Driving a Greener Digital Future

SINGAPORE'S GREEN DATA CENTRE ROADMAP

INFOCOMM MEDIA DEVELOPMENT AUTHORITY

Contents

Executive Summary

Transformative Potential of Digital

Digitalisation has been a transformative force in the economy and society. The digital economy today contributes ~17% to Singapore's Gross Domestic Product and is set to continue to grow strongly.

Singapore is also home to many international enterprises serving the region and the world, increasingly digitally. This builds on our position as a trusted business hub, with strong international connectivity (including international submarine cables), robust legal and intellectual property protection, supportive cross-border data flow policies, and a highly skilled tech talent workforce that serves international markets.

Last year saw the launch of Singapore's National Artificial Intelligence (AI) Strategy 2.0. AI is emerging as a key potential driver of future growth. It also demonstrates Singapore's belief in AI for Public Good, and its transformational potential to benefit the economy and society.

The harnessing of AI, coupled with the advent of other macro-trends such as the growing use of autonomous and robotic systems, immersive virtual interactions through higher bandwidth connectivity, are all expected to propel demand for compute resources. These "tailwinds" of economic growth, generated here in Singapore, therefore support the requirement for a diverse mix of top-tier compute-infrastructure, to serve current and future needs.

17.3%
Singapore's Digital Economy GDP (2022)

82%
of carbon emissions of domestic Information & Communications sector

Pioneering the Sustainable Growth of Data Centres

Data centres (DCs) provide a critical foundation, underpinning our digital services, operations, and transactions, as a digital-first Smart Nation, both domestically and internationally. Today, Singapore is a regional DC hub, with a total capacity exceeding 1.4 gigawatts. DCs here tap on Singapore's broader international position as a business and digital hub.

However, DCs around the world are heavy users of power and water. Industry and governments worldwide are increasingly conscious that DCs cannot continue to grow in an unsustainable manner, without managing the resource footprint.

This is a global issue. Singapore's status as a compact city-state merely brings us to the forefront of these considerations. However, it also makes us uniquely positioned to innovate and pioneer solutions that may then be applicable internationally, to help address this global challenge of sustainable DC growth.

The ability to make DCs green, will open the path to continued and sustainable expansion of capacity. The Digital Connectivity Blueprint launched in June 2023 spelled out our ambition - to map a path for continued growth of Green DCs and push the sustainability envelope. This Roadmap, developed with inputs from the industry, charts out some of the key pathways for that continued growth. This journey of innovation, however, is also a mutual journey of exploration as potential solutions and measures may be nascent. This is therefore reinforced by the shared commitment, through many years of close collaboration, by both the government and industry to work together to develop the ecosystem.

We aim to provide at least 300 megawatts (MW) of additional capacity in the near term, with potentially another 200MW and more through green energy deployments. Through the additional capacity, we aim to seed innovative ways to accelerate energy efficiency, as well as seed hybrid ways to unlock further capacity through green energy. To achieve this, we will partner the industry to push boundaries on two fronts:

1. Accelerate DCs' energy efficiency at hardware and software levels, and allow industry and end-users to put in place best-in-class technologies to maximise energy efficiency, capacity and economic potential; and
2. Accelerate DCs' use of green energy to expand capacity and explore how we can deploy this at scale to maximise opportunities for continued growth.

DC operators, in particular, are important catalysts for key partnerships – to bring together green efficiency and green energy solutioning partners to realise the broader goals of sustainable development. The DC ecosystem is multi-faceted, and we will facilitate an ecosystem view. The room for growth can be enlarged when key catalysts bring onboard partners on board, and everyone in the ecosystem plays a role.

This includes supporting industry-partnerships in delivering low-carbon energy sources. The green energy sources recognised will comprise bioenergy, fuel cells with carbon capture, and low-carbon hydrogen and ammonia, and vertical building integrated photovoltaics/building applied photovoltaics, fuel cells with carbon capture, and low-carbon hydrogen and ammonia for a start.

The DC ecosystem is multi-faceted, and we will facilitate an ecosystem view. The room for growth can be enlarged when key catalysts bring partners on board, and everyone in the ecosystem plays a role.

Incentives will also be provided to improve DC energy efficiency and facilitate enterprise end-users' upgrading to more efficient IT equipment, in line with the more frequent increased frequency of technology upgrades. We will also continue to bring in DCs with the best-in-class technologies for sustainability and economic value for Singapore. In addition, we will facilitate DCs to update and adopt energy-efficiency standards and forward-looking policies.

As we move into the next chapter of digital technology, we envision a dynamic DC industry with end-to-end ecosystem partnerships, which continues to serve global and regional business needs, while being at that the leading edge of sustainability.

This Roadmap is a living document, and we welcome the industry to continue partnering us on this pioneering journey to achieve sustainable growth and bring the ecosystem together to push boundaries and achieve sustainable growth.

Transformative Potential of Digital

Digitalisation has transformed the economy and society. The digital economy today contributes ~17% to Singapore's Gross Domestic Product (GDP) and is set to continue to grow strongly.

Singapore is also home to many international enterprises, which are increasingly serving the region and the world digitally. This builds on our position as a trusted business hub - with strong international connectivity (including international submarine cables), robust legal and intellectual property protection, supportive cross-border data flow policies, and a highly skilled tech talent workforce that serves international markets.

The democratisation of Artificial Intelligence (AI) through generative AI models since late 2022 has pushed boundaries and challenged traditional ways of work in industries, with the potential to revolutionise many sectors from healthcare to finance to media. Some analysts have projected that the generative AI market will exceed US$1 trillion by 2032.

Last year, we saw the launch of Singapore's National Artificial Intelligence Strategy (NAIS) 2.0. AI is emerging as a key potential driver of future growth. It also demonstrates Singapore's belief in AI for Public Good, and its transformational potential if done responsibly and sustainably, to benefit the economy and society.

The harnessing of AI, coupled with the advent of other macro-trends such as the increasing use of autonomous and robotic systems, immersive virtual interactions through higher bandwidth connectivity, are expected to propel demand for compute. These "tailwinds" of economic growth, generated here in Singapore, therefore support the requirement for a diverse mix of top-tier compute resources, to serve current and future needs.

Pioneering the Sustainable Growth of Data Centres

DCs provide a foundation for this growth, underpinning our digital services, operations, and transactions, as a digital-first Smart Nation, both domestically and internationally. Today, Singapore is a regional DC hub, with total capacity exceeding 1.4 gigawatts, and one of the highest concentrations of DCs in the region[1].

Demand for DC capacity here continues to grow strongly, as DCs tap on Singapore's broader international position as a business and digital hub. We will continue to build upon these foundations. This includes strengthening international connectivity by doubling the number of submarine-cable landings over the next 10 years, as announced in the Digital Connectivity Blueprint (DCB). There will also be continued emphasis on enabling cross border data flows, through our Digital Economy Agreements and work on harmonising international rules and norms. In addition, we will continue to expand our existing pool of tech talents and nurture a confident user base of enterprises and workers that harnesses the powers of digitalisation and AI.

Turning Constraints into Opportunities

DCs around the world are heavy users of power and water. Industry and governments worldwide are increasingly conscious that DCs cannot continue to grow in an unsustainable manner, without managing the resource footprint.

This is a global issue. Singapore's status as a compact city-state merely puts us at the forefront of these considerations. However, it also makes us uniquely positioned to innovate and pioneer solutions that may then be applicable internationally, to help address this global challenge of sustainable DC growth.

A key strength is that industry and government have worked closely over many years, to consistently push the boundaries for DCs' energy efficiency. Our Tropical DC standard – a world-first – enables DCs to save energy by running safely at higher temperatures and humidity levels. These complement and build on earlier standards such as the Green Data Centre Standard (SS 564)[2] and the Building and Construction Authority (BCA)-IMDA's Green Mark for DCs (GMDC)[3]. Efforts also include our pilot Data Centre Call for Application (DC-CFA), which piloted the ability to bring in new DCs that raised the bar for energy efficiency, while contributing strategic and economic value. These collectively support DCs to adopt best practices, on that continued path towards enhanced sustainability.

Case Study

Continuous Energy Efficiency Improvements in Existing DCs, Facilitated by GMDC

Equinix has constantly improved the efficiencies of its SG4 DC by introducing best practices, and using GMDC as a benchmark. These included increasing the chilled water supply temperature in a controlled and incremental manner; and reducing the Computer Room Air Handler (CRAH) unit fan speeds in data halls to match the requirements of the IT loads. Such practices enabled Equinix to achieve GMDC Platinum rating for SG4 in 2023, improving from the Gold Plus rating achieved during construction in 2020. Equinix continues to plan for further efficiency improvements to its SG4.

1. Singapore's operational DC capacity per capita exceeds that of Australia, China, Japan, Korea and the UK, and key DC markets in these countries such as Beijing, Hong Kong, Seoul, Sydney and Tokyo.
2. Published in 2011 and refreshed in 2020, SS 564 enables DC operators to systematically ensure energy efficiency and environmental sustainability in design, construction, and operation of DCs.
3. GMDC is a certification launched in 2012 and refreshed in 2019, to recognise DCs that meet energy efficiency and other sustainability criteria in these areas: energy efficiency, water efficiency, sustainable construction and management, indoor environment quality, and other green features.

The ability to make DCs green will open the path to continued and sustainable expansion of capacity. The DCB spelled out the ambition – to map a path for continued growth of Green DCs and push the sustainability envelope. This Roadmap, developed with inputs from the industry, charts out some of the key pathways for that continued growth. This journey of innovation however is also a mutual journey of exploration – as potential solutions and measures may be nascent. This is therefore reinforced by the shared commitment, through many years of close collaboration, by both the government and industry to work together to shape the ecosystem.

Taking an Ecosystem Approach

We aim to provide at least 300 megawatts (MW) of additional capacity in the near term, with potentially another 200MW and more through green energy deployments. Through the additional capacity, we aim to seed innovative ways to accelerate energy efficiency, as well as seed hybrid ways to unlock further capacity through green energy.

To achieve this, we will partner the industry to push boundaries and accelerate DC sustainability on two fronts:

1. **Accelerate DCs' energy efficiency at hardware and software levels**, and enable industry and end-users to put in place best-in-class technologies to maximise efficiency, capacity and economic potential; and
2. **Accelerate DCs' use of green energy to expand capacit**y and explore how we can deploy this at scale over time to maximise opportunities for continued DC growth.

The DC ecosystem is multi-faceted, encompassing players as diverse as suppliers of systems and equipment, sustainability solutions providers, enterprise end-users, energy suppliers and academia. DC operators, in particular, are important catalysts for key partnerships across this ecosystem – to bring together solutioning partners to realise the broader goal of sustainable development. **We will facilitate an ecosystem view, as the room for growth can be enlarged when key catalysts bring partners on board, and everyone in the ecosystem plays a role**.

This includes supporting industry-partnerships in accelerating energy efficiency at hardware and software levels as well as the use of green energy, through:

1. **Designing and Operating Energy-Efficient DCs**
   DC operators can work with equipment suppliers and solutions providers to ensure their facilities are configured and operated in an energy-efficient manner.
2. **Deploying Energy-Efficient Compute/IT Hardware Equipment and Using the Software Stack Efficiently**
   DC operators can nudge end-users on adopting or refreshing compute/IT equipment to the best-in-class energy-efficient hardware. This includes working with the software ecosystem, to ensure that the overall design is optimised across the stack.
3. **Delivering Green Energy Sources**
   DC operators and green energy suppliers can forge partnerships to create a virtuous cycle of demand and supply for green energy.
4. **Driving Innovation to Push Boundaries Further**
   DC operators can also work closely with academia to innovate in areas such as cooling technologies, green computing, and low-carbon energy.

Accelerate Energy Efficiency

A DC's energy efficiency improvement can be driven in several areas, in particular at the facility level and the compute/IT equipment level (which encompasses the full hardware and software stack).

Facility level efficiency refers to the efficiency of mechanical and electrical (M&E)[4] systems. A common and internationally used metric to measure DC facility energy efficiency is Power Usage Effectiveness (PUE)[5]. However, PUE alone is insufficient as it does not consider how efficiently the Compute/IT equipment consumes power per unit workload.

Compute/IT equipment energy efficiency refers to the efficiency of equipment such as servers (chips and memory) and networking that run the compute as well as the software that runs on the equipment. It optimises the overall energy consumption, with more compute delivered with the same amount of power consumed.

Improving Facility-Level Energy Efficiency

Energy efficiency can be improved by deploying energy-efficient systems and equipment, and optimising their configuration and operation. DCs with highly efficient systems can reduce M&E energy consumption to below 30% of the DC's energy consumption6. Current DC designs can achieve PUE performance of <1.3 at 100% IT load. We aim to uplift all DCs in Singapore to similarly achieve PUE <1.3 at 100% IT load over the next 10 years. This gives existing DCs sufficient time to plan for upgrades.

1. **Upgrade M&E Equipment**
   Simulations have shown that existing DCs can achieve 50% reduction in energy consumption of supporting infrastructure, with energy-efficient retrofits and upgrades for key equipment, e.g. chiller plants, uninterruptible power supplies and CRAHs. DCs with M&E systems nearing the end of their service life should consider facility refurbishments.

2. **Apply Tropical DC Methodology**
   Further PUE savings can be achieved by applying Tropical DC methodology that helps to safely raise the DC operating temperature for energy efficiency gains. A 2% to 5% cooling energy savings can be reaped for every 1°C increase in DC operating temperature.

Case Study

Applying Tropical DC Standard to Reap Energy Savings

Digital Realty adopted IMDA's new Tropical DC standard at one of its data halls in Singapore. Over four months, Digital Realty incrementally increased temperature set points at the data hall by 1°C, with the ultimate aim of increasing operating temperature in the hall to 26°C and above. Each temperature setpoint change was conducted with regular stringent checks and micro-calibrations by technical specialists and the facilities team. This ensured an optimal cooling environment, and that infrastructure and customer equipment in the data hall remained stable. At the end of these four months in October 2023, Digital Realty successfully increased the operating temperature in the data hall by 2°C and reduced its energy usage. Digital Realty plans to continue to push the temperature envelope with other end-users to operate even more sustainably.

4. Systems such as chillers, cooling towers, Uninterruptible Power Supply, generators, etc. that work together to ensure reliable and uninterrupted cooling and power supply to the compute/IT equipment.
5. PUE is an international measurement used to reflect the total power supplied to the DC versus the amount of power consumed by the core IT equipment.
6. A DC with PUE of 1.3 implies that M&E infrastructure consumes around 24% of the DC's energy consumption. Similarly, a DC with PUE from 1.5 to 2.0 implies that M&E infrastructure consumes around 33% to 50% of the DC's energy consumption.

3. Tailor Cooling Solutions to Meet DCs' Needs

The average server rack density in DCs has nearly quadrupled in the last decade from 2.4 kilowatts (kW)/rack in 2011 to 8.4kW/rack in 2020, reflecting the growth of compute-intensive workloads. This situation will be further aggravated with racks for AI workloads, which can require 20kW/rack to over 100kW/rack. While air-cooling can support up to 20kW racks, liquid cooling is needed for efficient cooling of racks operating at higher power densities. A variety of liquid-cooling technologies are available in the market with varying degrees of energy efficiency performance, cooling capacity, implementation and maintenance complexity to meet these needs:

- **Rear door heat exchanger** – passive/active heat exchangers replace the rear door of the compute/IT equipment rack with a liquid to air heat exchanger. The technology is more efficient than air-cooling and This solution can be retrofitted to existing server racks. No and no changes are required to be made to the standard compute/IT equipment which significantly eases the implementation;.
- **Direct to chip cooling** – cold plates sit atop the board's heat-generating components (central processing units (CPUs), graphics processing units (GPUs), memory modules) to remove the heat through liquid-filled cold plates. It offers highly efficient cooling at the source but requires some residual air-cooling and modifications to the compute/IT equipment hardware.
- **Immersion cooling** – servers and other components in the rack are submerged in a thermally conductive dielectric liquid or fluid. This approach is most energy-efficient as it eliminates the need for air-cooling, but requires specialised compute/IT equipment and facilities (horizontal immersion tank instead of vertical server rack).

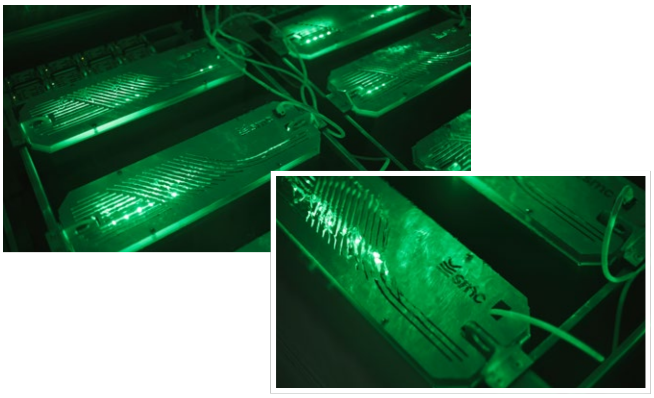
DCs should evaluate and deploy the most suitable cooling solution for their needs, taking into account factors such as rack density. A recent study published by the American Society of Mechanical Engineers on high-density DCs (when rack densities exceed 20kW) found that liquid cooling helps to reduce total DC energy consumption by 10% compared to fully air-cooled DCs. Some vendors estimate that immersion cooling may yield facility-level cooling energy savings as high as 90%.

Case Study

Deploying Advanced Immersion Cooling for High Power Density Racks to Achieve up to 50% Energy Savings

ST Telemedia Global Data Centres is collaborating with Firmus Technologies to host Sustainable Metal Cloud (SMC) in their facilities in Singapore. SMC is an AI cloud service which leverages immersion cooling to reduce the energy footprint of producing AI cloud services by up to 50% compared to traditional GPU cloud services available today. This is achieved by using single-phase immersion cooling, resulting in a partial PUE of less than 1.02, which is lower than other alternative cooling systems, and hence reduces the cost to operate GPU servers. In addition, the immersion cooling solution is designed in a modular fashion, which facilitates retrofitting or even deployment in unused grey space within an already built DC.

Row of immersion cooling tanks



Servers fully immersed in the liquid

4. Configure DCs to Support Diverse Cooling Solutions for Different Workloads

With the adoption of liquid cooling, DCs can transit from 100% air cooling to a hybrid model encompassing both air and liquid-cooled solutions. DCs can create zones within the data halls based on rack densities and provision the most efficient cooling accordingly, based on the chips/workloads deployed.

Case Study

Pushing the Envelope on Energy Efficiency

AirTrunk's new DC will implement liquid cooling and operate at elevated temperatures for air-cooled environments. To further improve overall cooling system efficiency, AirTrunk is implementing alternative heat rejection techniques, such as adiabatic coolers together with direct usage of condenser water for cooling. This eliminates the use of water-cooled chillers with cooling towers from the cooling circuit, and helps drive further energy savings.

5. Deploy Smart Energy Optimisation Tools

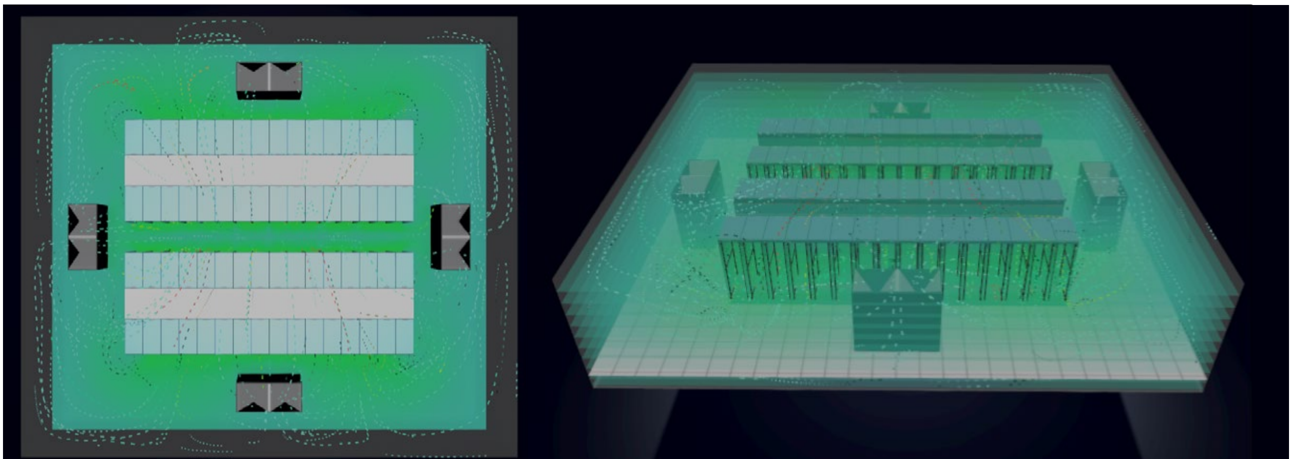
DCs can implement digital solutions that utilise sensors and digital twins to dynamically control and optimise M&E systems for energy efficiency.

- Digital twins can integrate real-time data on power consumption, temperature, and airflow, to provide a comprehensive view of a facility's energy usage, assess the status of the components, forecast potential issues, and run scenarios without disrupting the actual infrastructure. Operations managers can use this information to identify and rectify areas of inefficiency (e.g. under-utilised server racks or over-cooled spaces), ensuring high reliability and minimal downtime.

Case Study

Reaping Significant Operational Savings through Digital Twin Solutions

Red Dot Analytics (RDA) has developed digital twin solutions to help digitalise, optimise and automate DC operations and management for business and sustainability purposes. Iron Mountain Data Centers deployed RDA's DCVerse, an advanced AI–powered cognitive digital twin designed to optimise chiller plant and Computer Room Air Conditioning (CRAC) unit setpoints and enhance cooling efficiency in a risk-aware manner. This system uses real-time data, machine learning, and predictive analytics to recommend optimal control policies for the chiller plant and CRAC units in the data halls. Since adopting DCVerse, Iron Mountain Data Centers has managed to improve its PUE, saving over 200,000 kWh per month of average energy usage which translates to an estimated operational savings of close to S$900K annually.



Digital Twin of a data hall

Improving Compute/IT Equipment Energy Efficiency Across the Full Stack (Hardware and Software)

We aim for only energy-efficient compute/IT infrastructure to be used in all DCs in Singapore over the next 10 years. We will encourage end-users to further optimise the operation and utilisation of these equipment to right size their compute deployment and adopt carbon efficient sustainable software.

1. **Using Energy-Efficient Compute/IT Equipment**
   DCs and users of DCs should use energy-efficient compute/IT equipment, such as Energy Star certified equipment, or those compliant with the European Union's (EU) EcoDesign requirements. DCs can encourage or require their users to install energy-efficient compute/IT equipment especially during their server refresh cycles, typically every three to seven years, e.g. through their contractual terms.

2. **Operating Compute/IT Equipment Efficiently**
   Beyond procuring energy-efficient compute/IT equipment, it is also important that users of these equipment optimise the equipment power consumption during operations. Users can configure equipment to run efficiently by adopting the appropriate power settings (balancing between efficiency and performance) and enabling power management features such as dynamic control of equipment power.

3. **Optimising Server Utilisation**
   Compute/IT equipment users can also use virtualisation techniques to improve the utilisation of their server deployments. Coupled with workload consolidation, users can consolidate servers and reduce overall energy draw. These techniques can magnify efficiency gains when used with energy-efficient compute/IT equipment.

4. **Maximising Compute Utilisation Using Green cCmputing**
   Further energy efficiency can be achieved by optimising the software running on compute/IT equipment. IT users can leverage green software techniques like application modernisation and computational offload to reduce the computational demands of applications. This allows for more applications to run on the same hardware, maximising DC capacity.

5. **Carbon-Efficient Software Design**
   Software carbon intensity can be further reduced by monitoring detailed utilisation data like virtual CPU (vCPU), memory, and disk usage, to draw up a software "demand" profile that helps identify "carbon hotspots" within the software. Once identified, these hotspots can be addressed with targeted carbon reduction techniques to minimise carbon intensity.

Case Study

Facilitating Green Software Development

Microsoft and the Green Software Foundation worked with IMDA to develop digital sustainability guidelines for businesses and software developers to develop software that is sustainable by design. Launched in September 2023, the guidelines set out software sustainability principles and how they can be applied into software engineering and development processes, so that software is energy-efficient and carbon-aware. The guidelines also provide tools and solutions to help businesses and developers track, report and reduce carbon emissions or greenhouse gases created during the creation, running and maintenance of the software. IMDA will collaborate with industry partners to apply them in real-world applications.

Working Together

Improving energy efficiency requires collective effort. We are cognisant that this is no small undertaking. Hence, we will support the ecosystem to do so.

1. **Improve Facility-Level Energy Efficiency**
   We will help DC operators seeking to improve their DCs' facility-level energy efficiency, as well as those considering aggregating inefficient smaller DCs to one newer larger DC for scale and efficiencies. Such DC operators can tap on support schemes such as EDB's enhanced Resource Efficiency Grant for Emissions (REG(E)) and Investment Allowance for Emissions Reduction (IA(ER))[7].

2. **Improve Compute/IT Equipment Energy Efficiency**
   We will help DCs nudge enterprise end-users to install energy-efficient compute/IT equipment. Enterprise end-users will be able to tap on the new Energy Efficiency Grant for the DC sector by end-2024 to refresh to energy-efficient compute/IT equipment.

7. REG(E) aims to provide co-funding support corresponding to the level of emissions reduction, while IA(ER) grants a tax exemption on qualifying capital expenditure incurred, for eligible projects that result in measurable and verifiable carbon abatement. Refer to https://www.edb.gov.sg/en/our-industries/sustainability.html for more details.

Green Energy for Growth

Leveraging green (i.e. low-carbon) energy to power DCs, in addition to uplifting DCs' energy efficiency, is critical to enable continued sustainable growth in the longer term.

Many DC operators are keen to explore new and innovative low-carbon energy sources for our energy transition. There is potential for DC operators and energy suppliers to create a virtuous cycle of demand and supply for low-carbon energy. **Hence, we will facilitate the industry in pushing the boundaries to deliver low-carbon energy sources. The energy sources recognised will comprise bioenergy, fuel cells with carbon capture, low-carbon hydrogen and ammonia, and vertical building integrated photovoltaics/building applied photovoltaics for a start**.

We will structure our future capacity allocation exercises to seek proposals from DC operators on using viable low-carbon energy sources, on top of having to offer best-in-class solutions for lowering PUE and achieving IT energy efficiencies. We will provide operating parameters for such low-carbon energy sources in partnership with other agencies[8].

8. Such as the Ministry of Trade and Industry and Energy Market Authority.

Drive Further Innovation

It is imperative to push on with active research and development (R&D) in concert with players across the DC ecosystem.

We will therefore drive efforts to create innovations that provide commercial value and enable us to reap sustainability dividends, such as the following:

1. **The Sustainable Tropical Data Centre Testbed (STDCT)**
   The STDCT R&D programme by the National University of Singapore (NUS) and the Nanyang Technological University (NTU). This 500kW industry testbed facility at NUS was launched in 2023 to facilitate co-development and piloting of innovative cooling technologies with industry. It is driving research into innovations in cooling technologies, such as desiccant-coated heat exchangers with high heat and mass transfer efficiency, unibody heat sinks to avoid single point of failure and leakage issues for immersion cooling solutions.

2. **IMDA's Green Computing Funding Initiative (GCFI)**
   Launched in Jan 2024, GCFI aims to promote sustainable practices and efficient use of computing resources in the information and communications technology sector to complement efforts to 'green' digital infrastructure like DCs. This is in recognition that reducing the carbon emissions from computing and software is increasingly key with growing use of technologies like AI. GCFI will allocate S$30 million to encourage research around optimising software design and function for energy efficiency. It will focus on use cases currently unmet by commercial solutions, and will invite researchers and industry players to co-develop low-carbon digital solutions.

3. **IMDA's Green Software Development**
   IMDA is also supporting green software trials to make the software stack more energy-efficient. These trials enable industry to test and understand how carbon reduction techniques, such as better resource distribution across servers, apps and workloads, AI model optimisation, and computational offload, can reduce energy use and IT costs. Data and insights will be used to create guidelines for developing green software.

4. **Low Carbon Energy Research (LCER)**
   The LCER programme was launched in 2021 to develop low-carbon energy technologies in the domains of hydrogen and carbon capture, utilisation and storage, to support decarbonisation of the power and industry sectors. A total of S$110 million has been awarded to support 28 projects across two phases since 2021.

Anchoring Best in Class DCs

We will continue to bring in DCs with the best-in-class technologies for sustainability and economic value for Singapore.

The pilot DC-CFA attracted proposals on building DCs that are sustainable, strengthened Singapore's position as a regional hub and supported broader economic objectives. We will continue to seek such best-in-class DCs through future allocation exercises.

We will facilitate DCs to update and adopt energy-efficiency standards and implement forward-looking policies. This includes co-developing with industry enhanced energy-efficiency standards and certifications:

1. Refreshing GMDC by end-2024, in partnership with BCA, to raise the standards for energy efficiency in DCs.
2. Introducing compute/IT equipment energy efficiency and liquid cooling standards by 2025 to facilitate adoption.

We will also update our policies to support DCs to be sustainable, referencing international moves, standards, and best practices.

Water Efficiency

Besides energy, water is another significant resource used by DCs. The DC sector's demand for water is expected to increase. Hence, it is increasingly important for DCs to manage their water consumption efficiently.

1. Water Usage Effectiveness (WUE)[9] is a commonly-used metric for the efficiency of water consumption in relation to the IT workloads carried out by DCs. In 2021, the median WUE of DCs in Singapore that were large water users (i.e. with net water consumption of at least 60,000 m^3 in the previous year) was 2.2 m^3/MWh.
2. There is increased industry awareness on water efficiency management practices. Several operators have started monitoring their water consumption, with some going further to disclose their WUE data in their annual Environmental, Social and Governance reports.

We will work with the Public Utilities Board (PUB) to facilitate new and existing DCs to achieve WUE of 2.0 m^3/MWh or lower over the next 10 years, through:

1. Optimising Cooling Towers' Water Consumption

Cooling towers offer significant potential to improve WUE, as they account for up to 97% of a DC's water usage. DCs can adopt water efficiency plans to ensure that water is used efficiently for their cooling needs. DCs can also reduce water consumption by recycling blowdown water in their cooling towers, and increasing cycles of concentration (CoC)[10] through applying technologies such as electrolysis to clean cooling water.

Case Study

Improving Water Efficiency through Innovation

Hydroleap and Amazon Web Services (AWS) installed Hydroleap's electrooxidation technology to improve water efficiency for AWS' DC in Singapore. The technology increases the rate of water circularity and reduces make-up water consumption, which has helped AWS to meet its water efficiency goals. It also contributed to AWS being awarded PUB's Singapore Watermark and Singapore Water Efficiency Awards in recognition of its water sustainability efforts in Singapore. AWS intends to scale this technology to its other Asia Pacific DCs.

2. Support for Water Efficiency

DCs can work closely with PUB to implement best practices and water efficiency initiatives.

- PUB supports DCs to provideachieve water efficiency through providing guidance on best water practices to individual DCs, and supportfacilitates implementation of water efficiency initiatives under the Water Efficiency Fund[11].
- DCs with water consumption of at least 60,000 m^3 per year are also required to comply with PUB's Mandatory Water Efficiency Management Practices, including installing private water meters at key areas to track water usage, and submitting a Water Efficiency Plan to PUB.

9. WUE is calculated by taking the ratio of total DC water consumption and energy consumption of DC compute/IT equipment (m^3/MWh). Lower WUE indicates higher water efficiency. For example, DCs with WUE less than 0.2 m^3/MWh consume less than a glass of water for every MWh of energy used by compute/IT equipment.
10. CoC measures the ratio of the volume of water supplied to the cooling tower to the volume of blowdown water (fresh water used to replace water infused with minerals in cooling towers). The higher the CoC, the less fresh water is consumed from replacement.
11. PUB launched the Water Efficiency Fund in 2007 to encourage organisations to seek out efficient and innovative ways to manage their water demand. Refer to www.pub.gov.sg for more details.

Conclusion

As we move into the next chapter of digital technology, we envision a dynamic DC industry with end-to-end ecosystem partnerships, which continues to serve global and regional business needs, while being at that leading edge of sustainability.

This Roadmap is a living document, to guide further engagements with the industry. We welcome industry to continue partnering us, on this pioneering journey – to achieve a more sustainable growth and bring the ecosystem together to push boundaries.

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