifecycle: modular design, design for disassembly, procurement for reuse, extended refresh cycles, and robust end-of-life pathways including take-back programmes, recovery, recycling, resale, and reuse.

Regulatory and financial frameworks must reinforce this shift. Incentives for circularity, penalties for waste, and green finance instruments linked to circular performance and material efficiency could all play a role.

But none of this can manifest spontaneously. Stakeholders across the value chain must actively create this demand for circularity. Without it, circular infrastructure, along with the ecosystems that support it, cannot and will not materialise.

ECOSYSTEMIC CHANGE

What the data centre sector truly needs is scale and speed. And it needs these two things on ecosystemic and cross-sectoral levels. The final and potentially the most disabling illusion is the belief that data centre decarbonisation is merely a built environment problem. It is not. It is an ecosystemic challenge spanning energy, technology, manufacturing, finance, regulation, and digital infrastructure.

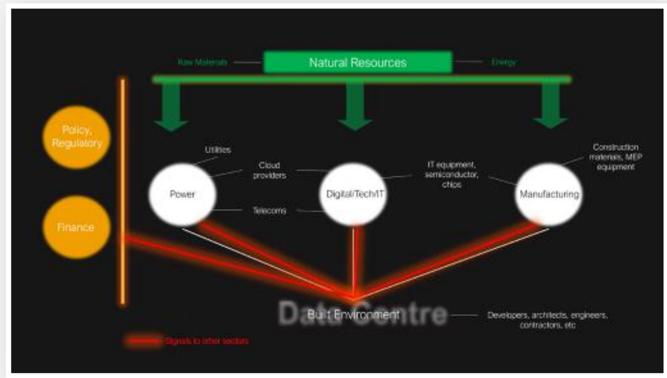

Figure 6. Data Centre Ecosystem Map

The built environment sector cannot solve this alone. Improvements within its boundaries are necessary but wholly insufficient. We must reach beyond traditional sector lines, engage multiple systems simultaneously, and hold all stakeholders accountable for progress. Signals must be sent in every direction. Quickly.

That is the real challenge. And that is the final illusion to break.

So the question remains: how will you reach beyond your sector and help decarbonise the entire data centre ecosystem?

Article contributed by:
Cundall

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A COLOCATION DATA CENTRE OPERATOR'S PERSPECTIVE ON GREENING DATA CENTRES FOR A SUSTAINABLE DIGITAL FUTURE

An operator's playbook for colocation sustainability at scale

Digital infrastructure is on a collision course with planetary boundaries. Power and water demand is rising at an incredible rate—yet customers, regulators and communities expect lower carbon, water and materials footprints. For colocation operators, this is both an existential risk and a generational opportunity: the businesses that decouple digital growth from environmental impact will win the next decade.

I hope this article offers a simple, operator centric approach to "greening" colocation data centres—grounded in current evidence and realistic about the trade offs—so we can support a sustainable digital future.

WHY THE URGENCY IS REAL

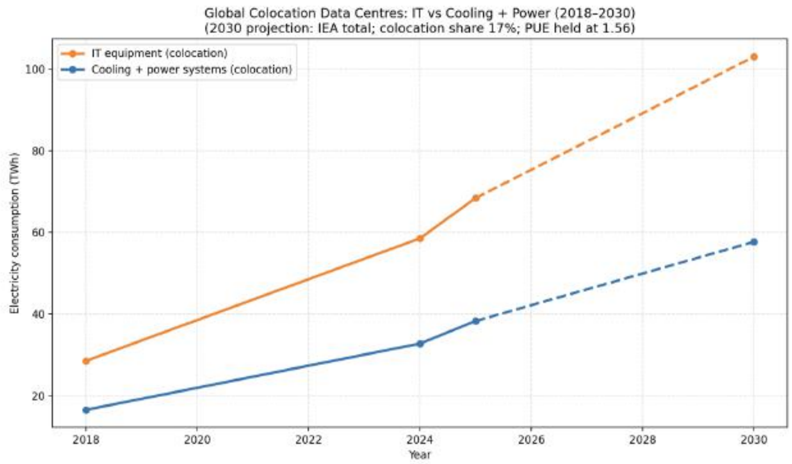
Global data centre electricity consumption has accelerated and is now projected to more than double by 2030 to ~945 TWh, with AI as the single biggest driver of the increase. At the same time, much of the sector's apparent energy efficiency progress (measured by PUE) has flattened in recent years, as a large installed base of legacy sites offsets advances at hyperscale campuses.

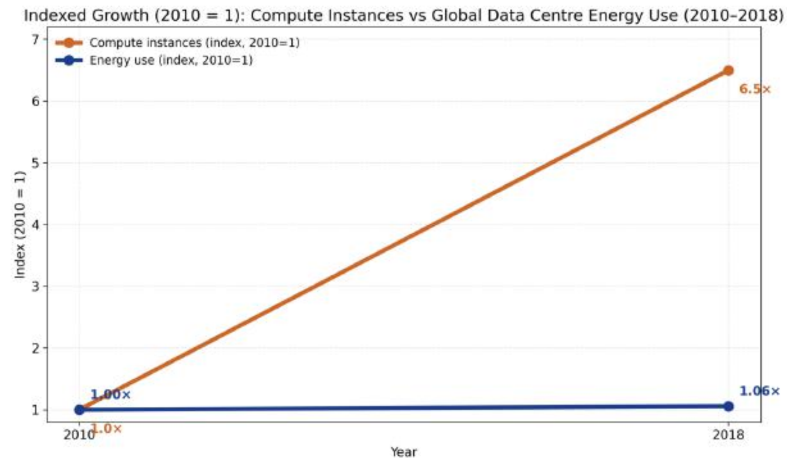
Is it all bad news?

No. The good news: a decade of consolidation and virtualisation demonstrated that workload growth doesn't equal energy growth—between 2010 and 2018, compute instances increased >6× while data centre energy use rose only modestly, thanks to efficiency, leading to lower PUE.

We are now out of "easy wins," especially as high density AI racks push thermal and electrical systems harder than traditional loads.

For colocation operators, the path forward is clear: deliver efficient, grid integrated, low carbon capacity, transparently, and at pace.





DESIGN FOR EFFICIENCY FIRST: THE PUE PLATEAU AND WHAT BREAKS THROUGH IT

PUE has flattened around ~1.55-1.60 globally since 2018, masking strong outperformance at newer, larger facilities and weaker performance at legacy ones. While PUE remains a useful KPI, operators should treat it as **necessary but insufficient**. Here's what moves the needle next:

- **For legacy data centres just keep it simple.**
  - Improve airflow by installing Aisle Containment, ensure blanking panels are installed in empty rack spaces.
  - Liaise with customers to optimise server placement for efficient cooling. Ensure SLAs are supply air based and raise setpoint temperatures accordingly.

   - Audits, inspections and retro commissioning to ensure all the above items are being managed and validated.

- **For new data centres**
   - Thermal architecture for AI densities. As racks creep from 10–20 kW toward 50–100 kW and beyond, direct to chip liquid cooling and hybrid air liquid designs will reduce the energy burden. Mandate a facility PUE around ~1.3 design for new builds at 25 percent IT load
   - Right sizing and dynamic operations. AI assisted control loops for cooling and heat rejection assets can flatten the part load; this is especially powerful in colocation where tenant loads are heterogeneous.
   - Warm water and higher ΔT strategies. Align supply temperatures with ASHRAE guidelines enabling more hours of free cooling and better liquid cooling efficiency.

The PUE story is evolving from "universal best practices" to **workload aware, density aware** plant design that tackles AI head on.

DECARBONISE THE POWER DELIVERY: PROCUREMENT, MATCHING AND GRID INTEGRATION

Efficiency reduces kW/h; decarbonisation changes the kg per kW/h. In growth markets where power is the constraint, colocation operators may have to help make clean power available, not just consume it.

- **Hybrid clean power portfolios.** Seek a diverse mix of grid renewables, including on site solar, and—where available and regulations allow—low carbon options (e.g., contracted hydro, nuclear backed credits, industrial scale batteries).

- **Demand flexibility as a product.** Consider curtailment strategies, load shifting, battery based peak shaving and participation in capacity/ancillary markets will reduce embodied grid emissions and unlock revenue.

For colocations, offering **"Sustainable Power SLAs"**- which combine availability with verified hourly carbon content-could become a competitive differentiator as customers adopt science based targets.

WATER, HEAT AND URBAN INTEGRATION

Sustainability isn't just about MW/h, it's also about **water and heat.**

- **Water stewardship.** As air cooled and adiabatic systems are weighed against water cooled options, operators must disclose **WUE trade offs** by climate zone.

- **Heat reuse as civic infrastructure.** With higher outlet temperatures from liquid cooled systems, **district heat reuse** becomes more practical in temperate locations-lowering net site emissions, decarbonising space and processing heat.

- **Harvesting/recycling wastewater.** Operators should consider simple on-site water treatment solutions

For urban and campus sites, early engagement with local authorities, utilities and district energy operators is key.

CIRCULARITY AND EMBODIED CARBON: BEYOND SCOPE 2

Whole life sustainability demands attention to Scope 3-embodied carbon in construction and MEP assets.

- **Retrofit and reuse first.** Reusing shells and structural elements can avoid 70 - 90 percent of embodied carbon vs. new build for many commercial building types; while data centre specifics vary, this directionally holds for heavy structures and is aligned with the push for more sustainable buildings.
- **Low carbon materials and modularity.** Specify low carbon concrete and steel, modular UPS and cooling blocks that can be right sized as load grows, and service friendly designs that maximise component life.

MEASUREMENT AND TRANSPARENCY: FROM PUE TO PORTFOLIO CARBON INTENSITY

What gets measured gets managed.

- **Expand KPI's.** Add CUE (carbon), WUE (water), ERE (energy reuse), temperature compliance, and hourly carbon matching to dashboards. The Uptime Institute notes many operators still aren't tracking sustainability metrics to meet regulatory reporting needs-closing that gap is urgent.
- **Capacity weighted views.** Because larger (often newer) sites tend to be more efficient, a capacity weighted PUE can provide a truer picture of portfolio performance than a simple average.
- **Independent assurance.** As growth accelerates toward 2030, third party verification of sustainability claims will become baseline-policymakers emphasise transparent data to manage the sector's grid and environmental impacts.

POLICY, SITING AND COMMUNITY LICENSE TO OPERATE

The next wave of expansion hinges on grid interconnections, community acceptance and policy alignment.

- **Policy horizon.** The IEA warns that in advanced economies, data centres could drive >20percent of electricity demand growth to 2030, challenging grid connection timelines and necessitating diverse energy sources alongside efficiency.
- **Siting with power realism.** Many jurisdictions face backlogs and capacity constraints; proactive coordination with utilities, and in some cases investment in local reinforcements, are becoming critical path.
- **Community benefits.** local renewable projects, workforce programmes and transparent impact reporting help secure the social licence to operate.

For colocation, site selection increasingly prioritises firm, low carbon power and interconnection lead times over traditional cost/land first strategies.

AI LOADS: DESIGNING FOR A STEP CHANGE, NOT A BLIP

AI is not simply "more of the same". Training and inference clusters demand high power density, tighter power quality, and liquid cooling—and they are expected to make up a much larger share of data centre energy by 2030. Operators should plan for:

- **Electrical architecture for ≥100 kW+ racks.** Busways, higher rated PDUs, and selective UPS bypass/segmentation to reduce conversion losses at scale.
- **Liquid cooling service models.** Offer colocation ready DLC (direct to chip or rear door heat exchangers) as a product, including leak detection, maintenance protocols, and tenant onboarding playbooks. This is central to bending the PUE curve for AI clusters while containing site overhead.
- **Thermal to grid synergies.** Liquid systems enable higher grade heat for district reuse, aligning sustainability returns with urban stakeholders.

A REALISTIC 3 STEP ROADMAP FOR COLOCATION OPERATORS

Step 1: Optimise today (0–12 months)

- Raise chilled water temperatures; implement variable primary flow; aisle containment; retune control sequences; target < 1.30 PUE in high performing halls.

- Consider energy matching pilots with existing PPAs; add on site BESS for peak shaving and limited backup overlap.
- Publish independently validated sustainability scorecards (PUE, WUE, CUE, ERE)

Step 2: Build for AI (12–36 months)

- Retrofit liquid cooling options and electrical upgrades to support ≥100 kW racks; introduce "AI ready" suites with documented procedures and SLAs.
- Expand demand response participation and local grid programs; structure hourly matched clean power options for tenants.
- Construct heat reuse connections where viable; integrate with municipal planning early.

Step 3: Transform the portfolio (36+ months)

- Liquid first new builds; modular electrical blocks that scale with demand; target capacity weighted PUE ~1.4 or better
- Pursue co developed clean power (hybrid PPAs, storage, firm low carbon) in power constrained regions; align siting with grid upgrades
- Embed circularity into capex cycles (low carbon materials, modular MEP).

THE CUSTOMER DIMENSION: TURNING SUSTAINABILITY INTO A PRODUCT

Greening data centres isn't just a compliance exercise; it's a growth strategy. All customers increasingly carry science based targets and suppliers must reduce Scope 2 emissions and support Scope 3 reductions. Colocation operators that are able to offer:

- **Carbon matched power,**
- **AI ready, liquid cooled suites with verified PUE/ERE,** and
- **Transparent, third party assured reporting**

will help customers hit their goals while commanding premium occupancy in capacity constrained markets.

THE STRATEGIC NARRATIVE: SUSTAINABLE BY DESIGN, RESILIENT BY DEFAULT

The sector's next chapter demands that data centres are seen as partners to the energy transition, not just large loads. The IEA underscores that as electricity demand from data centres surges, the industry must simultaneously double down on efficiency, renewables procurement and R&D to curb emissions growth. Globally policymakers highlight both the challenge and the potential: highly efficient, sustainable data centres that support (not hinder) the clean energy transition.

For colocation operators, this means building campuses that are grid savvy, heat aware, water responsible and circular-and proving it with data. If we get this right, the digital economy's foundations can grow and decarbonise.

CONCLUSION

Sustainability at scale will potentially be a core competency for colocation. By pairing workload aware efficiency with granular decarbonisation, transparent metrics, and community friendly design, operators can deliver the capacity boom the digital world requires-without compromising the climate goals society demands. The next decade will belong to those who make sustainability the product.

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COOLING DATA CENTRES FOR A SUSTAINABLE DIGITAL FUTURE

A more precise method of cooling to keep pace with data centre advancements

The digital world is growing rapidly, driven by streaming, cloud computing, and AI. However, this growth comes with a hidden cost: massive energy consumption and environmental impact. Traditional data centres, the backbone of the digital world, are energy-hungry and inefficient. They are like giant refrigerators, using lots of energy to cool down the equipment. But there is a problem: air cooling, the current standard, cannot keep up with the heat generated by powerful AI chips. It is time to rethink the data centre. The industry is stuck at a "Thermal Wall" and air cooling cannot sustain the digital future.

Liquid cooling is a solution: two common methods are cold-plates and total immersion. However, a local start-up, Hyprcool Pte Ltd, in collaboration with Ngee Ann Polytechnic's Centre for Environmental Sustainability (CfES), has developed a game-changing alternative: the Spraying Jet Impingement (SJI) liquid cooling system. This innovative technology simplifies data centre design and reduces environmental impact. SJI technology targets heat at the source, using a patented low-pressure dielectric liquid jet system. This approach eliminates the need for energy-intensive chillers and massive cooling towers. It marks a shift from "Room Cooling" to "Precision Cooling", making data centres more efficient and sustainable.

With SJI, computing power can be decoupled from environmental harm. It is not just a new way to cool chips; it is a new way to build data centres. Imagine data centres that are water-neutral, energy-efficient, fan-less, quiet and simple – that is the future SJI technology offers.

SJI: A SIMPLIFIED APPROACH TO LEAN FACILITY

The future of data centres lies in simplicity. Unlike traditional facilities burdened by complex mechanical systems, the SJI-powered Next-Generation Data Centre (NGDC) embodies a philosophy of radical subtraction. By targeting heat rejection directly at the chip level with dielectric jets, SJI eliminates the need for energy-intensive components.

SJI technology fits seamlessly into existing infrastructure. Unlike immersion cooling, it does not require reinforced floors or new racks. SJI chassis are designed to house standard servers and fit into current racks, making upgrades straightforward. Figure 1 shows the Hyprcool SJI chassis and rack.

Figure 1 Hyprcool SJI Chassis & Rack

The SJI technology simplifies data centre design, removing unnecessary complexity and waste. By operating facility water at 35°C to 40°C, SJI enables 100 percent "Free Cooling" year-round, eliminating the need for chillers and cooling towers. This approach can keep chip temperatures below 60°C while reducing energy consumption. The benefits of SJI extend to the facility design: no raised floors, no Computer Room Air Handler (CRAH) or Computer Room Air Conditioner (CRAC) units, downsized chillers, no expensive air-containment structures (Hot Aisle/ Cold Aisle), no pipe insulation, no complex Cooling Distribution Unit (CDU) and its high-pressure piping risks. Figures 2 & 3 illustrate the contrast between traditional mechanical layouts and the SJI-coupled Distributed Pumping System (DPS) approach.

THE SJI ADVANTAGE

Efficient Cooling for AI Chips: the Heat Flux (W/cm²) measures how much heat is generated per unit area of a chip. For AI chips, this is a critical metric - as GPUs get smaller and more powerful, they generate more heat in a smaller space. Cold-plates, a common liquid cooling solution, struggle with high heat density. They rely on copper and thermal interface materials (TIM) to transfer heat, which can be inefficient.

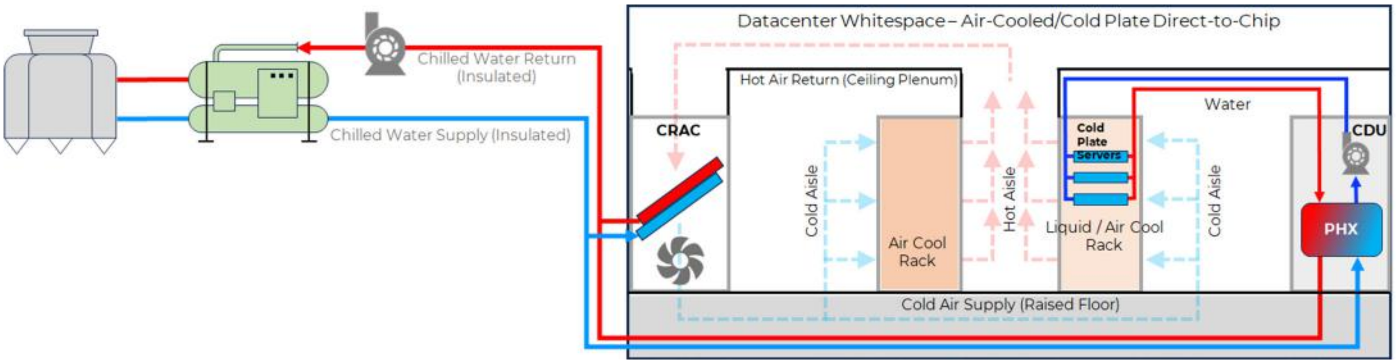

Figure 2 - Mechanical Layout of Air-cool and Cold Plate liquid-cool system

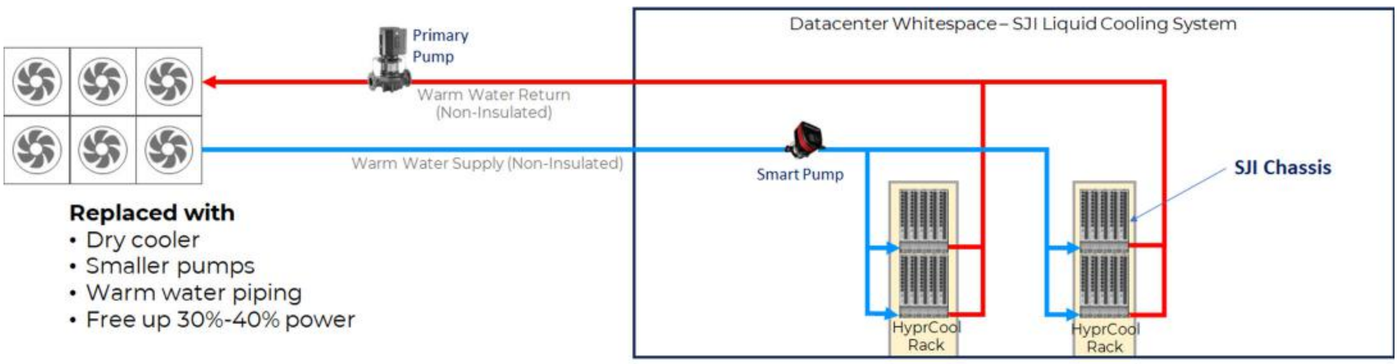

Figure 3 - Mechanical Layout of SJI liquid-cool system

SJI sprays coolant directly onto the chip, achieving the highest heat flux removal capacity in the industry. SJI achieves a Power Usage Effectiveness (PUE) of 1.04 - 1.10, comparable to immersion cooling, but can be implemented in existing (brownfield) racks. Immersion cooling requires a complete overhaul (greenfield build). SJI delivers "immersion efficiency" without the infrastructure costs. Additionally, SJI eliminates the need for internal fans in data servers, resulting in hidden energy savings. When factoring in this zero-Watt fan load, SJI often outperforms cold-plates by a wider margin than PUE alone suggests. Table 1 compares the performance of cold-plate, immersion, and SJI cooling solutions.

Metric	Cold-Plate (Indirect)	Immersion (Passive/Two-Phase)	SJI
Max Heat Flux (W/cm²)	300 - 500	600 - 800	1000 - 1200+
Typical System PUE	1.15 - 1.25	1.03 - 1.05	1.05 - 1.10
Cooling Coverage	Primary Chips Only	Whole Board	Whole Board
Internal Fan Power	50 – 200 W	0 W	0 W
System Pressure	High (30+ PSI)(>2 bar)	Low (Atmospheric)	Low (<0.7 bar)
Maintenance Complexity	Moderate	Very High	Low (Modular)

Sources of Information for Table 1:
- Heat Flux - (NVIDIA Technical White Papers (Blackwell B200 Architecture) and IEEE Semi-Therm Proceedings.
- PUE (Power Usage Effectiveness) - Uptime Institute Global Data Center Survey (2024/2025)
- Internal Fan Power (Parasitic Load) - Dell Technologies / HPE Server Energy Consumption Specifications
- System Pressure - CoolIT Systems and Motivair (Cold-Plate Manufacturers) Technical Manuals.

Table 1

THE END-TO-END HYDRAULIC ADVANTAGE

Current liquid cooling systems often struggle with high pressure and condensation risks. SJI technology solves these issues with a simplified hydraulic network:

- No Condensation: The primary cooling loop (Facility Water) operates above dew point, eliminating pipe insulation and moisture-management needs. The secondary dielectric liquid loop runs at higher temperatures than the facility water loop.
- Low-Pressure Safety: SJI operates at <0.7 bar, reducing leak risks and allowing lightweight piping. This contrasts with high-pressure cold-plates (>2 bar).
- Distributed Pumping System (DPS): Developed with Grundfos, DPS adjusts cooling water flow in real-time based on compute load, optimising energy use.

Like building HVAC systems, data centre cooling often falls short of optimal performance due to inadequate controls implementation. Consulting engineers design systems with integrated components and specify control logic, but execution often falters. Commissioning, a critical step, is frequently overlooked. An end-to-end solution from a single vendor, covering design, installation, controls, and commissioning, ensures the system operates as intended is paramount for minimising energy consumption.

ENVIRONMENTAL IMPACT: SJI COOLANT

Traditional cooling systems use refrigerants like R410A (GWP 2088) and R134A (GWP 1430), potent greenhouse gases. By contrast, Hyprcool's SJI dielectric fluid has a GWP of 20 and zero Ozone Depletion Potential (ODP). Switching to SJI reduces direct environmental risk by >100x, ensuring compliance with 2026 regulations.

THE SILENT DATA HALL: ZERO-FAN ENVIRONMENT WITH PDV

The Next-Generation Data Centre aims to eliminate high-velocity air movement. SJI removes heat directly from servers, leaving only residual heat in the data hall. Traditional CRAH/CRAC units are energy-intensive and inefficient. Passive Displacement Ventilation (PDV) uses natural convection to supply cool air at floor level, exhausting warm air at the ceiling – no fans needed. Combining SJI with PDV creates a True Zero-Fan environment, slashing energy consumption and creating a silent, vibration-free space. This synergy redefines sustainable data centre operations, achieving ultra-reliability and minimal environmental impact. Figure 4 shows the pilot SJI cum PDV systems operating at the Ngee Ann Polytechnic campus.

Figure 4 – SJI Liquid Cooling cum PDV Pilot Systems at Ngee Ann Polytechnic

SJI CHASSIS DEVELOPMENT: FROM PROTOTYPE TO PILOT

Hyprcool, in collaboration with CFES, began development work in 2018. After rigorous prototyping and lab testing, a pilot system with a complete piping network was launched in June 2024. This end-to-end approach ensured efficient cooling of data servers at Ngee Ann Polytechnic (Figure 4). Iterative testing validated SJI technology's performance and reliability. Figure 5 shows stress test results: all CPU cores stressed to 100 percent load, with temperatures kept below 60°C. Figure 6 shows the display of pPUE 1.04 for the end-to-end SJI liquid cooling system, including facility water pumping and outdoor dry cooler power.

SJI TECHNOLOGY GETS GLOBAL ATTENTION

The SJI system has moved from testing to real-world use with top tech companies. After successful pitches, CfES is now working with local and multinational companies to test SJI on their premises. The plug-and-play system is designed to work seamlessly, with real-time monitoring and a closed-loop cooling network. Figure 7 shows the fully self-contained standalone single chassis with Edge Server installed at different customer premises.

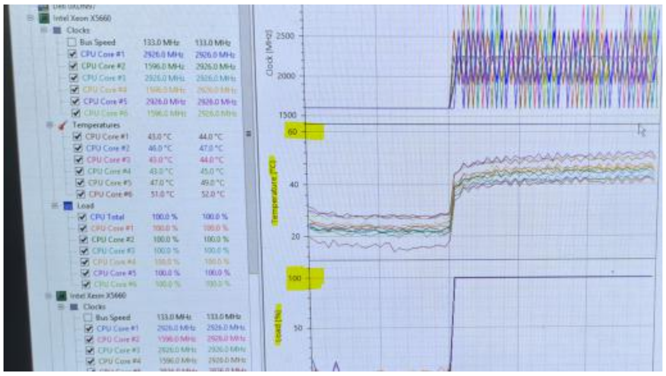

Figure 5 – SJI Live Data Server 100percent load Stress Test

Figure 6 – SJI Real Time Display of pPUE 1.04 for Data Servers Operation

CONCLUSION: A SUSTAINABLE DIGITAL FUTURE IS HERE

SJI is developed as a new way to cool data centres that is better for the planet. SJI technology helps to make data centres:

- Water-efficient: No water wasted in cooling towers
- Energy-efficient: Uses less power, no bulky fans or chillers needed
- Simple to build: Uses standard construction methods

The pilot project shows it is possible to cool powerful computers while reducing complexity and environmental impact. The SJI system is quiet, efficient, and a step towards a more sustainable digital future.

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Figure 7 – Standalone SJI Liquid Cooling System installed at various customer premises

MEETING THE GREEN CHALLENGE IN AI

Higher compute requirements are challenging data centre operators, but AI also offers sustainable solutions

The data centre industry is still processing how AI workloads impact energy, cooling and building demands. As how we use AI changes and the number of use cases grows, supporting AI workloads is like trying to hit a moving target.

A report by the International Energy Agency estimates that a typical AI-focused data centre consumes as much electricity as 100,000 households, but the largest such data centres being built today are expected to consume 20 times that.

Some of that energy consumption can be attributed to computing power, but a growing proportion of it is also needed for cooling AI server racks.

In Singapore, where temperatures rise as high as 37°C, cooling can account for up to 40 percent of total energy consumption.

As AI chips increase in power, data centre operators face greater challenges in infrastructure, operations and maintenance.

These challenges are being compounded by tougher regulatory requirements. Singapore's Infocomm Media Development Authority (IMDA) and Economic Development Board (EDB) are making available another 200MW of data centre capacity.

This second Data Centre – Call for Application (DC-CFA2) requires operators to achieve a power usage effectiveness of 1.25 (at 100 percent IT load) or better.

This means that when operating at full capacity, the data centre should use less than 25 percent of its IT power for cooling and other non-IT needs—which accounts for less than 20 percent of its total power usage.

Technologies are available to mitigate these energy challenges. For instance, high-efficiency uninterruptible power supply systems use various technologies to reduce power loss and heat generation.

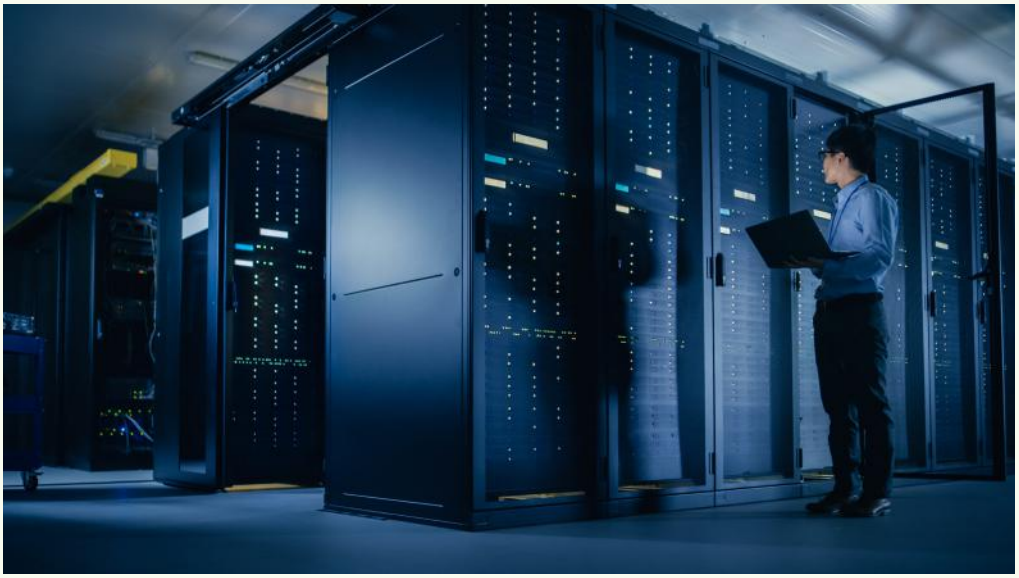
Right-sizing power infrastructure and optimising the distribution of power to minimise losses can also help. As AI-powered technologies advance, the adoption of various new digital tools should also lead to sustainable improvements.

THE INFRASTRUCTURE CHALLENGE

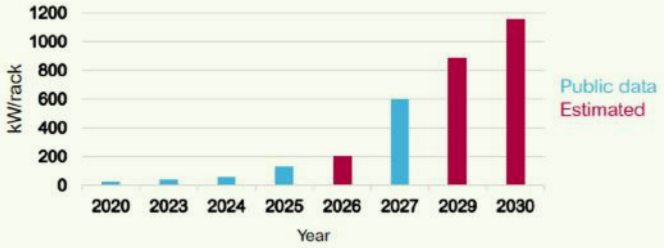
Data centres are made up of:

- Servers that process AI workloads,
- Data storage to retain information, and
- Networks that connect these elements.

These components are organised in racks of varying densities, with higher rack densities required for faster processing times, latency reduction, physical footprint optimisation, energy efficiency and sustainability.



AI compute rack densities are expected to increase exponentially in the coming years (see chart). This has implications for power, cooling and rack infrastructure.



Recognising this, Singapore last year launched a new IT energy efficiency standard for data centres. The standard, SS 715:2025, mandates the use of energy-efficient IT equipment.

It aims to cut the energy consumption of IT equipment in data centres by at least 30 percent through the selection and operational optimisation of IT equipment for energy efficiency and higher temperatures.

As rack densities increase, operators of existing data centres must retrofit power systems for energy-intense AI clusters while trying to predict how loads might change over time.

Collaborations will be crucial here – between tenants and landlords, as well as between operators and equipment or service suppliers.

Those building new data centres, meanwhile, will face stiff competition for energy supply and a grid connection. On-site generation and energy storage technologies are becoming necessary for alternative prime and backup power sources.

Such energy sources might include generators fuelled by hydrotreated vegetable oil, battery energy storage systems and even, to a limited extent, small modular reactors.

Data centres must also account for complexities associated with liquid cooling, which becomes more important once rack densities pass the 40-kW mark and air cooling is no longer efficient – whether in terms of energy, space or cost.

Liquid cooling is still a relatively new technology, however, and standards are not as well established. Deployment variables range from something as simple as the space required for cooling a standard rack, to the multiple installation considerations for different types of coolants.

This variation can create complexity and add to costs. Meanwhile, the need to accommodate heavier liquid cooling structures adds to the technical requirements of AI-ready server racks.

Racks already need to be wider, deeper, taller and stronger to accommodate AI workloads. Whereas an average server rack with standard computing power might weigh between 680 and 1,130 kg, a high-density AI rack can weigh over 1,800 kg.

Existing data centres may need new racks while newbuild designers must take future potential increases into account. To ensure sufficient buffer, AI compute racks should have a static weight capacity greater than 2,270 kg and a dynamic weight capacity greater than 1,600 kg.

The concrete slab floors beneath these racks should be rated for rack weights over 3,000 kg.

In Singapore's tropical environment, optimising the deployment of hybrid cooling architecture will be crucial.

The tropical data centre standard SS697:2023 suggests that raising the operating temperature of a data centre – to 26°C and above, from the typical 22°C and below – can yield energy savings of 2 percent to 5 percent for every 1°C increase.

A combination of air-cooled and liquid-cooled racks can operate effectively at such elevated temperatures.

By raising the setpoint of the chilled water used for cooling, there will be a smaller temperature difference between the cooling fluid and the ambient temperature. This allows heat to be transferred more efficiently.

THE OPERATIONS AND MAINTENANCE CHALLENGE

The higher rack densities and greater power variation required for AI data centres also create a tighter margin for error in operations. Situational awareness, constant vigilance and round-the-clock uptime become more important.

Any data centre plan requires not just well-designed infrastructure but also well-considered operations and maintenance plans – making use of digital planning, modelling and monitoring tools to assess capacity, manage loads and prevent incidents.

Higher rack densities and higher operating temperatures increase the risk of power cords overheating, for instance.

While this risk can be managed by ensuring all data centre equipment uses high-temperature cords, it makes sense to place temperature sensors on the racks and install monitoring systems for data centre infrastructure management.

As the data centre industry expands rapidly and grows more complex, the operations and maintenance challenge has also been complicated by talent constraints.

The Uptime Institute Global Data Center Survey 2025 showed nearly two-thirds of data centre operators report difficulties retaining staff, finding qualified candidates or both.

Uptime Institute's analysis of 25 years' worth of data has also found that human error plays a role in more than 66 percent of data centre outages.

These various challenges can be dealt with by taking advantage of digital tools, especially tools that incorporate AI.

Advances in technology make it possible to accurately gauge a site's ability to accommodate high-density AI compute racks.

Digital tools for data centre infrastructure management, electrical power monitoring systems, building management systems and electrical design can assess power and cooling capacity, rack density capabilities and available physical space.

AI-powered digital twins can model an AI computing environment, simulate operations, plan

maintenance and make recommendations for design and efficiency improvements.

Schneider Electric is already deploying digital twins to create real-time performance models that allow AI to autonomously optimise airflow and cooling based on varying AI workloads.

Sensors can deliver real-time data on factors such as temperature, pressure and flow – data that can be fed to AI-powered models that identify patterns, and surface potential issues.

The benefits of deploying these digital tools include reduced risk, lower costs, greater reliability and enhanced sustainability.

Expert partners will be crucial to dealing with these challenges while also greening AI data centres. Data centre operators should seek to lean on the experience of partners who have designed, deployed, operated and maintained green data centres in other parts of the world.

GREEN SOLUTIONS

To resolve power constraints, operators can partner local energy providers in the renewables space.

In Singapore, this will become easier as Jurong Island, home to much of Singapore's petrochemicals

activities, is making space for a 20ha low-carbon data centre park.

The area will be able to support up to 700MW of power capacity while also tapping greener energy coming up on 300ha of land reserved for new-energy and low-carbon technologies projects.

With the opportunity to build from scratch, operators should emphasise designing for sustainability.

DC-CFA2 requires at least half of a new data centre's power to come from eligible green energy pathways such as biomethane, low-carbon ammonia, low-carbon hydrogen, novel fuel cells with carbon capture and storage technology, or vertical building-integrated photovoltaics/building-applied photovoltaics.

Incorporating sustainable design and renewable energy from the start can reduce wasted energy and will likely also be key to securing the necessary approvals for data centre construction or expansion in Singapore.

While headlines may paint a power-hungry picture of AI data centres, we argue for a more nuanced perspective.

Operators that invest in digital tools and innovative strategies will overcome challenges, deliver on sustainability and ensure long-term success.

Article contributed by:
Schneider Electric

Get your e-Guide to Smarter AI Infrastructure Decisions

YOUR CLOUD IS SOMEONE'S HEATER

Redirecting surplus data centre heat to power agriculture and cut emissions in Southeast Asia

Southeast Asia is one of the fastest growing data centre markets globally. In 2024, ASEAN data centres consumed approximately 9 TWh of electricity, with demand projected to reach 68 TWh by 2030. Installed capacity is expected to hit 10.7 GW by 2035, raising a critical question: how can the region expand digital infrastructure without reinforcing long-term fossil-fuel dependence?

Rear Door Heat Exchanger (RDHx) technology offers a practical pathway. Studies show cooling energy savings of 23–50 percent, potential PUE improvements from 1.5–2.0 to as low as 1.035, and reduction of water use of up to 58 percent. Applied to Southeast Asia’s projected installed capacity by 2035, RDHx could eliminate tens of millions of tonnes of CO_2 emissions annually.

BACKGROUND AND CONTEXT

In 2024, global data centre energy consumption reached an estimated 415 TWh, representing about 1.5 percent of worldwide electricity use. This figure is projected to climb to 945 TWh by 2030.

In parallel, the region’s digital economy is also projected to expand from USD 300 billion to nearly USD 1 trillion by 2030, accelerating demand for digital infrastructure.

Cooling systems remain one of the main contributors to overall electricity use in data centres. Against this backdrop of rapid growth and infrastructure constraints, which technologies can support sustainable expansion of DC capacity without straining electrical grids or reinforcing fossil fuel dependency?

FROM AIR TO LIQUID: WHAT REAR DOOR HEAT EXCHANGER CHANGES

A Rear Door Heat Exchanger is mounted directly on the rear of a server rack and removes heat at the server exhaust. Liquid-filled coils absorb hot exhaust air and transfer the warmed coolant to a central heat rejection or heat recovery loop. This localised approach requires only a fraction of the energy used by traditional room level cooling.

RDHx can be active (with electronically commutated fans) or passive (zero operational energy cost). They are also compatible with chilled-water systems operating at higher supply temperatures, extending economiser operation and reducing compressor runtime even in warm climates.

In Southeast Asia’s tropical conditions, conventional CRAC/CRAH systems rely on mechanical refrigeration year round, as high ambient temperatures rarely permit free cooling. RDHx systems, by contrast, can function with chilled water supply temperatures of 20–22 °C, allowing economiser operation and significantly reducing compressor runtime. This is particularly advantageous in SEA, where average annual temperatures remain between 27 and 32 °C, limiting the effectiveness of traditional air cooling methods.

REAR DOOR HEAT EXCHANGERS (RDHX): TECHNOLOGY, SAVINGS & CO_2 IMPACT

By 2035, the following indicative savings will yield, assuming broad RDHx adoption across new and retrofitted facilities:

5–40 TWh
Annual electricity savings (applying 23-50 percent cooling energy reduction)

2.9 – 22 MtCO
avoided per year (at SEA average grid intensity of 0.54 kg CO_2/kWh

Up to 58 percent
Reduction in data centre water consumption across the region

Based on projected data centre electricity consumption of 68 TWh in Southeast Asia by 2030, with cooling accounting for 35–45 percent of facility energy use, applying RDHx efficiency gains of 23-50 percent could save up to 40 TWh annually. At a regional grid intensity of 0.54 kg CO_2/kWh, this represents 8.6–17.3 million tonnes of CO_2 avoided per year - equivalent to removing 1.9–3.8 million cars from the road.

Beyond energy savings, RDHx systems also enable recovery of captured heat for productive reuse, allowing data centres to function not only as energy consumers but as potential thermal energy sources.

FROM ELECTRICITY TO HEAT: UNLOCKING THE POTENTIAL OF DATA CENTRE WASTE HEAT RECOVERY

Data centres consume significant electricity, almost all of which is converted into heat and typically released to the environment. Capturing and repurposing this heat can improve efficiency, cut operating costs, and lower carbon emissions.

Southeast Asia offers strong potential for waste-heat utilisation. As a global leader in aquaculture with a substantial agri-food processing industry, the region requires consistent low- to medium-temperature thermal energy; currently largely supplied by fossil fuels. Redirecting server exhaust heat (25–70 °C) to nearby farms or processing facilities could establish a closed-loop thermal ecosystem that supports sustainable food production and reduces emissions, while improving economic performance.

HEAT TRANSFER PROCESS IN RDHX-BASED COOLING

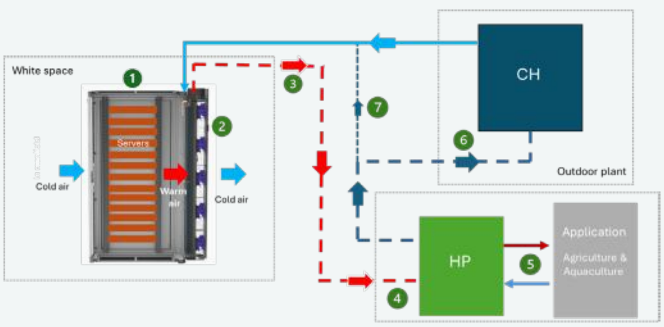


Figure 1 Using thermal energy from data centre for aquaculture and agricultural applications

STEP 1: CAPTURING WASTE HEAT VIA RDHX

1. Servers generate heat, warming exhaust air to ~40-55°C.
2. Rear Door Heat Exchangers (RDHx) absorb this heat into a liquid coolant loop (glycol-water mixture).
3. The coolant exits RDHx at ~35-45°C and circulates to the primary heat exchanger.

STEP 2: PREHEATING USING A HEAT PUMP (HP)

Since aquaculture RAS systems and agricultural dryers typically require 25-55°C water, a heat pump extracts and upgrades the heat (accounting for piping losses).

4. The low-grade waste heat (35-45°C) enters the evaporator of the heat pump (HP). The HP boosts the temperature to 35-60°C via compression cycle (depending on the application and distance).
5. The upgraded heat is then fed into the district heating water circuit.

STEP 3: HEAT DISTRIBUTION TO AGRICULTURAL/ AQUACULTURE FACILITIES

The heated water (35-55°C) is pumped to nearby aquaculture RAS systems for fish tank heating, or to agricultural drying facilities for crop/seafood processing, or to greenhouse climate control systems.

STEP 4: RETURNING COOLED WATER TO DATA CENTRE

6. The cooled water returns to the data centre for reuse in the cooling loop, or excess heat is rejected via chillers during periods when agricultural/aquaculture facilities have lower thermal demand.
7. Bypass connections allow direct heat supply when temperatures match agricultural/ aquaculture requirements without heat pump amplification.

This creates a continuous circular energy loop between the data centre and agricultural/aquaculture operations, maximising thermal energy utilization.

CIRCULAR ENERGY LOOPS: SEA-WIDE PROJECTION

A conservative estimate shows that redirecting 30–60percent of waste heat generated by Southeast Asia's data centres - equal to 20–40 TWh thermal by 2030 - to agri food applications could displace fossil fuel use at 0.25–0.35 kg CO_2/kWh thermal. This would avoid 5–14 million tonnes of CO_2 annually, equivalent to removing 1.1–3.1 million vehicles from regional roads. Achieving such outcomes at scale, however, requires supportive policy frameworks and market incentives, which remain at early stages across Southeast Asia.

Malaysia's Johor data centre corridor and Indonesia's Batam digital industrial zone are strong candidates for Agri Digital Symbiosis Zone pilots, supported by tax incentives and fast track approvals.

Application	Heat Recovery Rate	Fossil Fuel Displaced	Annual CO_2 Saving
Aquaculture (RAS)	Up to 96 percent	LPG, diesel, coal	8percent facility-level reduction; up to 9,208 t CO_2/yr/system
Fishmeal / seafood drying	55 percent + energy reduction	Rice husk, diesel, LPG	58.37 percent CO_2 reduction/tonne product
Greenhouse / CEA	33-66 percent of heating load	Natural gas, electricity	Up to 4,000 t CO_2/yr per 3.5 MW DC facility
Algae cultivation	Variable	Grid electricity, gas	14,000 kg carbon captured/100 m³ pond/17 harvests
Combined (SEA, 2030)	30-60 percent WHR redirected	Coal, LPG, diesel, biomass	5–15 Mt CO_2 avoided/year at 68 TWh scale

CONCLUSION

Southeast Asia stands at a critical juncture. The region's data centre market presents major economic potential, yet its rising electricity demand risks straining existing infrastructure and reinforcing fossil fuel dependence. With capacity expected to reach 10.7 GW by 2035, decisions made in the coming years will shape whether this growth can be achieved sustainably.

Rear Door Heat Exchangers offer one of the most immediately deployable and high impact options available. Requiring no structural changes to existing facilities, RDHx systems can reduce cooling energy use by up to 50percent and cut regional CO_2 emissions by several million tonnes annually. Combined with accelerated renewable energy procurement and grid upgrades, RDHx adoption can help Southeast Asia build a digital economy that is both competitive and genuinely sustainable.

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GREENING SINGAPORE'S DATA CENTRES

Building an AI-Ready, Low-Carbon Digital Hub

Singapore's vision of becoming a leading digital hub depends on the strength of its trusted digital infrastructure, with data centres sitting at the core. These facilities power cloud services and digital platforms across critical sectors from finance and healthcare to logistics and public services. As organisations scale their adoption of artificial intelligence (AI), the underlying infrastructure must keep pace: AI workloads drive higher power density, greater cooling needs, and increased operational complexity. At the same time, Singapore must stay on track with its national climate commitments.

The opportunity, and the test, is whether Singapore can add compute capacity while reducing carbon intensity. Achieving both will require coordinated action across policy, industry and the wider ecosystem: cleaner power, more efficient design, smarter operations, and stronger talent pipelines.

WHY DATA CENTRES MATTER TO SINGAPORE'S COMPETITIVENESS

Data centres are no longer "back-end infrastructure". They are enablers of economic competitiveness, supporting digital services, connectivity and the performance required for data-intensive applications. As AI adoption grows, demand is shifting towards high-density, high-resilience environments that can support accelerated computing.

But data centres are also resource-intensive. In a tropical climate, cooling loads are significant and land constraints sharpen the need for more space-efficient designs. These realities make efficiency and sustainability not just "nice to have", but fundamental to future growth.

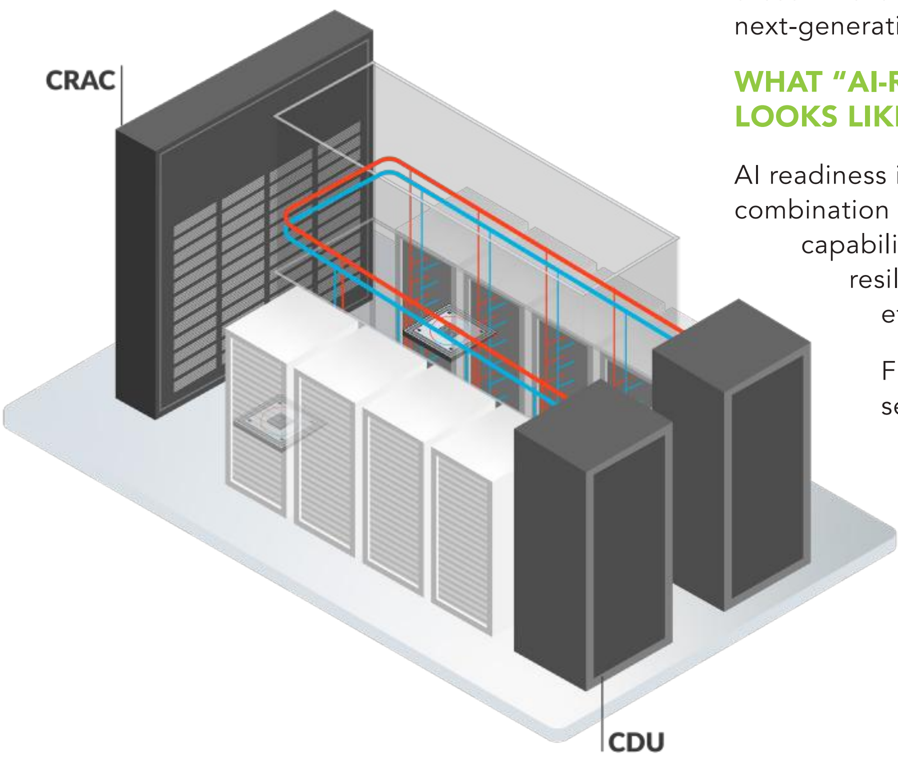
THE POLICY DIRECTION: GROWTH, CONDITIONAL ON GREENER OUTCOMES

Singapore's Green Data Centre Roadmap signals a clear direction of travel: the country intends to enable additional data centre capacity while raising expectations around sustainability and efficiency. In practice, this means progress will depend on measurable improvements, such as better energy efficiency, more effective cooling approaches and greater access to low-carbon or green energy. The roadmap also emphasises the role of partnerships and innovation to help the ecosystem move faster. Initiatives such as the low-carbon data centre park on Jurong Island serve as testbeds for these innovations, providing a proving ground for next-generation technologies.

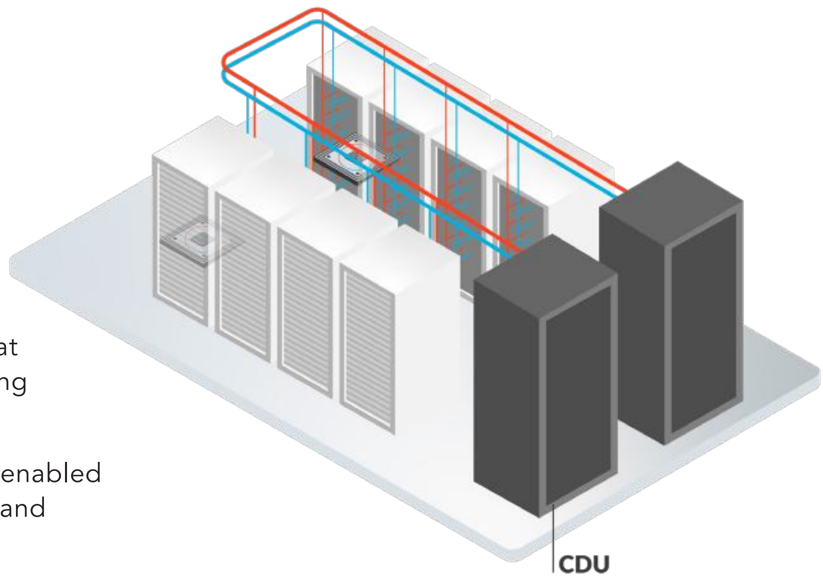
WHAT "AI-READY AND LOW-CARBON" LOOKS LIKE IN PRACTICE

AI readiness is not a single feature. It is a combination of power architecture, cooling capability, operational discipline and resilience, delivered in a way that remains efficient as workloads scale.

From an infrastructure standpoint, several pathways matter most:



Hybrid cooling (air-cooled aisles and direct-to-chip liquid cooling) combines air cooling with liquid cooling systems to balance efficiency, density and deployment flexibility.



With direct-to-chip liquid cooling, liquid coolant flows directly to cold plates on CPUs/GPUs, enabling efficient heat removal at the source and space-efficient cooling with compact CDUs.

- **Power efficiency and distribution** that can support higher rack densities while reducing losses.
- **Next-generation cooling,** including liquid-based approaches, to manage heat more efficiently than traditional air-cooling alone.
- **Operational optimisation,** including AI-enabled monitoring and control to reduce waste and improve performance over time.

These themes align with how sustainable data centres are being shaped globally through smarter systems, tighter control and continuous improvement.

INDUSTRY ACTION: HOW ST TELEMEDIA GLOBAL DATA CENTRES IS CONTRIBUTING

At ST Telemedia Global Data Centres (STT GDC), sustainability is embedded as a business priority because a resilient digital future must also be a responsible one. In 2024, STT GDC reported that 78.5 percent renewable energy usage across the Group, alongside continued progress towards carbon-neutral data centre operations by 2030.

In Singapore, this translates into practical initiatives focused on reducing emissions while supporting performance for next-generation workloads. These include:

- deploying advanced cooling approaches suited to high-density compute environments;
- applying AI-driven operational optimisation to improve efficiency;
- trialling lower-carbon alternatives such as hydrotreated vegetable oil (HVO) for backup generation, where appropriate.

The goal is not innovation for its own sake, but innovation that delivers outcomes: lower carbon intensity, stronger resilience and consistent performance.

FUTUREGRID ACCELERATOR: BUILDING CAPABILITY FOR THE NEXT GENERATION OF POWER AND AI INFRASTRUCTURE

One of the most important constraints for AI infrastructure is power,specifically how it is delivered efficiently at scale. In January 2026, STT GDC launched the FutureGrid Accelerator, positioned as Southeast Asia's first live High Voltage Direct Current (HVDC)-powered AI infrastructure testbed. Located at Nanyang Technological University's Electrification and Power Grids Centre (EPGC) on Jurong Island, the testbed is jointly developed with LITEON, supported by ERI@N and Amperesand, and designed to demonstrate HVDC integration with real AI workloads.

Beyond technology validation, the initiative also connects to a broader priority: building skills and pathways for the workforce needed to support next-generation digital and energy infrastructure.

In parallel, industry academic collaboration helps ensure Singapore develops the specialist capabilities required for the future. STT GDC is working closely with Singapore Polytechnic (SP) to advance applied research and talent development in sustainable digital infrastructure. This collaboration focuses on partnering innovative solutions for energy efficiency, cooling technologies, and

Celebrating the official launch of the FutureGrid Accelerator officiated by Ms Gan Siow Huang, Minister of State for Foreign Affairs and Trade & Industry; a new benchmark for HVDC-powered AI infrastructure in the region.

AI-driven optimisation, while equipping students with practical skills in sustainability and automation. By engaging academia directly, STT GDC helps to prepare the next generation of engineers and technologists to tackle the challenges of building low-carbon, AI-ready data centres. The partnership with SP exemplifies how industry and education can work hand in hand to accelerate the adoption of green technologies while nurturing future talent.

MANAGING THE TRADE-OFFS OF COST, MATURITY AND SPEED

Greening data centres is not without friction. New technologies often carry higher upfront costs, and some low-carbon pathways remain early-stage. Even when solutions exist, the challenge is deploying them at scale without compromising reliability, safety and time-to-market.

Regional competition adds pressure: other hubs are also investing in sustainability to attract workloads and capital. For Singapore, the advantage will come from being a place where the ecosystem can prove, scale and operationalise next-generation solutions quickly, while maintaining credible standards.

LOOKING AHEAD, SCALING WHAT WORKS

Looking ahead, Singapore's path forward involves

- scaling low-carbon and renewable energy access and integration;

- designing new facilities for high-density, efficient operations from day one;
- raising the baseline through standards and adoption across the ecosystem; and
- continuing to develop talent in AI infrastructure, power systems, sustainability and automation.

The Roadmap provides the direction; innovation initiatives such as the FutureGrid Accelerator provide places to test and learn; and industry collaboration provides the momentum.

CONCLUSION

Greening Singapore's data centres is both an environmental necessity and a strategic imperative. The question is not whether Singapore will grow digital infrastructure, but how it will do so, by raising efficiency, reducing carbon intensity and building the capabilities required for AI at scale.

STT GDC's work from sustainability progress across its portfolio to initiatives such as the FutureGrid Accelerator reflects an approach grounded in outcomes: performance, resilience and responsible growth.

By aligning policy, technology, and partnerships, Singapore can continue to strengthen its position as a future-ready digital hub, one that is also credible in its sustainability ambitions.

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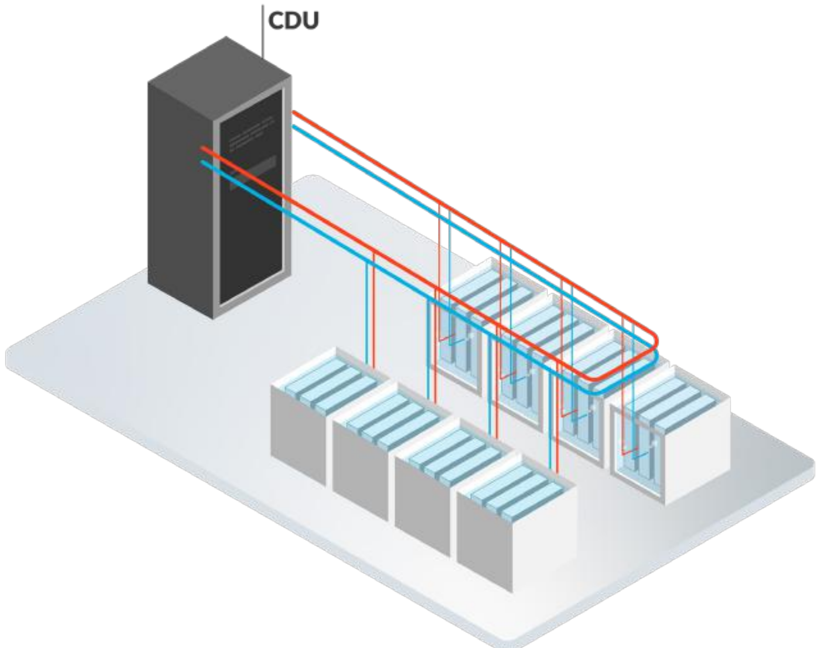

With Immersion liquid cooling, servers are fully submerged in dielectric fluid, delivering high-efficiency cooling and maximising compute density in a reduced footprint.

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ALIGNING INFRASTRUCTURE RENEWAL WITH SINGAPORE'S GREEN MANDATE

How structured asset replacement helps Singapore's ageing data centres maintain reliability while meeting rising efficiency and sustainability expectations.

INTRODUCTION

Singapore's data centre sector has long been recognised for its engineering discipline and operational reliability. Over the past decade, significant capacity was developed to support the nation's digital economy. Today, many of these facilities are 10 to 15 years old - technically robust, maintained, and still performing their intended function.

However, they are now operating in a vastly different sustainability, regulatory and performance landscape from when they were originally developed. The next phase of Singapore's data centre evolution will not be defined solely by new builds. It will be shaped by how effectively existing facilities are optimised, renewed and future-proofed, without compromising the reliability standards that underpin the sector.

THE SUSTAINABILITY MANDATE

The Singapore Green Building Masterplan and national sustainability agenda have shifted the goalposts for energy efficiency and carbon reduction. As energy-intensive assets, data centres are at the heart of this transition.

The latest BCA Green Mark for Data Centres reflects this shift, moving beyond "design intent" to focus on real-time operational performance and data transparency. For existing facilities, maintaining historical performance is no longer enough; the regulatory environment now demands continuous efficiency improvements.

This creates a critical juncture for operators: to meet these modern benchmarks, legacy infrastructure must be systematically updated through structured asset replacement.

ASSET REPLACEMENT WITHIN DATA CENTRES

For many operators, redevelopment is neither practical nor necessary. The core infrastructure remains serviceable. The challenge lies in elevating performance to meet contemporary benchmarks while preserving uptime. This is where structured asset replacement becomes central.

A structured asset replacement programme transforms risk into a planned and budgetable lifecycle strategy. It aligns engineering realities with business priorities while protecting uptime, enabling capacity growth, improving operational efficiency and supporting evolving sustainability requirements. Most importantly, it replaces reactive emergency interventions with a disciplined, multi-year roadmap executed safely within a live, mission-critical environment.

Asset renewal is therefore not simply about replacing equipment at end-of-life. It is about evaluating infrastructure against today's reliability, efficiency and supportability standards and intervening systematically.

WHY ASSET REPLACEMENT MATTERS

1. **Reliability and uptime protection**

   In critical environments, reliability is not a nice-to-have. It is the product. As equipment ages, failure rates typically increase, spares become harder to source, and the quality of vendor support can decline. Even when redundancy exists, the margin for error shrinks when multiple assets in the same system are nearing end-of-life at the same time. A proactive replacement strategy reduces the chance that a single component failure escalates into a service impact.

2. **Efficiency and operating cost reduction**

   Replacement is not just about avoiding failures; it is also one of the most effective levers for reducing energy consumption. Newer UPS systems, modern cooling technologies, and IT refresh cycles can unlock significant efficiency gains. Over the life of a data centre, energy and maintenance costs frequently dwarf initial capex; so, selecting the right moment to replace assets can materially improve total cost of ownership.

3. **Compliance, auditability, and risk reduction**

   Regulatory expectations, insurer requirements, and internal governance frameworks often require evidence of asset conditions, maintenance discipline, and lifecycle management. An asset replacement programme strengthens audit readiness by formalising inventory, condition assessments, risk scoring, and the decision trail behind replacement timing.

4. **Vendor lifecycle and support constraints**

   Vendors regularly phase out models, software, firmware, and spare parts. Once a platform becomes "end-of-support," repairs can become slow, expensive, or impractical, especially during a critical incident. Planned replacement avoids betting your uptime on scarce parts, unsupported firmware, or dwindling expertise.

   Note: While asset replacement discussions often focus on IT or 'White Space' equipment, the same lifecycle principles are critical for the backbone 'Grey Space' infrastructure—including Power, Cooling, Fire Safety, and Building Controls. Increasingly, these assets are owned by separate entities with different priorities. However, the performance of the White Space is dependent on the reliability of the Grey Space, a coordinated replacement strategy is essential to mitigate shared operational risk.

THE STRATEGIC ROADMAP

When thinking about lifecycle, asset age is only one input. There are several key factors which need to be included.

EXPECTED USEFUL LIFE

Typically, every asset has a lifecycle age range, either defined by manufacturers or recognised institutions such as CIBSE. Hence the Expected Useful Life of an asset is a starting point. These are used as a baseline guide for planning.

CONDITION-BASED ASSESSMENT

Regular physical inspections of an asset to assess its overall condition and performance are essential, even where multiple units are installed at the same location. Assessments provide vital information on asset-ageing and performance and can help to fine-tune lifecycle planning accordingly.

TOTAL COST OF OWNERSHIP

Total cost of ownership represents the full financial impact of owning and operating an asset over its entire lifecycle. It goes beyond the initial capital purchase to include ongoing operating expenses such as energy consumption, maintenance labour, service contracts, and repair needs. It also factors in downtime risk, obsolescence challenges, and opportunity costs that arise when ageing equipment limits capacity or efficiency.

BUILDING A REPLACEMENT STRATEGY THAT WORKS

Step 1: Create a trustworthy asset inventory. A replacement programme is only as strong as the data behind it. Establish a single source of truth and maintain it. This should be maintained in a database system, with governance to keep it current and accurate.

Step 2: Implement a practical risk scoring model. Risk scoring converts engineering signals into decision-ready outputs. A simple but effective model should consider criticality, redundancy, age, condition, failure history, supportability and maintenance burden. The outcome is a ranked list of assets and systems, so replacement decisions are transparent and defensible.

Step 3: Prioritise using a portfolio view. Replacement is rarely "one asset at a time." It's often best planned as system packages and can include equipment "right sizing", upgrade and modernization. Bundling reduces repeated disruptions and improves commissioning integrity.

Step 4: Align replacement planning to the financial cycle. A multi-year plan (typically 3–10 years) stabilises budgets and avoids "CAPEX spikes."

Step 5: Engineer for maintainability and future flexibility. Modernisation choices should reduce complexity, not increase it. Look for modular designs, improved monitoring, standardised or common spare parts and aligned capacity growth.

EXECUTION IN A LIVE DATA CENTRE: WHERE PLANS SUCCEED OR FAIL

1. **Live-site upgrade phasing**

   Replacing critical infrastructure while operations continue requires careful sequencing:

   - Define protected system states (e.g., always maintain N+1 at every step)
   - Use temporary infrastructure where needed (rental chillers, temporary UPS)
   - Schedule intrusive work to low-risk windows
   - Pre-stage equipment to minimise cutover duration

2. **Vendor and contractor coordination**

   Asset replacement is a multidisciplinary event: OEMs, electrical/mechanical contractors, controls specialists, commissioning agents, and operations teams. Success depends on:

- Clear roles and responsibilities
- Method statements and switching procedures reviewed end-to-end
- Factory acceptance testing (FAT) and site acceptance testing (SAT)
- Commissioning scripts that verify functionality under realistic load scenarios
- Aligning with Procurement teams to secure vendors skilled in live-environment replacements, reducing the risk of costly missteps.

3. **Pace, power, and cooling constraints**

   Legacy footprints can complicate upgrades. New equipment may require:

   - Different clearances, lifting plans, or access routes
   - Reworked cable containment, busway taps, or pipework
   - Changes to heat rejection approach or water treatment regimes
   - Temporary capacity to maintain redundancy during cutover

4. **Governance and change management Mission-critical changes must be controlled and repeatable:**

   - Formal MOPs/SOPs/EOPs updated alongside the physical change
   - Risk assessments and stakeholder approvals
   - Accurate as-builts and labelling
   - Post-change validation and handover training

   A strong change process doesn't slow delivery; it prevents rework and reduces incident probability.

BENEFITS OF A STRUCTURED REPLACEMENT PROGRAMME

When executed well, an asset replacement programme delivers measurable outcomes:

- Lower outage risk: fewer unexpected failures, better redundancy integrity
- Reduced operating cost: energy efficiency improvements and reduced reactive maintenance
- Improved planning accuracy through smoother capex profiling and fewer emergency procurements, supported by consistently updated as-built records and centralised documentation that ensure a current, accurate view of every asset.
- Operational efficiency: standardised assets, clearer documentation, better spares strategy
- Compliance strength: stronger audit posture with evidence-based lifecycle decisions
- Future readiness: facilities that can support higher densities, new technologies, and sustainability targets

CONCLUSION: REPLACEMENT AS A COMPETITIVE ADVANTAGE

In today's environment, asset replacement is no longer a reactive maintenance decision, it is a strategic lever for resilience, efficiency, and compliance. As facilities mature, performance optimisation alone is insufficient; structured lifecycle renewal becomes essential to sustain operational reliability while meeting evolving sustainability expectations.

Organisations that approach replacement as a continuous programme, grounded in data, risk prioritisation, and forward planning, will be better positioned to reduce downtime risk, control operating costs, strengthen regulatory alignment, and maintain long-term scalability.

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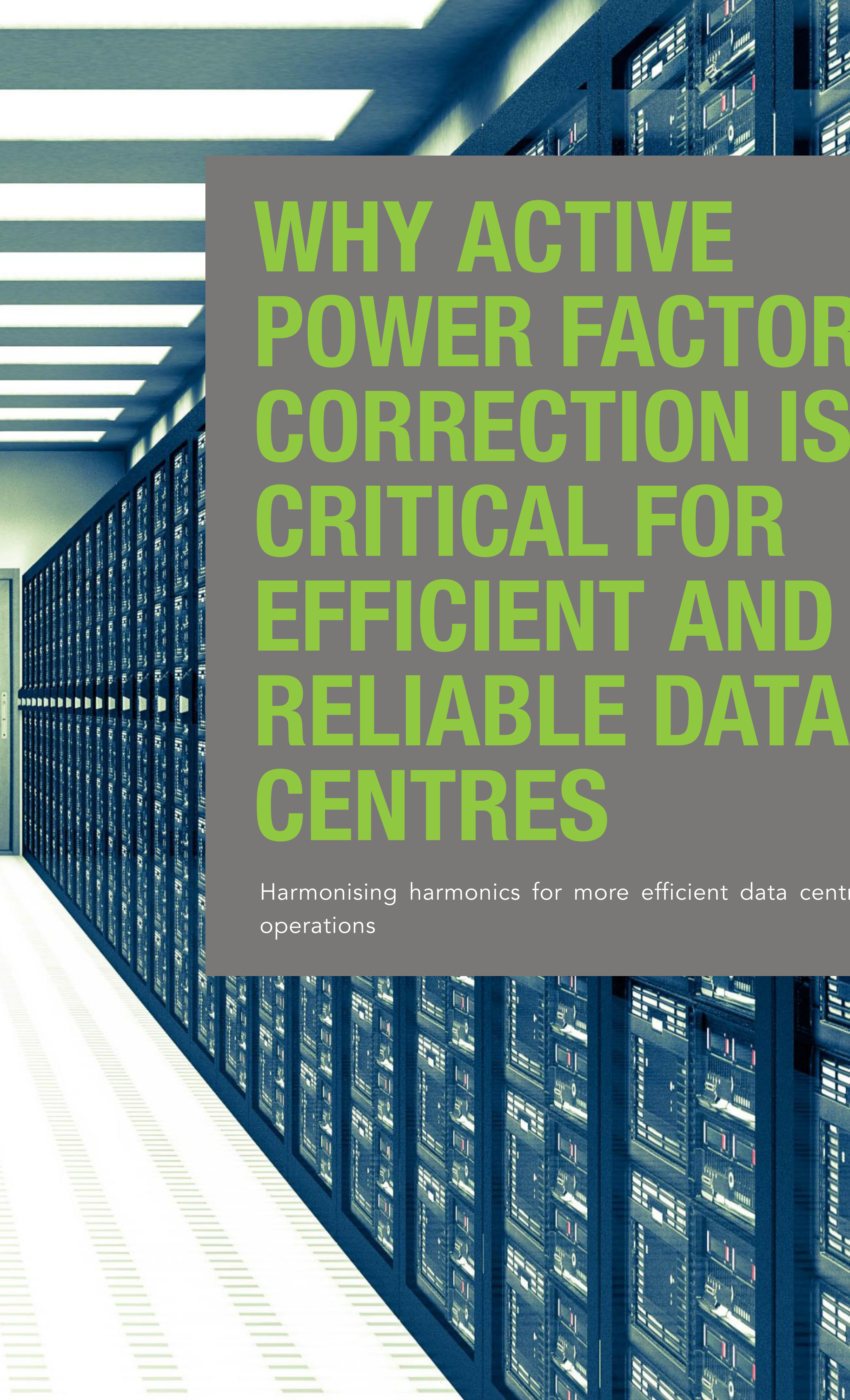
WHY ACTIVE POWER FACTOR CORRECTION IS CRITICAL FOR EFFICIENT AND RELIABLE DATA CENTRES

Harmonising harmonics for more efficient data centre operations



As data centre workloads and power density rise, harmonic distortion has become a critical yet often overlooked issue. Nonlinear IT loads, such as servers and UPS systems, create harmonic currents that disrupt power quality. These harmonics also limit usable power capacity by pushing transformers and distribution systems to thermal limits well before their rated load. If not controlled, they drive up operating costs and reduce reliability, causing equipment stress, early failures, outages, and downtime.

IMPACT OF HARMONICS IN DATA CENTRES

1. ESCALATION OF ENERGY AND OPERATING COSTS

Harmonic currents increase RMS current and generate excess heat in transformers, cables, switchgear, and UPS systems, increasing electrical and efficiency losses. In addition, bad harmonics can lead to extreme harmful currents that damage or even destroy electrical components. Lower power factor caused by harmonics can also trigger higher utility charges and penalties. The additional heat generated requires more cooling, further increasing energy consumption.

2. ARTIFICIAL CAPACITY LIMITS, STRANDED INFRASTRUCTURE

By inflating current levels, harmonics push electrical systems to thermal limits earlier than designed. This often forces oversizing of transformers, generators, and UPS systems or costly upgrades to support higher rack densities and AI workloads. Ultimately, power delivery, not compute, becomes the bottleneck, leaving IT capacity under utilised.

3. REDUCED RELIABILITY FROM INCREASED DOWNTIME RISK

Harmonic distortion (THDi/THDv) stresses power distribution components, causing overheating in transformers, conductors, PDUs, and busways. This accelerates wear and shortens equipment lifespan. UPS units, power supplies, and cooling systems face higher failure rates under harmonic rich conditions, increasing the risk of nuisance trips, voltage instability, and downtime.

4. ACCELERATED EQUIPMENT DEGRADATION

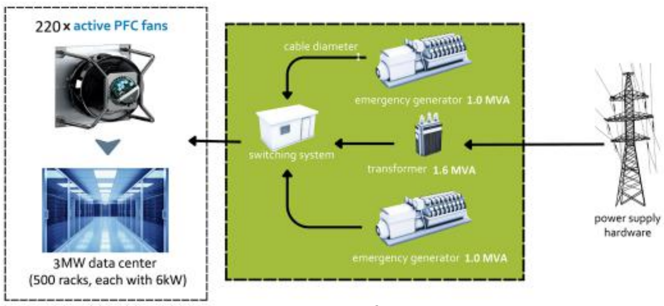
Harmonic-related heating reduces the lifespan of electrical and IT equipment, driving more frequent maintenance, repairs, and component replacements, and increasing the likelihood of unplanned outages tied to power failures.

5. POOR SUSTAINABILITY AND ESG PERFORMANCE

Decreasing power conversion efficiency and increasing energy use and PUE caused by harmonics increase carbon emissions per unit of compute, making ESG compliance and green data centre certifications more difficult to achieve.

6. INCREASED STRAIN ON GRID AND UTILITIES

High harmonic levels inflate apparent power (kVA) without delivering useful work, adding strain to utility transformers and local grids.



Reference: DatacenterDynamics

STANDARD VS. ACTIVE PFC FANS:

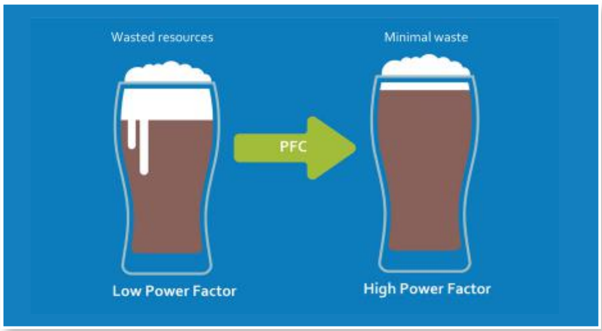
- Both cases used 220 fans
- The standard solution had higher THDU and THDI values
- Standard solution required oversized transformers and standby generators
- Active PFC: Lower costs

HOW ACTIVE PFC HELPS REDUCE HARMONICS AND POWER CONSUMPTION

Active Power Factor Correction (Active PFC) plays a direct and increasingly important role in reducing overall power consumption and enabling scalable growth in various ways.

1. **IMPROVES POWER UTILISATION EFFICIENCY**

   Active PFC aligns current with the voltage waveform, achieving near-unity power factor so more power drawn becomes usable real power instead of wasted reactive power.



2. **REDUCES DISTRIBUTION AND INFRASTRUCTURE LOSSES**

   By lowering current draw, Active PFC cuts I^2R losses across the electrical chain, reduces heat in cables, UPS systems, and power supplies, and decreases cooling demand linked to power losses.

3. **ENABLES HIGHER POWER DENSITY WITHOUT OVERBUILDING**

   As AI and GPU rack densities rise, Active PFC allows power systems to run closer to their designed capacity without derating or expensive oversizing.

4. **MINIMISES HARMONICS AND PROTECTS EQUIPMENT**

   Nonlinear IT loads generate harmonics that reduce efficiency and stress equipment. Active PFC significantly lowers harmonic distortion, improving transformer, UPS, and generator performance and reducing energy wasted as harmonic heat.

5. **SUPPORTS SUSTAINABILITY AND ESG GOALS**

   By boosting electrical efficiency and lowering energy use for the same compute output, Active PFC helps reduce PUE and Scope 2 emissions.

6. **IMPROVES GRID COMPATIBILITY AT SCALE**

   Poor power factor increases grid stress at hyperscale. Active PFC enables cleaner, grid-friendly power draw, supporting stability in the surrounding grid.

CONVENTIONAL METHODS OF MINIMISING CURRENT HARMONICS

Traditional methods typically use external harmonic filters to reduce THDi. While effective to varying degrees, these solutions introduce multiple drawbacks: dependence on separate suppliers, additional coordination to match filters to EC plug fans, extra wiring, larger installation space, and higher complexity.

EC FANS WITH INTEGRATED ACTIVE PFC

ebm-papst's integrated Active Power Factor Correction (Active PFC) reduces current harmonics without the drawbacks of conventional passive mitigation methods. Instead of using bulky passive components, it applies active rectification to precisely control and shape the input current.

With active rectification, the current waveform becomes smooth and sinusoidal, rather than pulsating, and remains closely aligned with the input voltage. This sharply lowers harmonic distortion and improves overall power quality.

By filtering out the disturbing harmonics, the fans achieve very good power factors of up to $\lambda=0.99$, reduce current peaks by up to 50 percent, and attain THDI values of less than 5 percent over a broad power range.

Finally, ebm-papst integrated active PFC EC fan provides seamless integration of high efficiency EC plug fans and Active PFC electronics, all in one product, from one trusted supplier.

Note: Measurements are taken on the entire fan unit, consisting of the motor, control electronics, and impeller, in various load states.

CASE STUDY: POTENTIAL FOR SAVINGS WHEN DESIGNING A DATA CENTRE WITH INTEGRATED ACTIVE PFC EC FANS.

TOTAL COST REDUCTION

- Net reduction of 38 percent lower costs overall

COST COMPARISON OF COOLING SOLUTIONS

- A study compared the costs of industry-standard fans versus ebm-papst active PFC fans in a 3 MW data centre cooling system.

DATA CENTRE SPECIFICATIONS

- 3 MW IT load
- 500 racks (6 kW each)
- a 2N redundant cooling system with one transformer (1.6 MVA)
- two standby generators (1.6 MVA each)

CALCULATION OF THE NUMBER OF FANS

- The number of required 3kW fans (220) was based on the transformer's apparent power and standard fan power.

BENEFITS OF ACTIVE PFC FANS

- Replacing 220 standard fans with three-phase active PFC fans reduced THDU to below 0.5percent due to extremely low THDI values.

COST SAVINGS ACHIEVED

- More efficient system allowing downsizing standby generators to 1 MVA each
- Keeping the transformer at 1.6 MVA
- Significant cost reductions in data centre design

Article contributed by:
ebm-papst SEA Pte. Ltd.

	Active PFC	Industry standard	Factors not taken into account in the calculation
System costs	€809,595	€809,595	• Extra space requirement for an overdimen-sioned system → hence construction costs and possibly rental costs • Cables and switchgear can be downsized with the active PFC solution
Active PFC fans	€66,000	—	
Transformer	€125,000	€187,500	
Generators	€380,000	€1,216,000	
Total	€1,380,595	€2,213,095	So in real terms the cost savings are even higher!
Saving/additional expense	-€832,500		
Saving	-37.6%		

REDESIGNING FOR EFFICIENCY WITH ACTIVE PFC:

- Smaller transformers and generators
- Savings on installation and operating costs


GO 25
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Make comfort sustainable
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Green
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