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Promoting Energy Efficient and Resilient Data Centres in the APEC Region

APEC Energy Working Group

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The APEC Workshop on Promoting Energy Efficient, Resilient and Green Data Centres was held on 28-29 June 2022 in Hong Kong, China. More than 100 delegates and experts from six APEC member economies attended the workshop to exchange views on the best practices, challenges and the application of innovative technology in data centres. We would like to thank you for the support from the speakers, experts and participants.

Contents

1. Project Background

In the 2011 APEC Economic Leaders' Declaration, APEC Ministers and Leaders agreed to reduce APEC's aggregate energy intensity by 45% from 2005 levels by 2035. At the 2014 APEC Leaders' Meeting, Leaders endorsed an aspirational goal to double the share of renewable energy in APEC's overall energy mix by 2030 (over 2010 levels) and increase cooperation to achieve it. Amid the COVID-19 pandemic, International Energy Agency Data Centres and Data Transmission Networks revealed that global internet traffic surged by almost 40% between February and mid-April 2020 during the COVID-19 containment measures, driven by growth in video streaming, video conferencing, online gaming, and social networking. This growth comes on top of the rising demand for digital services over the past decade since 2010. The number of internet users worldwide has doubled while global internet traffic has grown around 30% per year. However, rapid improvements in energy efficiency have helped limit energy demand growth from data centres and data transmission networks, which accounted for around 1% of global electricity use in 2019. Demand for data and digital services is expected to continue its growth exponentially over the coming years. The data and digital services are driving the APEC member economies to a transformational "Digital Economy". Hong Kong, China buttressed New Zealand's Policy Priorities for APEC 2021 on "Increasing inclusion and sustainability recovery" and "Pursuing innovation and a digitally-enabled recovery" in mitigating the impacts of COVID-19 by conducting this project to promote energy-efficient, resilient, and data centres in the APEC region.

This project aimed to analyse the energy-efficient, resilient, and green data centre guidelines, standards and certification schemes, and emerging innovative technologies and policies to progress towards energy efficiency and resilience improvements and transition to renewable energy. This report is to serve as a reference for APEC member economies to boost energy efficiency and resilience in new data centres installations and existing data centres operation and retrofits for combatting climate change and reaching net zero by 2050.

The objectives of this project were:

(1) to capacity build by studying and sharing the best practices, standards, certification schemes, and guidelines for improving energy efficiency and resilience and powering by new and renewable energy in the planning of new data centres and retrofitting existing data centres;

(2) to collaborate with policymakers, experts, academia, international data centre and energy organisations in promoting sustainable and resilient data centres for driving the COVID-19 economy recovery and combating climate change and reaching net zero in 2050; and

(3) to publish a report that aims to disseminate the best practices of data centre operations to promote resilient, energy efficiency, and new and renewable energy technologies in data centres for transforming into green, sustainable, energy-efficient, and resilient data centres to progress towards Digital Economy.

2. Introduction

2.1. What is Data Centre?

In this project, a data centre is an infrastructure to house an organisation's information technology (IT) operations and network telecommunications equipment for data storage, processing, dissemination, and applications. In a data centre, consumable energy items include IT equipment (e.g. server, network switch, communication network, storage devices) and electrical and mechanical facilities (e.g. cooling/heating, ventilation, security, lighting, vertical transportation, power subsystems, uninterruptible power supplies). A data centre can be on-site or off-site for a company. The company may opt for a colocation off-site data centre by recruiting a service provider to operate with a leasing server and network.

2.2. Trend of data centre development and energy consumption

Advancements in IT industries and applications (e.g. live broadcast, cloud computing meta-universe) have led to a continuous surge of data traffic. It is expected that by 2025, more than a quarter of global data transmission will be real-time, and real-time internet of things (IoT) data will account for more than 95% of the global data [1]. According to Cisco Annual Internet Report (2018-2023) [2], there will be 3.1 billion internet users in the Asia-Pacific region (72% of the regional population) by 2023, i.e. a 20% increase from 2.1 billion in 2018 (52% of the regional population). In the meantime, the average internet speed will also increase by around three times. Additionally, the surge in data storage demand caused by the pandemic drives the total net power consumption of data centres in Japan; Australia; Singapore and Hong Kong, China to reach 322 MW in 2020, which was twice that in 2019. In 2020, the transaction volume of data centre assets reached a five-year high of 2.2 billion U.S. dollars. In 2021, platform formations and merger and acquisition (M&A) transactions of data centres continued to thrive.

The data centre business attracted investments of more than $5 billion U.S. dollars from financing platforms and joint ventures [3].

The data centre industry is becoming one of the largest energy consumers in the world. Referring to IEA's report [4], data centres share 1% of the global final electricity demand in 2020 of 200-250 TWh. According to the United States Data Centre Energy Usage Report [5], the energy consumption of data centres in the United States was 70 billion kWh (1.8% of the economy's total energy consumption) in 2014 and was increased at an annual rate of 0.787% on average in the past five years.

The enormous energy consumption of data centres has resulted in a high level of CO_2 emissions comparable to those caused by aviation [6]. Against this background, there is a critical need for resilient, highly efficient and low-carbon emitting data centres to support the sustainable and green economic growth of APEC regions.

3. Summary of Energy Efficient and Resilience Data Centre Guidelines and Standards, and Certification Schemes

3.1. Guidelines and Standards

3.1.1. The American Society of Heating, Refrigerating and Air-Conditioning Engineers

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) published two standards and the Datacom Series [8]. The Standards and Datacom Series provide comprehensive guidelines and information on air conditioning systems, IT equipment, energy efficiency and general requirements of data centres. The list of standards for ASHRAE related to the data centre is as below.

(i) ANSI/ASHRAE Standard 90.4-2019 (Energy Standard for Data Centres) [7]
(ii) ANSI/ASHRAE Standard 127-2020 (Method of Testing for Rating Air-Conditioning Units Serving Data Centre (DC) and Other Information Technology Equipment (ITE) Spaces)
(iii) ASHRAE Datacom Series - Thermal Guidelines for Data Processing Environments
(iv) ASHRAE Datacom Series - IT Equipment Power Trends
(v) ASHRAE Datacom Series - Design Considerations for Datacom Equipment Centres

(vi) ASHRAE Datacom Series - Liquid Cooling Guidelines for Datacom Equipment Centres

(vii) ASHRAE Datacom Series - Structural and Vibration Guidelines for Datacom Equipment Centres

(viii) ASHRAE Datacom Series - Best Practices for Datacom Facility Energy Efficiency

(ix) ASHRAE Datacom Series - High Density Data Centres - Case Studies and Best Practices

(x) ASHRAE Datacom Series - Particulate and Gaseous Contamination in Datacom Environments

(xi) ASHRAE Datacom Series - Real-Time Energy Consumption Measurements in Data Centres

(xii) ASHRAE Datacom Series - Green Tips for Data Centres

(xiii) ASHRAE Datacom Series - PUETM: A Comprehensive Examination of the Metric

(xiv) ASHRAE Datacom Series - Server Efficiency – Metrics for Computer Servers and Storage

(xv) ASHRAE Datacom Series - IT Equipment Design Impact on Data Centre Solutions

(xvi) ASHRAE Datacom Series - Advancing DCIM with IT Equipment Integration

3.1.2. International Standards Organisation

There are two standards from the International Standards Organisation (ISO) for the data centre – (1) ISO/IEC 30134 Data Centres − Key Performance Indicators and (2) ISO/IEC TS 22237: Information technology–Data centre facilities and infrastructures.

International Standards Organisation (ISO) and International Electrotechnical Commission (IEC) jointly published "ISO/IEC 30134 Data centres − Key performance indicators". The standard covers the definition and calculation methods of nine Key performance indicators (KPIs), such as Power Usage Effectiveness (PUE), Renewable Energy Factor (RES), Energy Reuse Factor (ERF), Cooling Efficiency Ratio (CER), Carbon Usage Effectiveness (CUE), and Water Usage Effectiveness (WUE). IT equipment energy efficiency and utilisation are covered in this standard. These KPIs are presented in numeric values (with units where applicable) and can be traced against time in the graphical form.

The ISO/IEC TS 22237: Information technology–Data centre facilities and infrastructures is a series of technical specifications with seven parts. These specifications are based on the

EN50600 and provide suggestions on operations and management, security, and energy and sustainability management.

3.1.3. CENELEC's EN50600: Data Centre Facilities and Infrastructures Standards

EN50600 is a European data centre standard developed by the European Committee for Electrotechnical Standardisation (CENELEC) for new data centres. It includes requirements on the availability of power, cooling and telecommunication infrastructure, with four sections: overview, design, operation and management and key performance indicators. The CLC/TR 50600-99-1 and 2 provide recommended practices on energy management and environmental sustainability.

3.1.4. Standards from APEC member economies

Regarding the design and operation guides of data centres for different economies, the level of energy efficiency is usually certified under the commercial building category of the Green Building Standard for many APEC member economies. Two APEC member economies are observed with standards or guidelines dedicated to the data centre – (1) China and (2) Hong Kong, China.

3.1.4.1. China

(i) GB50174-2017: Code for Design of Data Centres

This code covered 11 areas in the design of data centres: rating classification and required features for data centres; site selection and equipment layout; environmental requirement; building structure; air conditioning; electrical systems; electromagnetic shielding; network and cabling system; intelligent system; water supply and drainage; fire protection and security. The code defines three classes of the data centre according to the nature of data centre use and the economic or social losses caused by network interruption. It provides guidelines on the 11 areas of these three classes of data centres.

(ii) GB/T 32910.1 to GB/T 32910.4 for Data Centre

This is a series of territory-wide technical guides with four parts - terminology, setting requirements for key performance indicators, electric energy usage effectiveness requirements and measuring methods and the renewable energy factor.

3.1.4.2. Hong Kong, China

Green Data Centres Practice Guide Version 1.0

The Green Data Centres Practice Guide aims to provide the best practices, assist industry practitioners in identifying and implementing measures, and improve the energy efficiency and environmental performance of data centres. The Green Data Centres Practice Guide lists best practices and options for relevant stakeholders to plan, design, construct, manage and operate green and sustainable data centres. It includes a list of metrics to measure the energy and sustainability efficiency of data centres and identify potential areas for improvement. The best practices are categorised into ten major areas, including general aspects, cooling system, power system, monitoring and managing energy efficiency, IT equipment deployment, IT application system and IT service deployment, telecommunications and network cabling, green construction, management and maintenance and green disposal.

3.2. Certification Schemes

3.2.1. LEED BD+C: Data Centres and O+M: Data Centres

Leadership in Energy and Environmental Design (LEED), developed by the US Green Building Council, is a voluntary set of rating systems that covers both new and existing buildings. LEED provides a framework for healthy, efficient, carbon and cost-saving green buildings. LEED certification is globally adopted. LEED certification is globally adopted. LEED includes rating systems for both building design and construction (named LEED BD+C: Data Centres [9]), as well as the operations and maintenance (named LEED O+M: Data Centres [10]) of data centres.

3.2.2. Certified Energy Efficient Data Centre Award

The Certified Energy Efficient Data Centre Award (CEEDA) [12] is a three-grading certification program for assessing the energy efficiency achievement of data centres. The program refers to other standards, including ASHRAE, Energy Star, ETSI, ISO, European Code of Conduct and Green Grid metrics. CEEDA covers the data centres of different ownerships and facility types, such as colocation, enterprise, telco, and design and operation stages.

3.2.3. Building Research Establishment Environmental Assessment Method (BREEAM)

BREEAM [13] is an assessment method for master planning projects, infrastructure and buildings. It recognises and reflects the value in higher performing assets across the built environment lifecycle, from new construction to in-use and refurbishment. In 2019 [14], the BREEAM Data Centres Annex Pilot was released to assess and improve data centres' sustainability and environmental performance. The BREEAM Data Centres Annex combines elements of the EN 50600 series of standards and covers water stewardship, building management, materials and ecology. This annexe applies to facilities with operator is responsible for the design, construction and operation of the facilities. This might not be appropriate for customers and service providers of co-location data centres.

3.2.4. National Australian Built Environment Rating System for Data Centres

The National Australian Built Environment Rating System (NABERS) is a performance-based rating system in Australia. The NABERS for data centres [15] was launched in 2014 and applies to tenancy, co-location and enterprise data centre with a certain level of energy consumption. The rating system measured the energy efficiency and environmental impact of data centres. Higher ratings under NABERS Energy connote lower greenhouse gas emission levels from the rated data centre. The NABERS Energy for data centres defines data centres and terminologies related to the assessment.

3.2.5. Green Mark for Data Centres

The Green Mark certification scheme was launched in January 2005 in Singapore. It is a green building rating system designed to evaluate a building's environmental impact and performance. It provides a comprehensive framework for assessing the overall environmental performance of new and existing buildings to promote sustainable design and best practices in building construction and operations. The Green Mark Scheme (Green Mark) for Data Centres [16] is launched by the Building and Construction Authority (BCA) and Infocomm Media Development Authority (IMDA) in Singapore. The scheme recognises data centre operators who have successfully deployed Green Data Centre best practices with demonstrated energy and environmental performance. The Green Mark Scheme for Data Centres comprises a rating system which enables data centres to benchmark their degree of greenness, thus encouraging operators to the improvement of energy efficiency of data centres.

3.2.6. ENERGY STAR Score for Data Centres

The ENERGY STAR Score for Data Centres [17] applies to data centres for the assessment of the energy performance of a building relative to its peers. ENERGY STAR is widely adopted in the United States and Canada. The assessment includes three main parts,

(i) Identifying the aspects of building activity that are significant drivers of energy use,
(ii) Normalising the factors, and
(iii) Performing statistical analysis of the peer-building population.

3.2.7. GB40879-2021 - Maximum Allowable Values of Energy Efficiency and Energy Efficiency Grades for Data Centres

GB40879-2021 - Maximum Allowable Values of Energy Efficiency and Energy Efficiency Grades for Data Centres is a domestic standard implemented in 2022 for energy efficiency assessment and grading data centres in China. This standard applies to new, reconstructed and expanded data centres. The standard provides related technical requirements, tests and calculation methods. The grading is divided into three levels, i.e. level 1 represents the highest energy efficiency level with PUE at or below 1.2 and level 3 represents the worst and with a PUE at or below 1.5.

3.2.8. BEAM Plus New Data Centres Version 1.0 and **BEAM Plus Existing Data Centres Version 1.0**

The Building Environmental Assessment Method (BEAM) Society Limited has launched two schemes for the assessment of energy efficiency and green performance of data centres. The two schemes are assessment tools that are tailor-made for data centres. The tools consider the local climate, ecological environment and actual conditions in Hong Kong, China. The assessment comprises ten essential aspects, including Energy Use, Management, Integrated Design and Construction Management, etc. The two schemes are as below.

(i) The BEAM Plus New Data Centres Version 1.0 (NDC V1.0) is designed to be user-friendly and comprehensive by including references to local and global industry green practices on energy consumption and efficiency of data centre facilities and IT equipment of the new data centre.
(ii) The BEAM Plus Existing Data Centres Version 1.0 (EDC V1.0) is practical, transparent and standardised in defining the key elements of green data centre, including management, use of materials and waste recycling practice, energy efficiency, water consumption, health and wellbeing, etc.

4. Challenges and Opportunities towards Better Energy Efficiency and Resilience Data Centre

4.1. Energy Efficiency

Figure 1 illustrates the general composition of the power consumption of a data centre [62]. Air conditioning systems and IT equipment are substantial sources of energy consumption. In many economies, the energy efficiency requirement of a data centre follows those of commercial or industrial buildings and is subject to the building type. Similar to commercial buildings, the energy consumption of the air conditioning system has been monitored for years and paid many efforts in approving its efficiency. However, for a data centre, energy efficiency is also affected by IT equipment and network architecture [63].

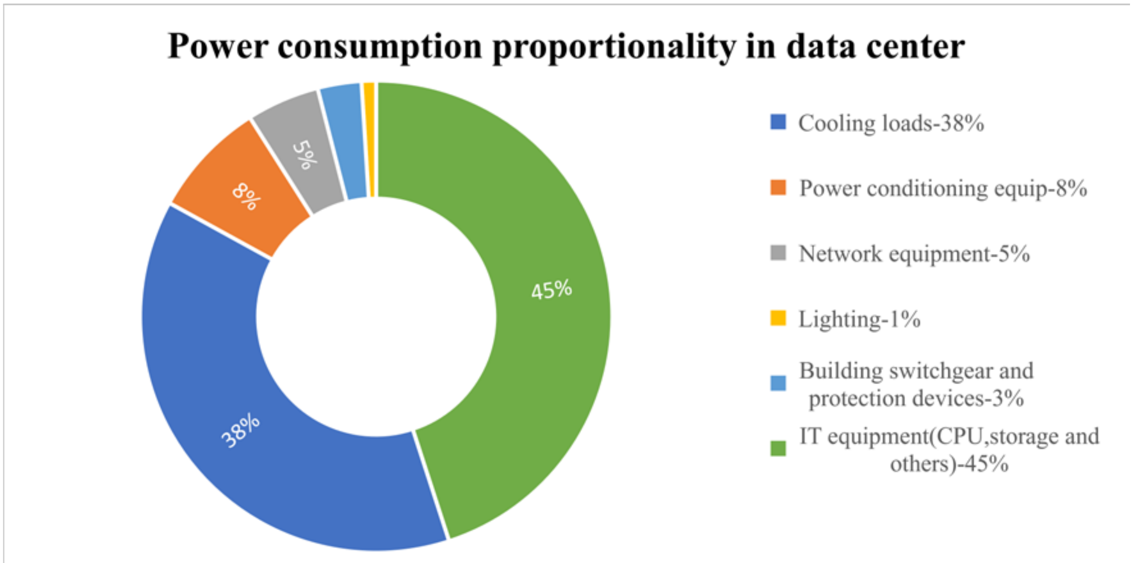

Figure 1. General power consumption breakdown in the data centre

4.2. Energy Resilience

Power outage is one of the business concerns in a data centre. Unexpected downtime may result in significant losses to companies owning the data centre. Apart from diesel or gas generators, the uninterrupted power supply (UPS) is used as a power backup to supply critical equipment during a power outage. Also, microgrids provide data centres with innovative architecture by integrating intelligent controls and multiple energy resources to improve the system flexibility for data centres.

5. The Importance of Energy Data Collection and Analysis and Templates

5.1. Energy efficiency metrics of data centres

To give a systematic review of the energy efficiency improvement technologies, Table I summarises the efficiency evaluation criteria for data centres.

TABLE I ENERGY EFFICIENCY METRICS AND BENCHMARK VALUES OF DATA CENTRE

			Standard Good Better
The Green Grid[19]	PUE	$PUE=\frac{P_{total}}{P_{IT}}=\frac{P_{IT}+P_{cooling}+P_{other}}{P_{IT}}$	**2.0 1.4 1.1**
The Green Grid	DCiE	$DCiE=\frac{P_{IT}}{P_{total}}=\frac{P_{IT}}{P_{IT}+P_{cooling}+P_{other}}=\frac{1}{PUE}$	**0.5 0.7 0.9**
Green IT Promotion Council [20]	DPPE	$DPPE=\frac{DC\ Work}{DC\ Energy-Green\ Energy}$	**NA**
FEMP[21]	HVAC System Effectiveness	$HVAC\ Effectiveness=\frac{Annual\ IT\ Equipment\ Energy}{Annual\ HVAC\ System\ Energy}$	**0.7 1.4 2.5**
FEMP	Airflow Efficiency	$Airflow\ Efficiency=\frac{Total\ Fan\ Power}{Total\ Fan\ Airflow}$	**1.25 0.75 0.5 w/cfm w/cfm w/cfm**
FEMP	Cooling System Efficiency	$Cooling\ System\ Efficiency=\frac{P_{Average\ Cooling\ System}}{Average\ Cooling\ Load}$	**1.1 0.8 0.6 kW/ton kW/ton kW/ton**
Herrlin et al	RCI	$RCI_{HI}=[1-\frac{\sum(T_x-T_{\max-rec})}{(T_{\max-all}-T_{\max-rec})n}]\times100\%,T_x>T_{\max-rec}$ $RCI_{LO}=[1-\frac{\sum(T_{\min-rec}-T_x)}{(T_{\min-rec}-T_{\min-all})n}]\times100\%,T_x<T_{\min-rec}$	**≥90% ≥93% ≥95%**
The Green Grid	CUE	$CUE=\frac{Total\ CO_2\ emission\ caused\ by\ the\ Total\ Center\ Energy}{IT\ Equipment\ Energy}$	**NA**

Source: The Green Grid Association, Green IT Promotion Council, Federal Energy Management Program (FEMP)

5.1.1. Power Usage Efficiency (PUE)

The Green Grid Association [19] introduced a metric named Power Usage Efficiency (PUE). PUE is the ratio of IT equipment power to the total data centre power consumption. IT equipment energy includes the energy associated with all the IT equipment (i.e. computation, storage, and network equipment) and auxiliary equipment (i.e. switches, monitors, and workstations/laptops used to monitor or otherwise control the data centre). The total power consumption of a data centre is IT equipment and other facility systems. The examples of facility systems are as below.

- Power delivery components, such as the Uninterrupted Power Supply (UPS), switchgear, generators, Power Distribution Units (PDUs), batteries;
- Cooling system components, such as chillers, computer room air conditioning units, direct expansion air handler units, pumps, and cooling towers; and
- Miscellaneous component loads, such as data centre lightings.

PUE focuses on the proportion of energy consumption and the reduction of unnecessary energy consumption that is conducive to the energy saving of data centres. For example, the smaller the PUE value, the more concentrated the energy consumption of the data centre is on IT equipment and the higher the energy utilisation efficiency of the data centre. Theoretically, an ideal PUE value is 1.0. The PUE is a general metric focusing on the prevailing energy distribution of respective data centre infrastructures. Although the specific type of energy efficiency of the core IT equipment is not considered [22], PUE is a clear and convenient metric for regulatory authorities to scrutinise the energy efficiencies of data centres and accordingly give warnings to those with low efficiencies. They can also help the operators of data centres to identify any measures needed to enhance energy efficiency.

Referring to research from Uptime Institute [23], the global average annual PUE was 1.57 in 2021, which is slightly lower than 2020's report of 1.59 and means that the function of data centre facilities has increased its energy use by nearly 60%. Figure 2 shows the statistics of the average PUE value of the world data centre of the agency in recent years. As observed in Figure 2, the average PUE value has remained relatively stable over the past five years after a substantial increase in efficiency in the first half of the 2010s.

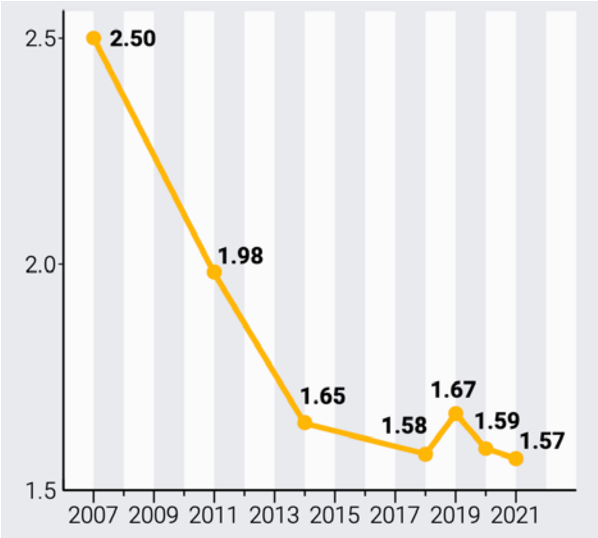

Figure 2 Average PUE value

Source: Uptime Institute [23]

5.1.2. Datacentre Performance Per Energy (DPPE)

The Datacentre Performance Per Energy (DPPE) [20] evaluates the actual data centre work production per carbon energy. DPPE is the ratio between the effective data centre workload and the non-green energy consumption. The higher the DPPE value is, the better the carbon performance and the higher the energy efficiency of the data centre.

DPPE includes tracking the carbon footprint. The increase in the DPPE value means the carbon footprint is reduced while its performance is improved. A comprehensive data centre assessment over a period can provide a better evaluation to demonstrate higher productivity by calculating DPPE, and this benefits policymaker. Still, the operation cost may increase due to the complex data required for measuring and calculating the DPPE.

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5.1.3. Metrics related to the air conditioning system efficiency

There are four metrics related to the air conditioning system efficiency.

(i) The Efficiency of the Heating, Ventilation and Air-Conditioning (HVAC) system is a metric for evaluating the ratio of IT equipment energy over the HVAC system energy. Under a fixed amount of IT equipment energy, a lower HVAC system efficiency corresponds to a relatively high HVAC system energy.

(ii) The airflow efficiency characterises overall airflow efficiency in terms of the total fan power required per unit of airflow. This metric provides a comprehensive measure of the air conditioning system efficiency in a data centre from the supply side to the return side. It takes the pressure drop and the fan system efficiency into account.

(iii) Cooling system efficiency is a metric to evaluate the efficiency of a data centre. As shown in TABLE I (in Section 5.1), an efficiency of 0.8 kW/ton can be generally considered a good practice, while an efficiency of 0.6 kW/ton is a preferred benchmark value.

(iv) Herrlin et al. [24] proposed a new metric of Rack Cooling Index (RCI), which measures the efficiency of cooling and maintenance of equipment racks within industry temperature guidelines and standards. The RCI considered several indicators for the energy utilisation efficiency of specific components within the data centre. They are crucial to informing operators of the need to optimise the internal structure of the data centre for higher energy utilisation.

5.1.4. Carbon Usage Effectiveness (CUE)

The limitation of carbon emissions is an essential dimension in data centre assessments. The Green Grid introduced Carbon Usage Effectiveness (CUE) [25]. It measures the carbon footprint of a data centre and is the ratio of carbon dioxide emissions caused by the total data centre's energy divided by the IT equipment’s energy. CUE depends on the amount and source of energy used by the data centre. The ideal value of CUE is 0, which means the energy sources of the data centre are zero carbon, e.g., the energy applied by renewable energy for the operation of a data centre. This metric provides a quantifiable standard for the measurement of the sustainability of a data centre and comparison between similar data centres.

5.2. Energy data collection of data centres

Energy data of existing data centres should be collected and monitored to enhance the energy efficiency of data centres and reduce unnecessary power loss. Analysis of these energy data would be helpful for a better understanding of the energy consumption patterns for data centres. These energy consumption patterns would also help to evaluate and improve the current control and operation strategies for data centres, as well as facilitate the design of novel energy-efficient data centres.

An energy survey of a data centre is a kind of energy data collection to understand the energy consumption pattern of a particular sector or segment. Based on the energy survey, industry stakeholders can identify the potential for energy conservation. Referring to the energy survey of the data centre carried out in Hong Kong, China, four types of data should be collected during the energy survey, listed below as a template for the energy data collection of data centres.

- General information, including company information, building information and premises information.
- Equipment information, including air conditioning arrangement, number of lighting fittings, IT equipment information, locations, and areas.
- Operational information, including operating hours and number of staff.
- Annual energy consumption, including IT, facility, and end-use load.

5.3. Energy data analysis of data centres

Detailed energy data analysis of data centres and energy modelling are essential to energy-efficiency and resilience schemes, including:

(i) Design of data centre systems: Establishing power models is necessary for the design of components and systems since it is unfeasible to build physical systems to test the effect of design choices on power consumption [36]. For example, Berge et al. [38] used the physical system approach for the Data Centre Efficiency Building Blocks.

(ii) Forecasting the trends in energy efficiency

(iii) Energy consumption optimisation

(iv) Energy resilience study: Analysing the energy resilience of individual data centres can be made by modelling the power flow. Figure 4 shows the power flow in a typical data centre. Not only the demand side, the power supply by the electricity, diesel, gas and renewables shall also be input to the model for matching of supply and demand pattern to review the resilience level of the data centre.

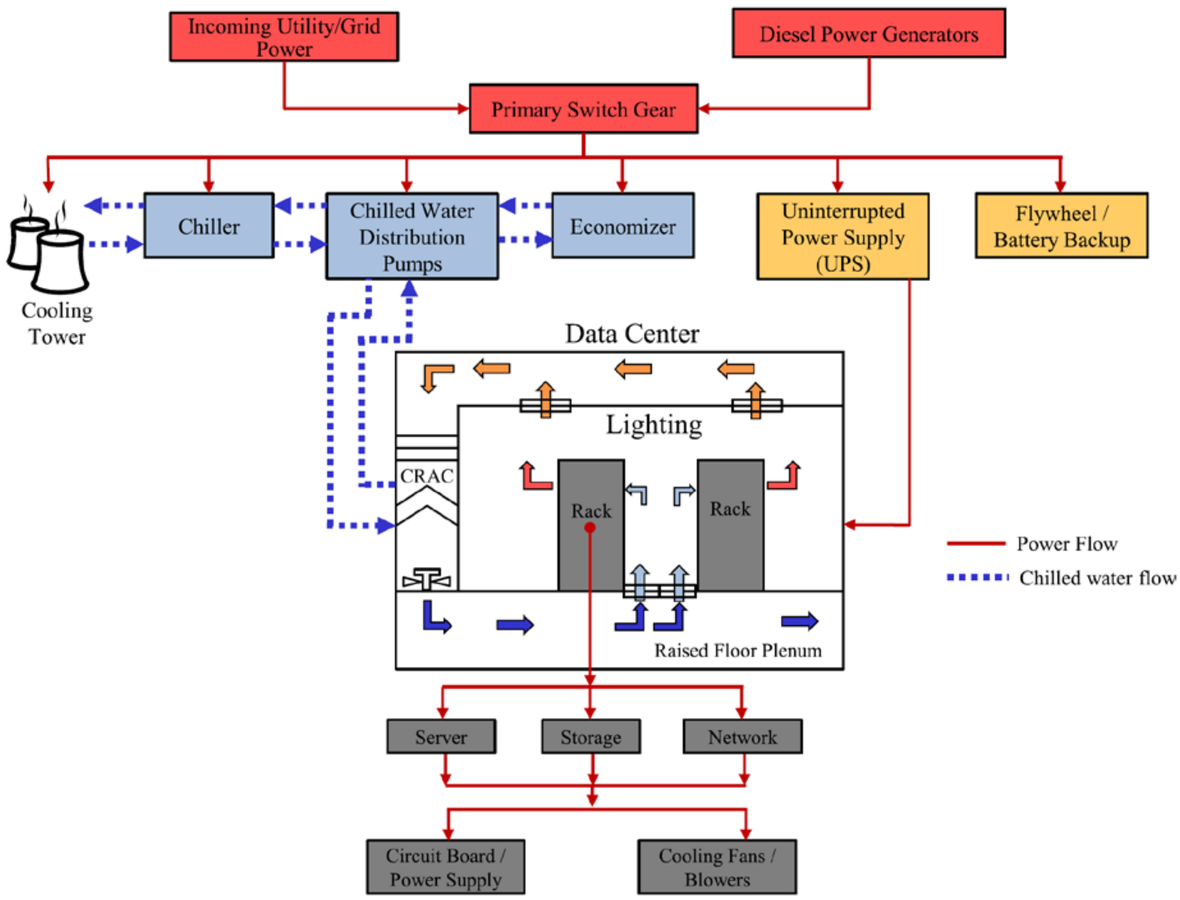

Figure 4. Power flow in a typical data centre [41].

5.3.1. Cooling system's energy model

The cooling system is designed based on the thermal model. A large amount of heat is generated when the data centre is working, and high temperatures will degrade the efficiency of the equipment or even damage the equipment. Commonly, there are two ways to cool the data centres down. One is the physical method, i.e., lowering the ambient temperature. The other is using different cooling devices. For example, Microsoft [84, 85] built some of their data centres on the seafloor to utilise the cold environment undersea to reduce the energy consumption of the cooling system. Underwater data centres are found to be more reliable and efficient than others. However, they are associated with some problems. Usually, repairing and upgrading the data centre equipment is inconvenient to satisfy the swelling computing capacity needs. There are two approaches to the problem. One is to launch more underwater data centres at the expense of increasing costs. The other is to increase the computing payload. Periola et al. [86] proposed a geometric processor paradigm (GPP) that includes higher surface area and more processing units. Besides adding processors, Periola et al. also introduced the processor pause feature (PPF) technology. With this method, the increased use of processors will not necessarily increase the power consumption of underwater data centres. Essentially, the PPF enables the sleeping mode of some processors in low demand for saving energy. The simulation result shows that applying GPP enhances the computing capability and reduces the number of interruptions in the data centre by 95% and 79%, respectively.

5.3.2. IT equipment's energy model

The power consumption models of servers and other IT equipment can be analysed and predicted by several energy models. These energy models can be classified into additive models, baseline power + active power (BA) models, and other models [73]. The power consumption models of servers can be summarised in TABLE II.

TABLE II - POWER COMSUMPTION MODEL OF A SERVER

Category	Author	Concerned factors	Error
Additive model	Basmadjian et al[77]	• CPU voltage and frequency • Memory frequency • Hard disk • Read and write rate • Fan rotate speed	2% for best <10% for worst
	Song et al[78]	• Average component power	<5% for worst <3.5% average
BA model	Dhiman et al[79]	• CPU utilisation	<10%
	Xiao et al[80]	• The utilisation of each kind of physical components • Throughput	<5.2%
	Garraghan et al[81]	• CPU utilisation • Die temperature • Fan speed	3%
Other model	Horvath et al[75]	• Clock frequency and • CPU utilisation	1% for average <4% for worst
	Lim et al[76]	• The average number • of instructions • Predicted number of • requests, CPU • utilisation, CPU speed	<10%

Figure 3 [74] portrays a data server's general power consumption composition. It is revealed that the CPU is the major contributor to server power consumption, followed by peripheral slots such as I/O devices and networks, power supply units, memory, etc. These models help to predict the power consumption of IT equipment and facilitate data centre operators in conceiving counteractions to enhance energy efficiency.

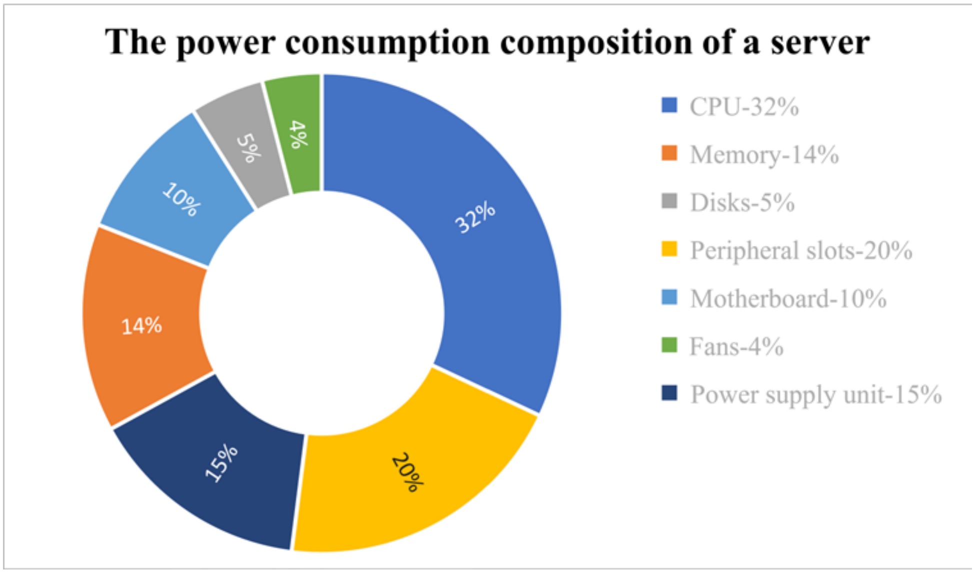

Figure 3. The general power consumption composition of a server

6. Summary of Best Practices of Energy Efficient and Resilient Data Centre

6.1. Energy Efficiency

There are three best practices for energy-efficient and resilient data centres.

(i) **Sizing of the facility:** One of the causes of data centre energy efficiency is the under-utilisation of facilities and lack of modular design. First, the facility needs to ensure that it meets the needs of the next 15-20 years, but it cannot be oversized. The unnecessary investment will reduce the efficiency of the facility.

(ii) **Real-time monitoring:** Data centres run multiple complex subsystems simultaneously. Therefore, unexpected failures are inevitable. Constant monitoring and reporting of different performance parameters are critical to data centre operators and managers. Real-time data analytics enables the real-time tracking of irregularities, data breaches, or other problems.

(iii) **Automation:** Manual reporting systems are commonly used in data centres. These systems require time-consuming manual tasks, such as activity-logging by staff, hamper the productivity of data centre operators, and hinder resources for developing other aspects of data centre management. Automated systems can enhance data centres' operation efficiency, strategic decision-making, and improvements of other offerings.

6.1.1. Efficiency Enhancement of IT Equipment

6.1.1.1. Procurement of energy-efficient IT equipment

When purchasing new servers, products that include variable-speed fans rather than a standard constant-speed fan as the internal cooling component can be selected. With variable-speed fans, a server can be sufficiently cooled while running slower, thus consuming less energy. The Energy Star program aids consumers in identifying high-efficiency servers. On average, servers that meet Energy Star efficiency requirements will be 30% more efficient than standard servers.

6.1.1.2. Power meter of IT equipment

Nowadays, power usage data of IT equipment can be measured by polling power distribution units (PDUs) connected to IT equipment [45]. PDUs are power strips used in data centre environments. High-end intelligent PDUs offer per-socket measurements, rich network connectivity, and optional temperature sensors [46], while dedicated PDU hardware provides accurate data on power consumption.

6.1.1.3. Utilisation of existing server and data transmission equipment

Servers take up most of the space and drive the entire operation. Many servers will draw full power during the process even when run at or below 20% load. To tackle the issue and address the potential future expanse in data demand of a data centre, the utilisation of existing servers and data transmission is one of the solutions. There are several methods of utilisation of existing servers, as listed below.

(i) A throttle-down drive reduces idle processors' energy consumption so that when a server will not draw full power despite running at its typical 20% load.

(ii) The power draw of servers can be modulated by installing power management software. Thus, the software can control individual devices on the rack to power down to enhance energy efficiency during the low-demand condition.

(iii) Multi-core processor chips allow simultaneous processing of multiple tasks by offering improved performance within the same power and cooling load as compared to single-core processors and consolidating shared devices over a single processor core.
(iv) Consolidating IT system redundancies is considering one power supply per server rack instead of providing power supplies for each server. The integrated rack-mounted power supplies will operate at a higher load factor (potentially 70%) than individual server power supplies (20% to 25%) for a given redundancy level.
(v) Short-term load shifting, such as sharing other IT resources, Central Processing Units (CPU), disk drives, and memory, for optimising electrical usage and improving long-term hardware energy efficiency.

6.1.2. Efficiency Enhancement of air conditioning system

6.1.2.1. Optimising plant design and operation

Data centres can deploy many opportunities in central plant optimisation in design and operation. Five examples are listed below.

(i) A medium-temperature, as opposed to low-temperature, chilled water loop design using a water supply temperature of 55°F (12.8°C) or higher improves chiller efficiency and eliminates uncontrolled phantom dehumidification loads.
(ii) Higher-temperature chilled water allows longer water-side economiser hours. Thus, the cooling towers can serve some or the entire load directly, reducing or eliminating the load on the chillers.
(iii) Optimise the condenser water loop.
(iv) A 5°F (2.78K) to 7°F (3.89K) approach to the cooling tower plant with a condenser water temperature reset will fit effectively with a variable speed chiller to offer considerable energy savings.
(v) A prudent design of efficient pumping is essential to a high-efficiency chilled water system. Pumping efficiency can vary widely depending on the configuration of the system, and whether the plan is for an existing facility or new construction.

6.1.2.2. Selection of different cooling systems

There are four major types of cooling systems, summarised in TABLE III.

TABLE III DIFFERENT COOLING SYSTEMS IN DATA CENTRES

Cooling system	Description of cooling system	Advantages	Disadvantages
Chilled-water system	The chiller provides cold water to help exchange heat.	1. The chilled-water system efficiency improves when data centre capacity increases. 2. Reliable.	This system has the highest capital costs for installations.
Air-cooled system	The heated refrigerant is flowing through pipes to be cooled in the condenser. Air is the medium of heat exchange.	1. It has the lowest overall cost. 2. It is easiest to maintain.	The refrigerant piping loops are not long enough to make it economical and reliable.
Hybrid air-water system	Use air and water as medium.	Advanced model than only one medium	More investment and control centre.
Directly (fully immersed) liquid-cooled system[87]	Servers are enclosed, immersed, direct liquid-cooled	Higher heat transfer capacity per unit.	Need to install additional leakage monitoring system

6.1.2.3. Using high efficient VFD-equipped chiller

Using efficient water-cooled chillers in a central chilled water plant, such as a high-efficiency VFD-equipped chiller with an appropriate condenser water reset, is typically the most efficient cooling option for extensive facilities. Chiller part-load efficiency should be considered since data centres often operate at suboptimal capacity. Chiller part-load efficiencies can be optimised with variable frequency-driven compressors, higher evaporator temperatures and lower entering condenser water temperatures.

Oversized cooling towers with VFD-equipped fans will lower water-cooled chiller plant energy. For a given cooling load, larger towers have a smaller approach to ambient wet bulb temperature, thus allowing operation at lower cold condenser water temperatures and improving chiller operating efficiency. The larger fans associated with the oversized towers can operate at lower speeds to lower cooling tower fan energy compared to a smaller tower. Condenser and chilled water pumps should be selected for the highest pumping efficiency at typical operating conditions rather than full load conditions.

6.1.2.4. Liquid cooling

Liquid cooling uses liquid instead of air as a refrigerant to dissipate heat. Immersion liquid cooling is the leading direct cooling technology used. Immersion liquid cooling has the characteristics of high cooling efficiency, high availability, and high reliability are considered a transitional technological innovation in the data centre industry. Liquid has 25 times higher heat transfer efficiency than air. It supports the highly efficient cooling of IT equipment. In addition, liquid cooling systems do not require fans and room air conditioners, which significantly reduces the energy consumption of data centres. It is revealed that the average annual PUE of liquid cooling data centres is as low as 1.09.

6.1.2.5. Maximising free cooling hours

Free cooling, which uses naturally cool air or water instead of mechanical refrigeration, is an approach to dissipate heat generated in data centres. The application of free cooling is subject to the local climate. For example, in Seoul City in the Republic of Korea, Kim et al. evaluated the benefits of free cooling through dynamic simulations, showing that temperature control can result in a 27% reduction in cooling load [90].

6.1.2.6. Air-side economizer

The cooling load for a data centre is independent of the outdoor air temperature. An air-side economiser is the lowest-cost option to cool data centres most nights and during mild winter conditions. Ham et al. conducted energy simulations of nine types of air-side economiser alternatives, which yielded cooling coil load savings of 76–99% compared to conventional cooling systems in data centres.

Considering humidity and contamination concerns associated with data centres, conscious control and design work is needed. Control strategies to deal with temperature and humidity fluctuations must be considered, along with contamination concerns over particulates or gaseous pollutants. A dew-point temperature lockout scheme should be part of the air-side economiser control strategy for data centres with active humidity control.

6.1.2.7. Water-side economiser

With the evaporative cooling capacity of a cooling tower, the water-side economiser can produce chilled water during mild outdoor conditions. This method is suitable for climates with wet bulb temperatures lower than 55°F (12.8°C) for 3,000 or more hours per year. It most effectively serves chilled water loops designed for 10°C (50°F) and above chilled water or lower temperature chilled water loops with significant surplus air handler capacity in daily operation. A heat exchanger is installed to transfer heat from the chilled water loop to the cooling tower water loop while isolating these loops from each other. The heat exchanger is located upstream from the chillers rather than parallel to them, which allows for the integration of the water-side economiser as a first stage of cooling the chilled water before it reaches the chillers.

6.1.2.8. Reviewing hardware location

Grouping equipment with similar heat load densities and temperature requirements can reduce the fan power supply and result in more efficient cooling system performance. This arrangement allows cooling systems to be controlled to the least energy-intensive set points for the location of different groups of equipment.

6.1.2.9. Airflow management

It is common to apply airflow management in a cooling system. Long distances may suffer considerable cooling losses due to recirculation, bypass, uneven distribution, and airflow leakage. The installation cost is relatively low. On the contrary, the short-distance cooling system can reduce or eliminate shortcomings, but the deployment cost is high [89].

6.1.2.10. Procurement of servers with an internal cooling system

There are vast improvements to servers' internal cooling systems and processor devices have been made to minimise energy wastage. Some new servers are equipped with variable speed fans rather than a standard constant speed fan as the internal cooling component. With variable-speed fans, a server can be sufficiently cooled while running slower, thus consuming less energy.

6.2. Energy Resilience

A reliable power supply is vital because unplanned downtime may impact the data centre. Apart from a dual feed from the utility grid, the site owner of the data centre can take action for reserving alternative power sources apart from the main grid.

6.2.1. The uninterrupted power supply (UPS)

The centralised UPS system with lead-acid batteries applied as an energy storage system is adopted in the industry. However, it experienced several shortcomings:

(i) Low power supply efficiency;

(ii) Large fault range;

(iii) Long failure recovery cycle;

(iv) Poor reliability; and short life of lead-acid batteries.

There are three practices to overcome the problems.

6.2.1.1. Distributed micro-UPS

Large internet companies have begun to upgrade the centralized UPS to distributed micro-UPS. The distributed micro-UPS means that a low-power UPS is embedded inside the server to serve as a backup power source in case of power failures. Distributed micro-UPS enhances data centres' resilience by reducing fault radius and operation and maintenance complexity. There are three examples of micro-UPS in the APEC region.

- Google Douglas Data Centre (distributed micro-UPS & lead-acid battery)

  Google's customized servers come with distributed micro-UPS. Therefore, Google's data centre no longer has UPS or battery rooms. The time for the battery to participate in the discharge is less than one or two minutes and the backup time is far less than the 15 to 30 minutes battery backup requirement of a traditional data centre. Thus, the capacity of the battery is tiny, typically around 3.2Ah.
- Amazon AWS cloud data centre (distributed micro-UPS & lead-acid battery) [108]

  AWS cloud data centre uses micro-UPS, which gives the system a better energy availability than 99.99999% uptime.
- Facebook Prineville Data Centre (distributed micro-UPS) [109]

  Facebook Prineville data centre uses distributed utility to power the server directly with only 7.5% energy loss, which is significantly higher than the conventional applications.

6.2.1.2. Li-ion battery

The low reliability and short service life of lead-acid batteries compromise the operational reliability of data centres. Compared with lead-acid batteries, Li-ion batteries have multiple advantages, including more extended service life, a quarter of the weight, and a charging speed that is more than four times faster than lead-acid batteries. Given that the price of Li-ion batteries is falling, lead-acid batteries are being increasingly replaced by Li-ion batteries.

6.2.1.3. Modular UPS

Modular UPS possess properties of hot plugging, short maintenance time and higher reliability, thus significantly reducing the risk of downtime associated with power supply problems. Modular UPS has superior scalability and reduces the initial investment cost associated with data centre expansion to support business growth. Consequently, modular UPS has been widely used in banking [112] and communication [113] sectors.

6.2.2. Microgrid

Microgrids include renewable energy generation, energy storage systems, and traditional standby diesel generators. They are more resilient than conventional standby generators used alone, therefore, a feasible grid system to power the data centre [107].

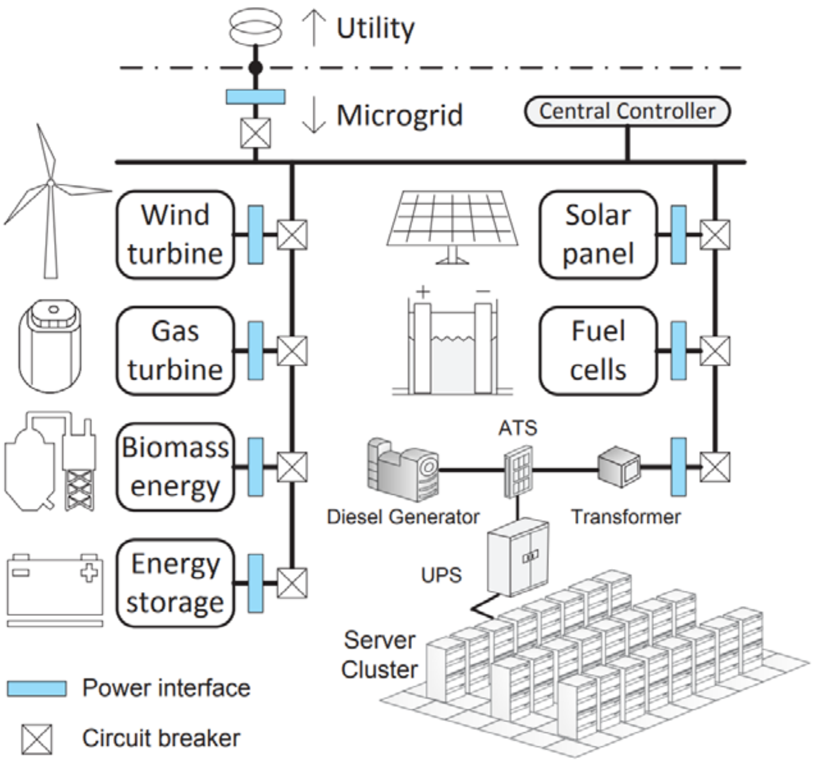

Figure 5. Conceptual diagram for a data centre powered by renewable with microgrid

Examples of microgrid

- eBay Salt Lake City Data Centre, The United States

The eBay Salt Lake City Data Centre is powered by a microgrid that employs Bloom Energy fuel cells powered by natural gas. eBay Inc.'s data centre is the first facility of its kind in the world to use Bloom Boxes [99]. The Bloom Energy Boxes use solid oxide fuel cell technology, converting natural gas into electricity through electrochemical reactions without involving any combustion. This new design is more sustainable, efficient, and reliable. The radical design frees eBay Inc. from relying on expensive equipment that is rarely used in emergencies. Thirty Bloom Boxes are the primary power source for the entire IT load, using the local utility grid for backup.

- Alibaba Qiandao Lake Data Centre, China

  Alibaba Qiandao Lake Data Centre [115] is installed with a rooftop PV power generation system and hydropower generators. They are connected to a 240V DC microgrid to directly supply power to the server, with diesel generators as the backup power source. When the light is insufficient or the hydropower is low, it can switch to the utility mode to ensure the operation of the equipment.

7. Summary of New and Renewable Energy in Data Centres

The data centre has three main approaches to utilising renewable energy [92]. The first approach is the on-site generation, meaning the renewable energy source is directly generated on-site. The second approach is off-site generation, which means that the data centre owners invest in renewable energy in places with sufficient renewable sources. The third approach is purchasing renewable energy from other entities to reduce the carbon footprint.

7.1. On-site Generation

Rural areas with abundant space are suitable for establishing data centres, and associated on-site renewable energy power stations should be there for renewable energy sources. Among the three abovementioned approaches, on-site renewable generation is the most widely used to integrate renewables into data centres. The on-site generation has various benefits. Firstly, it can reduce the emission of greenhouse gases (GHG) like CO_2 and other pollutants [93]. Secondly, renewable energy is generated and consumed at the data centres, thus eliminating the need for long-distance power transfer and minimising transmission loss and the cost of transmission infrastructure associated with power transfer. Thirdly, it helps reduce electric bills. However, there are some problems in these rural regions with abundant renewable resources, such as network latencies and labour force unavailability. If the data centres are far from the city, the long distance will increase the data transmission time and cause network latencies. When the data centres are located in the suburbs, it is time- and cost-consuming for professionals to commute to the site to maintain and update the data centres.

Photovoltaic (PV) panel can be installed at different scales and is commonly adopted in new green building. In Thailand, SUPERNAP is a hyper-scale data centre powered by a solar power system. In Johor, Malaysia, there is a 500MW data centre campus powered by renewable solar energy [94]. In Romoland, California of the United States, the AISO.net facility is a solar-power data centre [95].

For wind energy applications, the Other World Computing at Illinois of the United States [96] is an example of an on-site wind power system. The wind power generated is used to supply electricity to the company's headquarters and data centre which supports the company's web hosting and ISP services. The single wind turbine installed in this data centre is implemented with other energy efficiency measures to reduce the overall electricity needs. The wind power generation is estimated to be 1.25 million kilowatt-hours of power per year, which is twice the company's electricity demand.

Biogas is another new renewable energy to supply data centres. Biogas produced by the anaerobic digestion of biomass, can be used as fuel for data centres. There are three main benefits of using biogas power data centres. The first one is the economic benefit. Data centres using biogas can gain extra credits from carbon emission trading through a clean development mechanism (CDM) [97], thus reducing the operating costs of data centres. The second one is the environmental benefit. Compared with traditional fuel energy, biogas production from waste emits a lower level of carbon emission and consumes harmful waste, thus reducing the impact on nearby neighbourhoods and environments. Finally, compared with wind and solar energy, biogas has a more stable power output, which improves the reliability and stability of data centres. There are many successful cases of data centres powered by biogas. Microsoft built a Biogas-Powered data plant in Wyoming [98], in which servers are energized by fuel cells using methane biogas as the main biogas. The eBay Salt Lake City data centre employs 6 MW Bloom Energy fuel cells powered by natural gas. Although biogas is not carbon-free, it can reduce carbon emissions by approximately 46% compared to data centres powered by traditional coal fuels [99].

7.2. Off-site Generation

Off-site generation serves as a complement to on-site generation. Due to some infeasible factors, such as limitations in renewable energy potential and space unavailability, the data centre will rely on the power grid to transfer renewable energy for supplying the IT equipment far away. This approach enables the utilisation of remote renewable energy for data centres. Data centres in economically developed cities show low utilisation of renewable energy due to the need for more space to house renewable energy infrastructures. Off-site power generation is a solution to boost renewable utilisation. The industrial practices of off-site generation are summarised in TABLE IV. These successful examples demonstrate the potential of off-site generation and its relatively higher flexibility in the site planning of renewable energy systems as compared to offsite generation.

TABLE IV PRACTICAL CASES OF OFF-SITE GENERATION

Company	Capacity	Renewable type	Project location
Facebook	1300 GWh per year	Wind power	Sarpy Data Centre is supported by renewable energy from Enel Green Power’s Rattlesnake Creek Wind Farm in Nebraska [100].
Apple	50 megawatts	Photovoltaic solar power	Apple PV plant: Pinal County (east of its data centre in Mesa, Arizona)
Google	150 megawatts respectively	Solar power	Alabama and Tennessee

7.3. Renewable Energy Provided by Third Parties

Data centre owners can purchase renewable energy provided by a third party as per contractual arrangement. Energy Attribute Certificate (EAC) is a certificate which labels electricity as renewable. The EAC enables the tracking of renewable energy sources [101]. As such, companies can credibly claim their renewable electricity consumption and efforts to reduce the environmental impact associated with electricity use.

7.3.1. Renewable Energy Certificate (REC)

REC is a way to track the electricity produced by renewable sources in the unit of megawatt-hour (MWh) unit. There are two types of RECs [102] - bundled and unbundled RECs. The bundled RECs are formed between a company consumer and the electricity provider during the new construction stage for an electricity package. REC facilitates the consumers to reduce the carbon impact caused by their companies' electricity uses and move towards the sustainability target. Unbundled RECs are RECs that are not paired with electricity providers and can be purchased from REC retailers at any time. Due to easy access to unbundled REC, companies increasingly adopt renewable energy via unbundled REC.

7.3.2. Green Pricing or Green Tariffs

Many electricity providers allow their customers to purchase REC via Green Pricing or Green Tariffs, which require short-term and long-term commitments from consumers, respectively.

Program Characteristics	Green Pricing	Green Tariff
Cost savings potential	No, products average around 1.5 cents/kWh premium	May be cost-competitive, depending on structure and term
Price stability	No, continue to pay utility rate that is subject to change	Possible under certain program structures
Contract length	Shorter contract terms (typically month-to-month)	Longer agreements possible (10-20 years)
Ease of joining	Typically a simple sign-up process	Often limited availability, longer contract is potential barrier
Choice of RE resource	Utility determines	Customer may have input

Figure 6. Comparison between Green Pricing and Green Tariff, Department of Energy, the United States [103]

7.3.3. Power Purchase Agreement (PPA)

Power Purchase Agreement (PPA), according to the Department of Energy (DOE) of the United States [104], is an arrangement in which a third-party developer installs, owns, and operates an energy system on a customer's property (Figure 7). The customer purchases the system's electric output for a predetermined period. PPAs are long-term contracts spanning 10-20 years. PPA is commonly used for renewable energy systems. Under PPA, the data centre owners commit to buying future renewable energy generation at an agreed price. In 2021, 31GW PPAs was recorded from the data centre industry [105], including Amazon and Google [106]. The data centre industry is the sector with the largest capacity of PPAs (Figure 8).

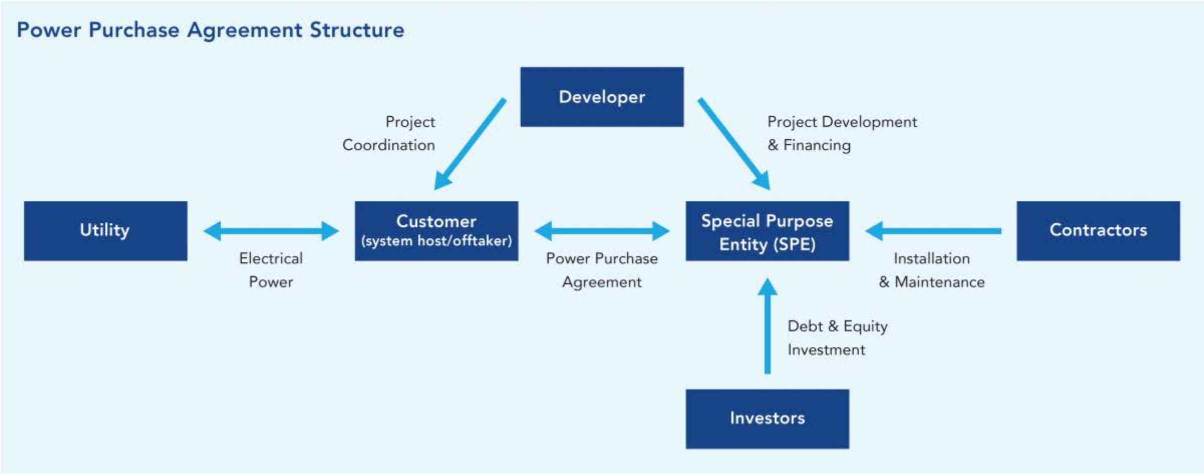

Figure 7. PPA structure, DOE [104]

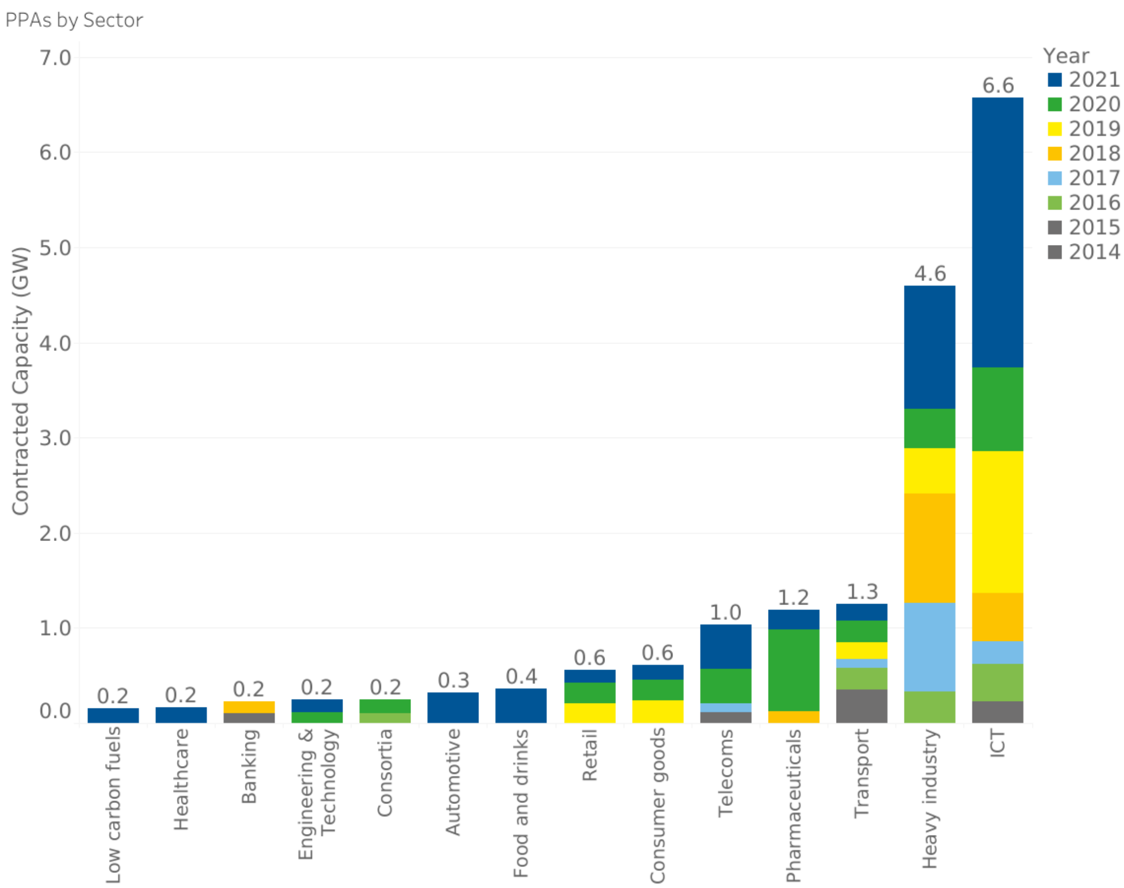

Figure 8. PPAs by sector, RE-Source [106]

7.4. Integration of hydrogen

There are three kinds of integration methods for using hydrogen in the green data centre.

(i) With data centres usually equipped with 12-48 hours of backup power, hydrogen fuel cells for backup power are one of the emerging technologies recently apart from conventional UPS or diesel generators.

(ii) Hydrogen is considered an alternative to fossil fuels. There are hydrogen engines for energy supply under testing.

(iii) Referring to the Hydrogen Council [91], data centres shall be benefitted from hydrogen, considering its responsive and versatile nature and can be used irrespective of the site location. Hydrogen can be used for balancing and storing fluctuating renewable power.

The potential of adopting hydrogen in green data centres is observed and subject to the mutuality of technology and the formation of related regulations and guidelines.

8. Emerging Technologies for a Green Data Centre

8.1. IT Equipment

8.1.1. Virtualisation

Virtualisation is a method of running multiple independent virtual operating systems on a single physical computer. It allows the same amount of processing to occur on fewer servers by increasing server utilisation. Instead of operating many servers at low CPU utilisation, virtualisation combines the processing power onto fewer servers using at higher utilisation. Virtualisation can drastically reduce the number of servers in a data centre, therefore reducing required server power. Consequently, the size of the necessary cooling equipment. Some overheads are needed to implement virtualisation, but this is minimal and justifiable compared to the potential energy savings.

8.1.2. Dynamic power balance between the supply and server demand

Bostoen et al. [82] focus on the dynamic power balance between the supply and server demand. They concluded that existing power-reduction techniques are based on dynamic power management. In Bostoen et al. study, each energy-saving technology, trade-offs among power, capacity, performance, and reliability are systematically reviewed. Dynamic power management dynamically activates the associated equipment concerning the data processing task. This way, the equipment will only consume energy when required to provide data services.

8.1.3. Optimising data centre architecture

Nowadays, optimising the data centre network architecture has become the mainstream direction in computing research. Fat-Tree [64], VL2 [65] and BCube [66] proposed to increase the network throughput. They have all focused on the improvement of aggregate bandwidth but lost sight of the power consumption of these network architectures. Shang et al. [67] introduced a metric of network power efficiency (NPE), which represents the end-to-end bps per watt (or in bit per joule) in data transmission. By comparing different architectures, it is revealed that the Flattened Butterfly [68] architecture performs the best and has the highest NPE. Referring to Flattened Butterfly, the sleep-on-idle technique and power-aware routing can significantly improve the NPEs for all the data centre architectures, especially in the case of low traffic load [67].

Other research focuses on developing new architectures or introducing different control methods to optimise data centre architecture.

(i) Botero et al. [69] presented a novel architecture proposed by All4Green [70] to monitor and control data centres using data centre agents to negotiate with suppliers and users to get a new running condition. Their target is to reduce 10% energy consumption based on existing strategies and the connected CO2 emissions.

(ii) Hadj-Ahmed et al. [71] proposed a control method based on dynamic optimisation of computing resource capacity to save energy. Hadj-Ahmed et al. used Google's trace workload actual data to illustrate the balance of switching off and rearranging.

8.2. Air conditioning system

8.2.1. Immersion cooling

Immersion liquid cooling has been successfully adopted in scientific, academic, research, super high density, and associated high-performance computing (HPC) applications. Chi et al. [87] used an actual data centre to verify their model by comparing it with a hybrid air-water-cooling system. The partial PUE value of the hybrid air-water-cooled system is 1.48. Chi's model's PUE value is 1.14, which gets 34% more efficient than a hybrid air-water-cooled system.

However, some constraints in the implementation of liquid cooling are yet to be solved, including the enhancements needed for the operation and maintenance of the liquid cooling system as well as the need to lower the high capital costs.

8.2.2. Evaporative cooling utilisation

Evaporative cooling, also known as adiabatic cooling, is a cooling and ventilation technique that uses water as its refrigerant. During the evaporative cooling process, water (liquid state) is evaporated into steam (gaseous state). This transition requires energy extracted from the air in the form of heat. As a result of this process, the surrounding air is cooled down.

Evaporative cooling employing an indirect/direct system is a highly sustainable and energy-efficient cooling method for data centres. It uses 10% of the energy needed for mechanical cooling while delivering equal temperatures to traditional mechanical cooling systems.

8.2.3. High-temperature data centres

A higher operating temperature in data centres allows longer free cooling hours, saving significant amounts of cooling energy and reducing the number of chillers needed in data centres. Free cooling is an effective way to reduce the energy consumption of cooling systems. There are many positives associated with high-temperature data centres.

- Longer free cooling hours: A study suggested that when the operating temperature rose from 27°C to 35°C, the annual air-side free cooling hours could be increased from 80% to 99 % in Europe.
- Higher chiller efficiency: Research showed that every 1K increase in the chilled water temperature would bring a 2% improvement in the chiller efficiency.
- Alternative site selection options: Currently, the high-latitude area in the Pan-Arctic region has gradually become a hotspot for data centres' site selection because of longer free cooling hours.
- Waste heat recovery improvement: The main barrier to waste heat recovery and reuse in data centres is that the heat collected from data centres, although plentiful, is low quality. Thus, increasing the operating temperature of data centres makes it possible to recover more high-quality heat.

8.3. AI-Based Optimal Control in Data Centre Operation

A data centre contains many components, such as cooling, workloads, servers, storage and networks. Experts believe that artificial intelligence can help enterprises obtain more energy efficiency achievements by leveraging successful models.

Artificial intelligence (AI) applications can monitor, analyse, and optimise the data centre's energy allocation to different systems. In addition, machine learning algorithms can use massive historical data to generate reliable load forecasts. Advanced optimisation methods can result in greater flexibility and energy efficiency.

For example, Google uses the DeepMind system to improve the energy efficiency of its data centre. Results showed the potential of artificial intelligence in data centres. In just 18 months, the system helped Google reduce 40% of cooling energy and 15% of total energy. This case proves that data centre operation integrated with AI can assist the transition to the green data centre.

8.4. Utilisation of Energy

8.4.1. Waste heat recovery in data centres

The heat dissipated from cooling systems can be used when there is a heating demand in other parts of the building, neighbouring buildings, or a district heating network. For example, it is possible to transfer the energy to the district heating or cooling network nearby. If the temperature of the surplus heat is low, it might also be used in a low-temperature district heating or cooling system.

Waste heat can be used directly or to supply cooling required by the data centre through the absorption or adsorption chillers, reducing chilled water plant energy costs by over 50%. The higher the cooling air or water temperature leaving the server, the greater the opportunity for using waste heat. The direct use of waste heat for low-temperature heating applications such as preheating ventilation air for buildings or heating water will provide more energy savings. Heat recovery chillers may also provide an efficient means to recover and reuse heat from data centre equipment environments for the comfort of typical office environments.

8.4.2. Thermal storage for improving resilience in data centres

Thermal storage, a method of storing thermal energy in a reservoir for later use, is particularly useful in facilities with high cooling loads, such as data centres. It can enable optimal electrical demand savings and improve the reliability of the chilled water system. In cool and dry night-time, the cooling towers can directly charge a chilled water storage tank, thus using a small fraction of the energy otherwise required by chillers. A thermal storage tank can be an economical alternative to additional mechanical cooling capacity. For example, water storage provides the additional benefit of backup make-up water for cooling towers.

8.4.3. Interaction with smart grid - participating in demand response

Demand response [107] refers to the process by which facility operators voluntarily curb energy use during peak demand. Many utility programs offer incentives to business owners to implement this practice on hot summer days or during high energy demand but with low power supply.

Demand Response works with load management through a building management system or taking several reduction measures such as dimming a third of their lighting or powering off idle office equipment. These can be a simple, efficient, inexpensive process and may reach to 14% reduction of peak loads.

Moreover, data centres significantly impact on power load balancing in the smart grid. As a large energy consumer, the data centre is a potential demand response participant. Data centres participating in demand response programs can help the grid achieve a better load balancing effect, while the data centre can also reduce its power consumption and electricity costs.

8.4.4. Cross-region computing and data transmission

The fast-growing scale data centre industry calls for higher requirements for land, energy, climate, and other conditions. For cities, especially first-tier cities, their resources need to be increased to meet the development needs of a data centre.

Taking China as an example. The eastern region has a great demand for computing and electricity, but there is a need for more supporting resources such as land and renewable energy. The western region of China has rich renewable energy, a cool climate, and low electricity price, thus making the region suitable for constructing green data centres with longer free cooling hours and renewable energy integration. The strategy "Transfer the data generated in the eastern region to the western region for storage and calculation" is now implemented to construct more green data centres in the west that provide computation services needed in the east in China. This strategy can solve the problem of imbalance of computing resources and computing demand among the eastern, central, and western regions.

The example is a showcase for land-extensive economies to utilise the geometrical advantages of different regions in the economy and enhance the energy efficiency of a data centre.

9. Roadmap for Transition to the Green Data Centre

Many existing data centres must be designed and built with sustainability and energy efficiency. The different parts of data centres have different lifespans. For example, a hyperscale data centre could last 15 to 20 years. The frame of data centres may last nearly 60 years. The IT equipment is usually updated every 3 to 4 years [60]. Given the typical 20-year lifespan of a data centre, it is not realistic and cost-effective to rebuild these data centres. With the data centre industry poised for strong and sustained growth, transiting to a green data centre requires a synergy effect of several factors.

(i) Regulations and guidelines
(ii) Emerging technology
(iii) Adoption of new and renewable energy

Regulations and guidelines

More than a commercial building, the green building measurements to a data centre may be in a separate set of requirements. The metrics, such as PUE and CUE, shall be adopted for either mandatory or voluntary regulations for having a green data centre. Data collection of the actual energy performance of the data centre is essential for tracking the level of the greenness of the data centre. To support the regulation, localising design guides for the trade to reference or follow in addition to the international standards will help promote green data centres due to climate, power grid conditions and renewable energy availability.

Emerging technology

The primary energy consumption of the data centre is by the IT equipment and air conditioning systems. Conventionally, the main focus of energy saving was on air conditioning systems because these usually take up the most significant energy cost [61]. Transiting to the green data centre requires a new focus on improving the energy performance of physical IT equipment and software, the related emerging technologies such as monitoring IT equipment power, software energy management, utilisation of servers and optimising the network architecture.

Adoption of new and renewable energy

It is significant progress to reduce the energy consumption of the data centre through technical means, but more is needed to become a green data centre. Combining renewable energy and green power with low carbon emissions is the crucial step towards a genuinely green data centre. However, renewable energies like wind power and solar power are volatile. The power instability of green data centres is expected to increase with the increasing penetration of renewable energy. Therefore, microgrid or energy flow management should be adopted to optimise a data centre's energy flow and data flow to ensure energy resilience.

10. Recommendations

Based on the previous discussion on the opportunities and technologies for data centres, the below sections set out the recommendations to improve the energy efficiency and resilience of data centres.

10.1. Improve Energy Efficiency

(i) **Use energy-efficient servers:** Vast improvements in the internal cooling systems and processor devices of servers have been made to improve server efficiency, particularly when in low-load conditions. Most servers run at or below 20% utilisation most of the time. Variable-speed fans can be used to deliver sufficient internal cooling for servers while consuming less energy.

(ii) **High-temperature data centres:** Data centres offer many opportunities in central plant optimisation, both in design and operation, especially in part load conditions. The most effective means is to increase the chilled water temperature, increase the temperature difference of supply and return chilled water, reduce the cooling water temperature, etc.

(iii) **Adopt efficient chilled water systems:** Data centres offer many opportunities in central plant optimisation, both in design and operation, especially in part load conditions. The most effective means is to increase the chilled water temperature, increase the temperature difference of supply and return chilled water, reduce the cooling water temperature, etc.

10.2. Improve Energy Resilience

(i) **Cross-region computing and data transmission:** The current resources of cities, especially first-tier cities, have yet to meet the development needs of the data centre industry. The computing and data storage demand can be shifted to regions with rich renewable energy, a cool climate, and low electricity price.

(ii) **Integrate with the smart grid:** Participating in demand response programs can help the grid achieve better power balancing, allowing more renewable penetrations. Energy consumption of data centres is enormous and spans multiple locations. Data centres are potential demand response participants. Participating in demand response programs can reduce data centres' power consumption and electricity costs.

(iii) **Integrate with Hydrogen:** Hydrogen can be used directly or in fuel cells for balancing and storing fluctuating renewable power in a data centre. The adoption of hydrogen needs support for the research and pilot trial for mutualising the technology and commercialisation.

11. Conclusion

COVID-19 has accelerated the surge of global internet traffic due to the rapidly expanding and growing demand for e-office, e-learning, e-commerce, and e-entertainment, thus bringing society into a "Digital Economy" era. The developments in the digital economy depend on data centre services and energy use.

Data centres are required to achieve high efficiency, high resilience, and low carbon emission as they represent an essential source of high energy consumption and play an important role in attaining carbon-neutral economic development. Establishing a green and low-carbon data centre is a trending research target.

This report reviewed the development of data centres in the APEC region, summarising the available policy and standards for energy-efficient data centres. Examples of new and renewable energy applications and applied I&T technologies for moving towards energy-efficient, resilient and green data centres were reported. The best practices of energy efficiency and resilience for the green data centres were identified to act as a good reference for other projects. The method of adopting renewable energy and identified constraints and solutions are provided in this report. In light of the growing demand for data centres in the coming years, emerging technologies for aggressively enhancing the energy efficiency and resilience of data centres should be employed. Data monitoring, collection and analysis by modelling should be adequate for reviewing the achievement of measures. There is still a long way towards upgrading the existing data centres to green and low-carbon ones with high penetration of renewables. To begin with, the target of energy efficiency for a green data centre set by the policymakers will help to give the direction of green data centre development, together with technical support from localised design and operation guides.

This report can be a reference for industries and other stakeholders for designing and operating the data centres to move towards APEC goals and carbon neutrality. It can be a reference for enterprises and other stakeholders for developing and managing the data centres to move towards APEC goals and carbon neutrality.

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Appendix – Workshop Summary

Contents

1. Background

In the 2011 APEC Economic Leaders' Declaration, APEC Ministers and Leaders agreed to reduce APEC's aggregate energy intensity by 45% from 2005 levels by 2035. At the 2014 APEC Leaders' Meeting, Leaders endorsed an aspirational goal to double the share of renewable energy in APEC's overall energy mix by 2030 (over 2010 levels) and increase cooperation to achieve it.

According to International Energy Agency Data Centres and Data Transmission Networks, it revealed that global internet traffic surged by almost 40%[1] between February and mid-April 2020 during the COVID-19 containment measures, driven by growth in video streaming, video conferencing, online gaming, and social networking. This growth has come on top of the rising demand for digital services over the past decade since 2010. The number of internet users worldwide has doubled while global internet traffic has grown by around 30%[2] per year. However, rapid improvements in energy efficiency have helped limit energy demand growth from data centres and data transmission networks, which accounted for around 1% of global electricity use in 2019. Demand for data and digital services is expected to continue its growth exponentially over the coming years, with international internet traffic expected to double by 2022 to 4.2 zettabytes[3] per year. The number of mobile internet users is projected to increase from 3.8 billion in 2019 to 5 billion[4] by 2025. Internet of Things (IoT) connections are estimated to double from 12 billion to 25 billion. There was a growth in demand for data centres and network services. The data and digital services allow the APEC member economies to a transformational "Digital Economy".

Hong Kong, China (HKC) buttresses New Zealand's Policy Priorities for APEC 2021 on "Increasing inclusion and sustainability recovery" and "Pursuing innovation and a digitally-enabled recovery" in mitigating the impacts of COVID-19. In connection with this, Hong Kong, China conducted "Promoting Energy Efficient and Resilient Data Centres in the APEC Region (EWG 05 2021A)" to promote energy-efficient, resilient, and green data centres in the APEC region.

2. Objective

2.1. Project Objectives

This project aims to encourage member economies in improving energy efficiency and resilience and powering by renewable energy in data centre operations in the APEC region. The project's objectives are to promote APEC's goals to reduce energy intensity by 45% from 2005 levels by 2035 and double the share of renewable

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energy in the overall energy mix by 2030 (over the 2010 levels).

2.2. Event Objectives

The workshop "APEC Workshop on Promoting Energy Efficient, Resilient and Green Data Centres" that came alongside this project with two half-day sessions was held on 28-29 June 2022. The workshop aimed to encourage member economies to improve the energy efficiency and resilience of data centres, and the utilisation of renewable energy in their operations in the APEC region, to accelerate APEC's move towards its goals of reducing energy intensity and adopting renewable energy. The workshop provided the capacity-building opportunity for APEC member economies to appreciate the standards, guidelines, and certification schemes of energy efficiency, resilience, and green data centre. The workshop shared best practices for translating knowledge into practical actions in APEC member economies. More than 100 delegates and experts from six APEC member economies attended the workshop to exchange views on the best practices, challenges, and the application of innovative technology in data centres.

3. Workshop Summary

3.1. Opening Remarks of Workshop

Presenter: Mr WONG Kam-sing, GBS, JP, Secretary for the Environment, the Government of the Hong Kong Special Administrative Region, Hong Kong, China

APEC economies consumed approximately 60% of the world's energy. With the continuous increasing consumption of energy, a goal of reducing aggregate energy intensity by 45% by 2035 was set by APEC leaders in 2011. To respond to this goal, Hong Kong, China (HKC) set an aggressive target to reduce energy intensity by 40% by 2025 in 2015. From 2005 to 2019, the domestic energy intensity decreased by over 30% with the joint efforts of the public and different sectors of HKC.

The HKC Government published the "Hong Kong's Climate Action Plan 2050", which outlines four proactive decarbonisation strategies, covering "net-zero electricity generation", "energy saving and green buildings", "green transport" and "waste reduction", to resolve the climate crisis and achieve carbon neutrality before 2050. Considering over 60% of domestic carbon emissions are attributed to generating electricity for buildings, strategic minimising the building energy consumption is crucial. It is also a way to lower the public financial burden caused by the increasing usage of clean fuels during electricity generation.

HKC is not only an international financial, trading, and logistic hub, it is also home to regional offices and headquarters of many global corporations. It is essential to have high-performance and secure data centres. HKC is equipped with a robust telecommunications infrastructure and reliable power supply, developed as a location for data centres.

Recognising the growing up of demand for data services and energy, new data centres with green and resilient designs are encouraged. Simultaneously, the existing data centres are suggested to be transformed, to address the upcoming challenges.

To promote green computing initiatives throughout the entire lifecycle of a data centre, the HKC Government collaborated with the industry actively, to research, develop and promote best practices and technologies for energy-smart data centres, i.e. the Green Data Centres Practice Guide. The HKC Government would consider expanding the scope of regulation regarding the energy efficiency standards of building services installations. Mr WONG concluded that the operation of data centres and information and communication technology applications contribute significantly to environmental sustainability, which would lower the overall energy consumption of the whole economy.

3.2. Session 1 - Guidelines, Standards, Certification Schemes of Data Centres

3.2.1. Sharing 1.1: Energy Efficiency for U.S. Data Centres: Distributed and Evolving Regulation

Presenter: Dr Christopher PAYNE, Research Scientist, Lawrence Berkeley National Laboratory, The United States

Dr PAYNE shared the Federal Energy Management Program (FEMP) Data Centre Program and the policy landscape for the private and Government sectors in the United States (US).

Federal Energy Management Program (FEMP) Data Centre Program

The Federal Energy Management Program (FEMP) Data centre Program is launched by the Department of Energy, the United States. The program aims to assist government agencies and other organisations with optimising the design and operation of data centres. Design and operation of energy and water systems in data centres to enhance the agency's mission. FEMP offers resources related to data centre efficiency to government sectors and other organisations throughout the world. The provided resources include technical assistance for helping people understand energy efficiency opportunities in data centres, software tools for characterising the energy-saving opportunities in data centres, programmatic resources that identify components of the industry, and on-demand and real-time training for Government agencies and other organisations.

Private sector

Private sector entities were largely regulated at the state level. The American Society for heating refrigeration and air conditioning engineers (ASHRAE) published two notable standards to guide the efficient performance of data centres. Notably, ASHRAE standards are mainly generated via the industrial consensus. The first is ASHRAE 90.1 for commercial office buildings. It commented on the use of economizers in helping to cool data centres that are present in commercial buildings. The second is ASHRAE 90.4, which covers the mechanical energy use, mainly for cooling the data centre, and electrical energy, primarily for powering the IT equipment. ASHRAE 90.4 intends to take away the least efficient or most energy consumptive data centres rather than pushing toward a high efficiency. However, the adoption of ASHRAE 90.4 is challenging in the U.S. because many states did not have commercial energy codes bearing on data centres.

Dr PAYNE shared two cases in the U.S., which were Washington State and California. Washington state identified an energy code requirement for data centres. They adopted mechanical and electrical sections of the 2016 version of ASHRAE 90. 4. In 2020, Washington state adopted a more stringent mechanical requirement for energy performance and defined these requirements differently in different parts of the state as per climate status in these areas. California set the building energy code (named Title 24) with a three-year update cycle. California Title 24 defines computer rooms and applied the data centre efficiency requirement to computer rooms. Unlike the Washington Code, which only offered one way of achieving compliance, California Title 24 offers a prescriptive compliance path and a performance path for fulfilling compliance.

Government sector

For the U.S. Government and its data centre operations, in addition to those state requirements, the government tries to push the data centre performance of its operations a little higher. Besides, the Government tends to manage the overall growth of data centres within its operation. It caps and consolidates data centres into a single large data centre. Also, it is encouraged to migrate on-site equipment rooms to the cloud of IT resources. Over the decade, the Government implemented a series of optimisation initiatives. The Federal Data centre Consolidation Initiative (FDCCI) was implemented in the year 2010 to contain growth in government data centres. In 2014, Federal Information Technology Acquisition Reform Act (FITARA) was implemented to mandate that agencies consolidate and optimise their data centre fleets. In 2016, Data centre Optimization Initiative (DCOI) was announced with mandates to report energy, cost savings and originally PUE. Recently, the Government launched the Energy Act of 2020, requiring additional actions of the government sectors on data centres.

Dr PAYNE reported that the regulations of data centre energy in the U.S. were growing and evolving. Some requirements help drive the efficiency of data centres owned or operated by the U.S. Government. There are drivers for more regulations to the data centre, including crypto-mining, high water use associated with data centres and their evaporating cooling, etc.

3.2.2. Sharing 1.2: BEAM Plus Data Centres & Green Data Centres Practice Guide

Presenter: Ir CS HO, General Manager, BEAM Society

BEAM Plus Tools - Building Environmental Assessment Method (BEAM)

To develop HKC as a green data centre hub, the Building Environmental Assessment Method (BEAM) tool has been developed to measure the green performance of the data centre. It is HKC's Green Building Rating Tool to access the data centre and tell the development trend of the environmental friendliness, encouraging the data centre towards a greener. For BEAM, there are different tools for Stages of Project Development, including Master Planning (BEAM Plus Neighbourhood), Building Design and Construction (BEAM Plus New Buildings v2.0, and BEAM Plus New Data Centres v1.0), Operation and Management (BEAM Plus Existing Buildings v2.0, and BEAM Plus Existing Data Centres v1.0), and Fit-out / Renovation (BEAM Plus Interiors v1.0).

Features of BEAM Plus Data Centres Manual v1.0

BEAM plus data centres manual v1.0 embraces three principles, namely, handiness, emphasis and uniqueness. The benefits of the BEAM plus data centres tool include the provision of the Data Centre's Whole Life Cycle Environmental Performance, the improvement of energy performance and the certification of green data centres.

BEAM Plus Assessment

Ir HO estimated that the data centres in HKC achieved an average PUE of 1.82 in 2018. Based on the assessment route of BEAM, the evaluation criteria can be summarised. For new data centres**,** a maximum of 17.5% energy saving could be achieved by a Platinum-rated data centre with a target PUE of 1.5. The maximum energy saving percentage for existing data centres was estimated similar to the new data centres.

Green Data Centres Practice Guide

Green Data Centres Practice Guide is developed to provide the best practices, assist industry practitioners in identifying and implementing measures, and improve the energy efficiency and environmental performance of their data centres. The Green Data Centres Practice Guide provides a list of best practices and options for relevant stakeholders to plan design construct manage and operate green and sustainable data centres. It also provides a list of metrics to measure the energy and sustainability efficiency of data centres and identify potential areas for improvement. The best practices covered in the Practice Guide are categorised into ten major areas, including general aspects, cooling system, power system, monitoring and managing energy efficiency, IT equipment deployment, IT application system and IT service deployment, telecommunications and network cabling, green construction, management and maintenance and green disposal.

3.3. Section 2 - Energy Data Collection and Analysis of Data Centres

3.3.1. Sharing 2.1: Data Centre Energy Use in APEC

Presenter: Mr Glen SWEETNAM, Senior Vice President, Asia Pacific Energy Research Centre (APERC)

Mr SWEETNAM reported the energy used details in Data centres. There was 55% of the energy used in the data server and air conditioning was 38%. Data centres cost 200 TWh and accounted for 1% of global Internet electricity consumption.

The importance of data centre energy use varies by the economy

In Japan and Hong Kong, China (HKC), the shares of data centre energy consumption to overall energy consumption were relatively small. Electricity consumption of data centres shared in Japan in 2018 accounts for 1% of total energy consumption, and data centre energy consumption shared in HKC in 2019 accounts for 3% of total consumption. From the global perspective it's not a large use, but clearly in local areas. It could be significant and the localized effects on distribution systems could also be very significant.

Future consumption could depart from historical trends

In the future, the energy train can depart from historical trends in other words. We are sort of living through an era in which we can increase the use of data centres dramatically, but not have a significant increase in energy use. Because Moore’s law is approaching the limitation, the trend will change if Moore’s law becomes invalid. Mr SWEETNAM reported a simulation of future energy consumption of data centres, there will be an increase of 11% by 2030. If there is a situation of both the end of Moore's law and the dramatic increase in the industrial Internet of Things use, there will be an increase of 89% by 2030, and a 95% confidence range went from an increase of only 14% to an increase of 244%. So, continuing to monitor and measure data centre energy use is important to make sure people can track this trend.

Cryptocurrency mining is another load to monitor

It was estimated that current usage is about 100 TWh[5] a year. So, crypto-currency mining is only about half the level of the data centres overall but another one that power consumption could take off. Computing where electricity is cheap and computing power is cheap so once again monitoring that and trying to make sure people or Government understand.

Mr SWEETNAM concluded that computer servers occupy 55% and air conditioning occupies 37% of total data centres’ power consumption. The electrical and mechanical loads are the keys to reducing energy consumption and increasing energy efficiency in data centres. Despite the rapid growth of the last 10 years data centre power consumption remained relatively flat. Nevertheless, data centre energy use could be important in service sector economies or specific local situations. If energy efficiency improvements failed to keep pace with increased activity, these data centres in cryptocurrency power demand to grow rapidly. Mr SWEETNAM suggested closely monitoring the data centre energy use and keeping track of it.

[5] https://digiconomist.net/bitcoin-energy-consumption/

3.3.2. Sharing 2.2: Energy Survey of Data Centre in HKC

Presenter: Ms Becky CHIM, Engineer, Electrical and Mechanical Services Department (EMSD), the Government of the Hong Kong Special Administrative Region, Hong Kong, China

Purpose of energy survey

Ms CHIM shared that energy surveys have been conducted to understand the energy consumption pattern of the particular sector or segment in Hong Kong, China. By referring to the data collected from the surveys, the Government can identify potential areas to formulate energy efficiency policies and set energy-saving targets. After the implementation of the energy efficiency measures, the energy data collected through surveys is used to compile the energy indicators to monitor the progress and effectiveness of the energy efficiency measures.

Energy survey in HKC

In Hong Kong, China (HKC), EMSD has published annually the “Hong Kong Energy End-use Data” for over 20 years. It is well structured and covers energy consumption in different sectors, segments and further down to end-use. It provides an understanding of the energy consumption patterns and usages in HKC and served as a reference for the Government to formulate and evaluate energy efficiency policies.

Data centre segment

To refine the current commercial sectors, the business development in HKC had been reviewed. By referring to the business reports and consultation with other Government departments, it is noticed that the data centre in HKC is booming and its energy and consumption might have a significant rise. Therefore, HKC conducted an energy survey on local data centre businesses.

Data collection

In the survey, the data were categorised into four parts. The first one was general data. It includes company information, building information, premises information, etc. The second one was equipment information including air conditioning arrangement, the number of lighting fittings, IT equipment information, locations, and areas. The third one was the operational information, which includes operating hours and the number of staff. The last one was the annual energy consumption, which includes annual IT load, annual facility load and end-use.

Scale-up factor

By analysing the energy consumption data and the activity data collected, Ms CHIM shared that the highest correlation factor identified could be used to scale up the total energy consumption of the segment. Two scale-up factors were considered in the data analysis, the total net floor area of data centres and the total number of server racks of data centres. As the total number of server racks had a stronger correlation with the energy consumption in the survey, it was therefore taken as the activity to scale up the territory-wide total energy consumption of the segment.

Survey challenges

Ms CHIM highlighted several survey challenges. The first challenge is the definition of the data centre for setting the data modelling structure. By referring to international guidelines/ standards and conditions in HKC, the data centres in the survey were classified into two types, operated by a service provider and enterprise owned. The list of establishments for data centres in Hong Kong, China not available was another challenge for the survey. Ms CHIM shared their experience in compiling a list of establishments by conducting searching from different sources of information, such as business reports, consulting other Government departments, etc. The third challenge was the difficulty in collecting data from data centre operators. After sending questions to data centre operators, they expressed their concern about disclosing their energy consumption which is considered sensitive information. To address their concern, a designated Government hotline was set for addressing interviewees' inquiries about the information requested in the questionnaire. Moreover, only aggregated data would be disclosed to maintain confidentiality for all the data collected.

Ms CHIM summarised the elements for conducting a data survey for data centres:- First, to understand the local data centre market development and to define the most suitable data collection structure; Second, to engage survey specialists who understand the energy consumption components in data centres. The specialist could collect the required information more efficiently.

3.4. Section 3 - Women's contribution and opportunity in Data Centre Development

3.4.1. Sharing 3.1: Impact of COVID-19 on women in the STEM workforce: Asia-Pacific

Presenter: Prof. Frances SEPAROVIC, Foreign Secretary, Australian Academy of Science, Australia

Prof. SEPAROVIC summarised the impacts of COVID-19 on women in the Science, Technology, Engineering, and Mathematics (STEM) workforce in the Asia-Pacific region in the presentation. It helped the participants to understand the impacts, uncover solutions, and offer ways for the STEM system to work together for gender equity.

The project research was based on a survey about women in STEM. The survey involved 865 women from 31 Asia Pacific economies. 80% of them have postgraduate quantifications. 53% of them worked at a university and worked on research and 49% have permanent positions. The women, who were surveyed, were of different stories, which highlighted their experiences as women.

The research results showed that the pandemic has a significant impact on women in STEM across the APEC region. This could be attributed to four aspects: the commitment of women to STEM, personality, flexibility and mental health. It was reported that 59% said personal passion was the reason they would stay in STEM. For example, 56% of women with caring responsibilities had access to flexible work. 39% of early career women are in fixed-term contracts and less secure. In addition, the surveyed women said that they need to embed flexibility in the roads to recovery, such as flexible work arrangements and measures of work productivity. Some specific and difficult challenges mainly include negative mental health impacts. 50% reported negative health impacts concerning work or home life, and 30% reported an increase in workload and a decrease in productivity. Prof. SEPAROVIC reported that were four aspects that reflected the impacts on women in STEM in the Asia-Pacific region: the professionals at work, challenging boundaries, social change and individual well-being in Asia-Pacific and beyond.

For professionals at work, Prof. SEPAROVIC reported four key findings. It was found that women in STEM have less secure employment and are more susceptible to job loss. COVID-19 has exacerbated gender inequity in STEM workplaces as women balance work and non-work responsibilities. Also, women are reluctant to leave STEM, but lack of career opportunities in their careers is the main reason they leave.

Prof. SEPAROVIC proposed several actions to tackle these problems It is recommended to acknowledge existing disparities and develop baseline measures to understand inequity in organisations. In addition, maintaining existing diversity, inclusion and equity activities and evaluating them is also important for professionals at work. The action to develop flexible and inclusive workplaces for all genders, and develop flexible measures to measure productivity and success in STEM is of vital significance.

For challenging boundaries, it was found that COVID-19 restrictions such as lockdowns blurred the boundaries between work and home as there was the widespread adoption of work from home. Given this, it was recommended to deepen understanding and awareness of the impact of increased online engagement on work and personal lives and ensure digital accessibility and support to all. Another finding is that many women experienced a substantial increase in caring and domestic duties. Therefore, it was necessary to have more accessible and affordable childcare and paid parental leave. In addition, it was also found that overlapping of work and home spheres has a significant impact on women’s productivity and capacity to do research. The action called for this point is to support the development of new skills for online teaching and collaboration.

For social change and individual wellbeing, Prof. SEPAROVIC stated that mental health has been impacted by isolation, managing competing priorities and lack of opportunity to ‘switch off. Individuals' opportunity to feel part of their community and access support networks has been also affected. In addition, women with caring responsibilities and those who reduced their working hours have been particularly affected. Prof. SEPAROVIC proposed several helpful actions. It was recommended to acknowledge individual health and wellbeing as priorities and to ensure access to mental health support now and in the post-pandemic recovery. Also, taking flexible approaches to better respond to individual circumstances is effective. Furthermore, it was necessary to explore and develop professional support networks and to offer flexibility and grant extensions where possible for grant applications and research deliverables.

For Asia-Pacific and beyond, Prof. SEPAROVIC concluded several key findings. The pandemic led to the rise of common social changes across all economies and as such global solutions are required. Different parts of the region shared different perspectives on the capacity of their economy to respond and their access to infrastructure, and the need for regional strategies and collaboration are needed. The recommended actions were to drive ongoing commitment and action to advance the APEC Women in STEM Principles and Actions, to recommit economies and communities to the UN Beijing Declaration 1995 and SDGs and track progress on gender equity aspired to in these frameworks. In addition, it was important to create opportunities to share best practices among economies in the region, including consideration of the International Science Council's initiative to address the gender gap in science and mathematics. Furthermore, leveraging existing domestic strategies that address gender equity in STEM and using them as a blueprint to extend their reach throughout the region is also an effective method.

3.4.2. Sharing 3.2: Empowering Young Women in APEC for Climate and Energy Innovation

Presenter: Ms Natalie CHUNG, Members of the Council for Sustainable Development and the Green Tech Fund Assessment Committee, Hong Kong, China

Data centres are responsible for around 1% of global electricity demand. With a 60% increase in data traffic per year, data centres are becoming a more prominent source of greenhouse gas emissions, posing decarbonisation challenges for APEC economies. Ms CHUNG reported that women innovators are not gaining enough support in the net-zero transition, in particular for STEM industries. For instance, only 2.3% of all venture capital funding was received by women-led startups in 2019.

Ms CHUNG quoted a research result from Project Drawdown (2020), which showed that educating girls is the top 6 solution for climate change. Gathering fuelwood for cooking is the daily chore of millions of women and girls in North Asia and Southeast Asia, preventing them from education. Burning biomass also creates significant greenhouse gas emissions and indoor air pollution, posing threats to women's health and the climate system. It was observed some co-benefits can be achieved through the education of girls and better family planning for enhanced climate adaptation and resilience.

Ms CHUNG demonstrated several examples of women's contribution to tackling climate change and highlighted several international networks for training women. BRICS Youth Energy Summit was one of the largest events for youths in BRICS countries on energy cooperation. There is a growing recognition of young female climate advocates across Asia and the APEC region, such as Brazil, China, India, and Russia. There are numerous networks internationally and locally to train women leaders in taking up a more prominent role in contributing to the climate crisis, such as United Nations Sustainable Development Solutions Network. Another example of empowering women was the Government setting up different funds for entrepreneurs to commercialise decarbonisation technologies, such as the Green Tech Fund set up in 2020.

Ms CHUNG concluded that there are many hidden women entrepreneurs and innovators around us. What is needed is to facilitate them to innovate for data centre decarbonisation, through the provisioning of funding opportunities and platforms for training the future generation of entrepreneurs and ESG professionals.

3.5. Section 4 - New and renewable energies, and innovative technologies applications for data centres

3.5.1. Sharing 4.1: China's Strategy for Adopting Renewable Energy and Carbon Emission Reduction for Data Centre

Presenter: Prof. Junhua ZHAO, Associate Professor, The Chinese University of Hong Kong (SZ), China

Background

China's data centre and power grid are planned independently. In this circumstance, the utilisation of renewable energy in supplying the data centre is insufficient. Prof. ZHAO reported that there were 80,000 data centres in China in 2020. They consumed around 2.2% of electricity in China. Considering most computing power consumption were located in the east of China while the energy resources are located in the northern and western regions in China, China's National Development and Reform Commission (NDRC) proposed the domestic project of East-to-west computing resource transfer project, aiming to build 8 computing hubs. They were trying to relocate the data centres for matching the computing power with the energy resource distribution. Besides, the Chinese Government built the inter-provincial ultra-high voltage transmission DC/AC power transmission system to transmit electricity from northern and western China to the eastern coast load centre.

Methodology of study

The grid energy flow and data centres computing flow are considered as a bi-level programming model to evaluate the benefits of carbon reduction and energy cost of the ECRTP. This bi-level programming model could facilitate the planning of data centres and electricity networks, improve the utilisation of renewables and the decarbonisation effect, and lower the electricity cost.

Scenarios settings

Different scenarios were considered to study the impact of significant factors such as optimisation goals, power generation policy scenarios, planning schemes and carbon prices on the benefits of ECRTP. The benefits of ECRTP were analyzed annually from 2020 to 2030. Among these scenarios, a baseline scenario was set. In the baseline scenario, the optimal goal was to minimise the costs of electricity costs, carbon costs and total cost of electricity and carbon. The policy scenarios considered include the Announced Pledges Scenario (APS) and The Stated Policies Scenario (STEPS). Besides the Scheme of the National Development and Reform Commission (NDRC), an optimised scheme in terms of carbon emission reduction benefits, which was termed "The Proposed Scheme"(TPS), was included in the study.

Evaluative Metric

To analyse the benefits of ECRTP, five comparing metrics were adopted, including total carbon reduction of all data centres, electricity cost reduction of all data centres, the carbon intensity of data centres, average electricity cost of data centres and consumption of renewable energy.

Results

Different results could be obtained from the five aspects.

1. In terms of energy flow and data flow between provinces in China, the TPS outperformed the NDRC scheme with better utilisation of renewable energy resources as the computing power might further relocate to western and northern provinces where the renewable energy resources are rich.
2. Regarding the benefits of carbon reduction & electricity cost, the TPS was largely superior to the NDRC scheme in terms of carbon reduction and electricity cost reduction. The TPS had higher benefits in terms of carbon reduction and lower electricity costs.
3. For the sensitivity analysis of carbon prices, the TPS had the greater electricity cost reduction of the proposed scenario relative to the NDRC scenario.
4. For scale planning of data centres at the provincial level, under different schemes, the growth potential of data centres in different provinces was different. In TPS, the data centre in Yunnan had greater growth potential with its abundant hydropower. However, in the NDRC scheme, Yunnan was paid little attention.

In conclusion, Prof. ZHAO recommended that the ECRTP can provide more benefits if engaging more renewable energy resources supply to the data centre.

3.5.2. Sharing 4.2: Provision of Grid Services by Data centres

Presenter: Dr Nanpeng YU, Associate Professor, Department of Electrical and Computer Engineering, University of California, Riverside, The United States

The presentation of Dr YU included four parts: background, provision of Frequency Regulation Service in Power Transmission Grid, provision of Phase Balancing Services in Power Distribution Grid and conclusion.

Data Centre Energy Consumption and Efficiency

The data centre industry consumed a lot of energy in 2020, the worldwide data centres consumed between 200 to 400 terawatt hours of energy. Dr YU estimated that the data centres account for roughly 2% of total electricity use in the United States. Data centres are one of the most energy-intensive building types. According to the U.S. Department of Energy’s Office of energy efficiency and renewable energy, data centres consumed 10 to 50 times the energy per floor space of a typical commercial building. As for energy efficiency, the metric of power used effectiveness (PUE) was typically used. PUE is a ratio of the amount of energy used in data centres by the amount to run the processors. Dr YU reported that PUE has been reduced significantly from about 2.5 in 2009 to about 1.67 in 2019. According to the latest data from Google, Facebook and Amazon, the PUE of their latest cloud data centre were reduced to below 1.2.

Provision of Power Grid Services by Data centre

Besides reducing energy costs and emissions, the data centres are expected to provide different types of grid services. Data centres can provide services at three different levels. For the transmission system and wholesale market, the data centre can provide an ancillary service, i.e. frequency regulation. For the distribution system, the data centre can provide distribution peak shaving, retail energy time-shift, distribution voltage support and phase balancing. For a microgrid, the data centre can support voltage and minimise energy costs.

Provision of Frequency Regulation Service

Due to the increasing integration of renewable energy around the world, the intermittent output of these renewable energies and higher frequency regulation service costs, the power system operators have an increasing need for frequency regulation services. There are two types of frequency regulation services. One is the conventional resources like generators, the other is the fast-moving resources such as batteries and data centres. The feasibility and profitability are the two key points for providing frequency regulation service by the data centre. Regarding feasibility, the data centre can track the frequency regulation signals very well. For profitability, it will be profitable for data centres if the frequency regulation service price is higher than the electricity price. The overall framework of the proposed frequency regulation service provision by the data centre has two different phases: hour-ahead market and real-time operations. The data centre control system will try its best to follow the frequency set points. Dr YU shared an example for this issue, a data centre with 100,000 servers, the introduction of a dummy load and realistic server power consumption model allows real-world frequency regulation signal following with over 95% accuracy.

Data Centres to provide the Phase Balancing Service

The unbalance in power distribution systems would affect power quality and damage electrical equipment and appliances. A high neutral current will result in the tripping of a protective device. The integration of a new data centre into an existing distribution network can exacerbate the degree of unbalance in the distribution circuit. Therefore, the idea is that by moving the computing load of a data centre from one phase to another, the unbalance then can be significantly mitigated. This is the principle that the data centres can provide balancing services.

Dr YU concluded that with the increasing deployment of data centres around the world, it was crucial to think about how to leverage them to provide valuable services to the electric grid. It was not only technically feasible but also economically profitable for data centres to provide services to power transmission and distribution systems, it was critical to combine data centre operations knowledge and machine learning algorithm to develop sophisticated controls for data centres.

3.5.3. Sharing 4.3: Internet Data Centre – Grid Planning

Presenter: Prof. Joe DONG, Professor, School of Electrical and Electronics Engineering, Nanyang Technological University, Singapore (formerly with the School of Electrical Engineering and Telecommunications, University of New South Wales Sydney, Australia)

Power System Resilience

Resilience is the ability of a power system to withstand and quickly recover from disturbances or interruptions caused by physical or cyber incidents and remain stable in operation. Considering the physics of the power grid requires a balance of energy at all times, the ability and availability of resources (energy and network to transfer energy) in the grid are essential in maintaining power grid resilience. Data centres become the new major demand growth. The data centre can support the grid resilience by being the physical power system controls and assisting energy market trading.

Energy Management of IDCs

The basic components of an internet data centre (IDC) consisted of IT, cooling and energy equipment. The energy management techniques target controlling the power consumption of each component via proper control and scheduling, such as server control, air conditioning control, workload scheduling, and energy storage scheduling.

DC2G Integration - Mutual benefits

IDC is a type of temporal-spatial flexible load in power grids, which can provide a flexible resource on the demand side. There is a need for future grids to explore more flexible resources from the demand side. The Internet Data Centre-to-Grid Integration (DC2G) can upgrade the operational management of IDCs to maximise profit and exploit the flexibility of IDCs to enhance grid resilience.

DC2G Integration - Integrated Planning

Considering the coupling relationship between IDCs and power grids, an integrated planning scheme can be designed for better resilience. The integrated planning scheme can be formulated by three objective functions, including the minimisation of IDC's average service delay, the system's total cost, and the peak-to-average ratio of the system's power load. In detail, the first objective is from the service quality perspective, which aims to provide services as fast as possible. The second objective is to optimise the fixed cost of the data centres and battery energy storage systems from investment and operating costs. The last objective is to contribute to the deferral benefit of distribution system planning and provide better pricing as a user from the demand side.

DC2G Integration - Participating in Energy markets

The IDCs were characterised by energy prosumers, load flexibilities, and strategic players, which have the potential to obtain profits and arbitrage in electricity markets. Moreover, IDCs can maximise their profits in local energy markets as prosumers, price-makers, and ancillary service providers compared to engaging in grid-scale electricity markets.

IDCs can engage in local energy markets via a two-stage framework. In the first stage, IDCs can participate in energy trading of multiple local energy markets. In the second stage, the IDCs can participate in energy balancing.

Future Opportunities

Considering the IDCs can communicate with each other via the Internet and IDC loads can be redistributed across different power grids via request allocation, coordinate management of multiple power grids with spatial IDCs could be exploited in future work. As a service market and different markets can be coordinated and also through the cloud and the users and also participating retail energy market for the wholesale energy market as well. This is a new form for the electricity market into the next stage given the increasing data centre. Moreover, the regional power grids and regional data centres can be coordinated through sharing and request coordination. This allows the opportunity for managing the power grid with data centres and enhancing the data centre resilience.

3.6. Section 5 - Best practices of energy efficient, renewable and resilient data centres

3.6.1. Sharing 5.1: Recent digital strategies of Alibaba Cloud data centre to reduce carbon emissions

Presenter: Dr Xin FANG, Business Director, Data Centre, Alibaba Cloud, China

Dr FANG introduced the recent digital strategies of the Alibaba Cloud data centre to reduce carbon emissions. Alibaba planned to establish a green and efficient data centre. Alibaba's Zhejiang Renhe Cloud Data Centre, which opened in September 2020, deployed the world's largest liquid-cooling cluster, with the lowest PUE of 1.09. Dr FANG reported that carbon emission is a concern in Alibaba's data centres. In 2021, Alibaba published a carbon neutrality action report.

Alibaba Cloud Infrastructure

To achieve their target of carbon neutrality, Alibaba's infrastructure made multiple strategies related to planning design cited sections and so on. Alibaba's infrastructure improved the promotion of renewable energy by investment all transactions. Dr FANG thought immigration like the Micro Gates Data Centre from East to the West was also an effective way to acquire more green energy. Besides, new energy-saving techniques are also critical.

Faraday

Dr FANG introduced available strategies to enhance efficiency and reduce carbon emissions. Firstly, Carbon

Asset Management (Faraday) is the software which could help quickly review the carbon footprint of data centres and provide primary analysis. It contains the carbon bill, third-party verification, short-term and long-term carbon prediction, and dynamic carbon neutral strategies. Secondly, there are several technical reduction solutions such as cooling system optimiser, capacity management, liquid cooling and renewable energy integration. Based on the liquid cooling system, Renhe data centre has the lowest PUE(1.09).

Alibaba cooling system optimiser

There is another product of the AI power platform to optimise the operating conditions of the cooling system. Alibaba uses its cooling system optimiser to help shorten waiting time and quickly find the optimal result to realise the nearly lowest energy consumption of the cooling system.

Dr FANG mentioned that Alibaba Cloud would focus on technological innovation and R&D investments in both software and hardware, and were committing to power cloud computing with 100% clean energy no later than 2030.

3.6.2. Sharing 5.2: Zero Carbon Transformation Experience Sharing from Huawei - Boosting energy transition towards a net zero carbon future

Presenter: Mr Patrick PAN, Planning and Consulting Expert, Electric Power Digitalisation Department, Huawei Technologies Co., Ltd., China

Mr PAN provided sharing in three parts - net-zero transformation, energy transformation, and digital transformation. Carbon neutrality and peaking targets drive the energy industry to achieve green, low carbon and digital transformation. Huawei proposes a net zero carbon intelligent campus solution. It is divided into three steps, from low carbon innovative campus to a near zero carbon smart energy campus and finally reaching the net zero carbon campus. For the three transformations, the strategies are different.

Net zero transformation

Mr PAN mentioned that Huawei considers carbon footprint monitoring, statistics, and disclosure across the value chain. Integrated carbon management and trading platform are needed for full-lifecycle management of carbon assets. Meanwhile, the linkage between carbon and energy supported decision-making and optimisation of carbon and energy and reduces carbon costs.

Energy transformation

Mr PAN reported the replacement of fossil energy with green energy, multi-energy complementary, and multi-energy co-supply for energy transformation. Optimisation of power, network, load, storage and efficient energy conversion is important. Actions such as smart operation analysis, visualized, manageable, and controllable energy system running, saving energy and improving efficiency are taken.

Digital transformation

The intelligent IoT platform implemented real-time sensing of all elements and connected all things. Moreover, the digital platform implemented online monitoring bridged information silos, and implemented all-domain convergence and unified management and control. Intelligent decision-making supported agile service development, and efficient innovation is available. These will be realised in four flows: carbon emissions flow, energy flow, information flow, and value flow.

Mr PAN reported Huawei will use innovative DC technologies to build a future-proof data centre. It contained four parts, i.e. power, cooling, O&M, and deployment. In the power part, it uses converged modular power POD, which includes an integrated transformer, LV panel, modular UPS and Lithium-Ion battery. It saves space and is scalable for phased deployment. A cooling system uses a fan wall and indirect evaporative cooling. In the O&M part, it integrates AI self-driving and ICT facilities. AI will be adopted for the PUE optimisation, energy consumption prediction, unattended inspection, health prediction and alarm root cause analysis. For the deployment part, it takes prefab modular architecture, and horizontal and vertical scalable, which reduce upfront cost by 30%.

Mr PAN reported that the Huawei Smart Prefab modular DC brought a lot of benefits. The PUE value of the data centre was lowered by 8%, and the TTM descends 50%. The initial investments were cut down by 30%. Huawei designed a data centre in Dubai. The capacity of this data centre was 12MW and the PUE value reached 1.28 in a desert area. Also, one of the Huawei data centres in Beijing applied the prefab modes. Compared with the traditional solution, the TTM of prefab mode only was a third of the traditional solution and the PUE value was from 1.45 to 1.15.

3.6.3. Sharing 5.3: Operation Best Practice of energy efficiency in data centres

Presenter: Mr Arno VAN GENNIP, VP of Operation Engineering, Equinix

Operation Core Principle

As a colocation provider, Equinix developed the operation core principles of data centres. The specifications of the data centre design should be tested at 100% of that design. Once in operation, the settings of the cooling system should be adjusted to the actual load and operational conditions. Power generation, distribution, and consumption are determined by the energy requirement of the data centre. Taking the PUE 1.6 data centre as an example, more than 80% of the energy to operate the data centre sits in its cooling system. The IT load is customer driven and hence can not be influenced.

Cooling System-Energy Efficiency

The controls of the cooling system include the following four aspects: automatic measuring supply air temperature, supply water temperature, air temperature difference ΔT_{air} and water temperature difference ΔT_{water}; introducing the KPI dashboard to get a grip of the above four parameters; energy efficiency in data centres start with airflow management, then controls of that air, then controls of the chilled/condenser water and only after that by replacement of equipment.

Cooling System-Environmental sustainability

In addition to energy efficiency, environmental sustainability has gained the attention of the data centre. This includes taking care of the amount of water used and employing various new technologies to avoid the use of chemicals in the water treatment plant. On the one hand, the use of adiabatic cooling reduces the amount of electricity to operate the cooling system. On the other hand, new refrigerants with 0 to 1 GWP have little impact on the environment. Diesel generators are the right choice for backup power sources until the promised hydrogen economy is available. Alternatives to diesel generators as a backup power source exist in the market but are yet uncommon. An alternative for diesel is HVO which is more and more available However, it is still available in many economies in APEC. This will reduce the CO2 carbon emissions by 90%, a bit more expensive than diesel but well worthwhile. All the electricity supplied to the IT equipment is turned into heat. Hence, it is very sustainable to reuse that own created heat as much as possible and to look at possibilities to export that heat for reuse.

Mr VAN GENNIP concluded that the cooling system is the core for enhancing the energy efficiency of the data centre, which needs a lot of technical support. With the increasing number of data centres in recent years, it will be a daunting task in the future to coordinate and run the huge number of data centres in concert. For data centre clusters, the technical upgrade of the cooling system is also worthy of attention.

3.6.4. Sharing 5.4: Best practices for energy efficient and environmentally sustainable data centres

Presenter: Prof. Rabih BASHROUSH, Global Head, IT Infrastructure Advisory, Uptime Institute

Prof. BASHROUSH started by explaining the energy consumption for data transmission and storage.

Bitcoin energy consumption increased from less than 20 TWh in 2017 to 172 TWh in 2021. 105 countries' electricity consumption reports in 2018 showed a total annual consumption of 171 KWh. Bitcoin energy consumption in 2021 is equivalent to the energy consumption of 105 countries in one year. The increase of internet users leads to energy consumption increasing. The internet companies of Facebook, Whatapp, Instagram, and Tock Tick took 8 years, 8 years, 7 years, and 3 years to reach 1,000,000,000 monthly active users, respectively. Google's energy consumption rose 33% year over year between 2017 and 2018, and Netflix's rose 84% year over year in 2019.

Prof. BASHROUSH estimated that the data centres currently consume 2% to 4% of the world's electricity generation, energy efficiency can be improved by following four aspects: the increased efficiency of IT and DC infrastructure, adoption of the best practices to reduce e-waste to landfill, increased production and usage of renewable energy and offsetting initiatives (carbon capture, heat reuse, plant trees and water usage).

Energy Consumption Reduction - Energy Efficiency

By far, the most likely causes of data centre energy efficiency are the under-utilisation of facilities and lack of modular design. First, the facility needs to ensure that it meets the needs of the next 15-20 years, but it cannot be oversized. The unnecessary investment will reduce the efficiency of the facility. Prof. BASHROUSH recommended we should make sure the right size of the facility first, then use the modular design and finally introduce infrastructure services. The high energy efficiency of a data centre is to ensure that its utilisation rate is high, which is the purpose of right-size and modular design. Air containment, adiabatic cooling, temperature setpoint, modular UPS systems, AC/DC conversion, etc. are typically best practices. Prof. BASHROUSH reported that IT infrastructure utilisation is 15% to 25% of the time, idle operation around 80% of the time, but still consuming electricity. So, the electrical infrastructure must be running to support the work of these IT infrastructures. Therefore, the next goal is to increase IT infrastructure utilization to 30%-40%.

Energy Consumption Reduction - Renewable Energy

There is an increase in the use of renewable energy (REF-(site selection, PPA, direct investment, VPPA, ReGos/RECs, etc.) in data centres by piloting power purchase agreements in rich renewable energy areas and encouraging renewable energy production. If the workload is more flexible, it may not have to run at a certain time of the day. Match workload to renewable energy availability when possible. It is recommended to utilise green energy solutions such as Green Hydrogen fuel cells where applicable.

Energy Consumption Reduction - Circular Economy

Optimising the age of the kit to increase use-phase efficiency while reducing e-waste in landfill is an effective way. Its purpose is to know the age of your equipment, extend equipment life and reduce order cycles for new products. On the other hand, introduce operating procedures to encourage the recycling of equipment. Finally, track and measure GHG Scope 3 impact (soon to be mandatory in some jurisdictions) to judge whether digital services will affect downstream and upstream.

Energy Consumption Reduction - Offsetting & Other Initiatives

Energy Reuse Effectiveness (e.g. through heat reuse), Water Usage Effectiveness, and carbon capture technologies are packaged in the respective offsetting and other initiatives.

With the rapid growth of information technology and the increasing demand for digital services, the soaring data centre has led to an exponential increase in power and energy consumption. These are the four main measures for improving energy efficiency and environmental sustainability in data centres. Going forward, data centres will not only focus on mechanical and electrical infrastructure but will look for opportunities in other areas to provide more comprehensive digital services.

3.7. Closing Remarks of Workshop

Presenter: Mr Barry CHU, Project Overseer, Hong Kong, China

Mr CHU concluded that APEC, as embracing digitisation, data centres were one of the key infrastructures in supporting digital transformation. The energy demand continues to grow, which was driven by the wide adoption of advanced technologies, such as artificial intelligence, virtual reality, blockchain as well as cryptocurrency. The growing energy footprint and environmental impact that go along with it could not be ignored. A concerted effort was required to ensure data centres were designed and operating efficiently, reliably and with low-carbon emissions to support the sustainable digital transformation in the APEC region.

Computer servers and their cooling were the primary energy loads in data centres. Increasing energy efficiency was essential to improve the competitiveness and growth of businesses in the long term. Reducing the power consumption not only cut down the operating expense but also alleviated constraints on the power supply, equipment cooling as well as space. In this connection, sharing by various trade experts, on “Digital strategies to reduce carbon emissions” and “Best practices for energy efficient and environmentally sustainable data centres”, were well received. Proposing areas for collaboration via the APEC Expert Group on Energy Efficiency and Conservation, which has been actively promoting various energy-efficiency practices and technologies could be considered by APEC member economies.

Data centre operation requires a reliable and affordable power supply. Grid integration and renewables were alternative approaches which help cut down carbon emissions as well as offer resilience against energy price volatility and supply chain security risk. The sharing on “Energy Management and Grid Resilience Support” and “Data centre-to-Grid Integration,” was both thought-provoking. The growth in data centre loads results in higher demand for energy storage capacity. Integrating data centres and the grid offers a triple-win opportunity for data centres to monetise existing energy storage assets in conjunction with improving the resilience of the grid and enabling the integration of more renewables.

Data transparency is indispensable to raise the awareness of the public and operators and stimulate competition to strive for higher energy performance. Speakers highlighted the importance of monitoring data centres’ electricity demand, which gives an early warning signal when the energy consumption departs from historical trends. Data transparency can also facilitate policymakers to monitor the progress and effectiveness of the energy efficiency measures, and thus accelerated green data centre development.

Mr CHU encouraged more collaborations between data centre operators and Government agencies to enhance sustainability in next-generation data centres.

4. Summary of Discussion

(i) Session 1 - Guidelines, Standards, Certification Schemes of Data Centres (moderated by Ms Jovian CHEUNG, EGEE&C Secretariat)

Q1. In 2019 the United States removed the PUE target, would Dr PAYNE share with us what is the disadvantages or limitations, and what are the reasons the United States remove these targets?

Answer from Dr Christopher PAYNE: It was difficult for the industry to agree on that metric and an effective metric for measuring the performance of data centres. It was partly because different data centres use energy differently. There was a lot of concern about the IT side of the PUE metric in terms of the requirement on the portion of the metric to be effective. Therefore, there were many industries concerned about the scale of its use. PUE was an early standard metric. Lots of people used it and it does have that benefit. The second problem in the use of PUE was that it was a ratio. The energy consumption of information technology could continue to go up while the PUE remains constant or even goes down. That does not constrain the total carbon emission.

Q2. Could Dr PAYNE share with us what kind of carbon reduction targets will be a focus in the outcoming years in the United States?

Dr Christopher PAYNE: There are carding reduction targets in some states, such as California. Those tend to be very macro-economic, they are not specific in data centres. Data centres are very energy intensive. The state-level carbon targets are relatively small fractions. However, many private entities and the Government have committed to using carbon-free electricity to power data centres. In that context, identifying carbon-free electricity becomes a driving force to provide more renewables on the grid. The U.S. government sector just established a carbon target in which government agencies use carbon-free electricity for 50% and 100% of their load by 2030 and 2050, respectively. So, the primary carbon reduction target in the government sector is the development of carbon-free electricity to drive data centres.

Q3. There were a lot of small data centres in Hong Kong, China. Because the energy price is a supply chain security issue, would Ir HO share with us how data centres, particularly small data centres can go through this energy transition in the third party energy resources?

Ir CS HO: It should be optimistic to see small data centres being phased out. The trend is going towards the bigger and bigger because big data centres have higher efficiency.

Q4. Would Ir HO share the opinion about energy-self-sufficient data centres for microgrids in the United States and Hong Kong, China?

Ir CS HO: One thing was the difference between small and large data centres. Edge data centres are smaller data centres, operated by big companies. There is a difference between the size of the data centre and the certification of the data centre. So, it is easier to achieve a self-sufficient smaller data centre in the edge situations. It is a significant challenge to bring renewable energy to a large data centre. A possible way is to adopt distributed energy systems in which the rejected heat from data centres could be utilised, and large-scale renewables like wind power could be implemented. Another possible and powerful solution is to shift data centre loads geographically from location to location to match available renewable resources.

(ii) Session 2 - Energy Data Collection and Analysis of Data Centres (moderated by Ms Jovian CHEUNG, EGEE&C Secretariat)

Q1. It was mentioned that the data centre energy consumption is a relatively small portion of the total energy consumption in the APEC economies. Would Mr SWEETNAM share the view of whether it is worth collecting the data of the data centre regarding the APEC member economies?

Mr Glen SWEETNAM: The commercial sector in Hong Kong, China uses 2/3 of the electricity while the residential uses 1/4 of the electricity. So, the data centre is not the first place to make the biggest impact. The data centres seem to be doing a very good job. When data centres get exponential growth, the problem could be addressed quickly if there is a monitoring system.

Q2. The Government of Hong Kong, China (HKC) collected the information regarding the data centre, would Ms CHIM share with us, how the HKC Government use the collected data? Is there any procedure to inspect the data centre data?

Ms Becky CHIM: The energy data collected is served as the reference for the Government departments of Hong Kong, China when they are formulating the energy saving policy or targets. For example, setting the overall energy saving goal and the policy-making of the mandatory energy efficiency labelling scheme. Similarly, the Government could refer to the energy consumption patterns and usage of the data centre segment to formulate the relevant energy-saving policy or targets. To assure data quality, follow-up interviews and onsite inspections were conducted after the collection of data.

(iii) Session 3 - Women’s contribution and opportunity in Data Centre Development (moderated by Ms Christine TSE, Senior Engineer, Electrical and Mechanical Services Department, The Government of the Hong Kong Special Administrative Region, Hong Kong, China)

Q1. Would Prof SEPAROVIC share with us some good practices, and examples of monitoring and evaluating the process of gender equality, especially for the engineering professionals, industry and data centre industry?

Prof. Frances SEPAROVIC: In the university environment, it’s important to keep records of how many people and what genders are involved. At my university, some engineering positions were created just for women. One important thing is that there is a much high proportion of women in the student population, but there is a very low proportion of women in the lecturing population. Hence, in chemistry, some positions were created for women. In the data centre industry, it would be good to encourage women to apply and to keep records of what’s happening and monitored.

Q2. Would Prof SEPAROVIC share how to increase the interest in education in the engineering professions, especially for girls?

Prof. Frances SEPAROVIC: It is good to establish role models, and talk to school girls about careers in science. Although some people say that doesn’t work, I do believe that it makes a big difference, to see that women are doing engineering and science.

Q3. Would Prof. SEPAROVIC and Ms CHUNG share how to empower Europe and women through local and international networks? It is very important to make use of the networks to empower youth and women. How to support a woman in a STEM career?

Prof. Frances SEPAROVIC: Flexible work patterns are something that has emerged and being able to participate online is helping us create networks worldwide. It’s important to have a network, such as joining professional associations, participating in events, and asking questions.

Ms Natalie CHUNG: An increasing number of companies integrate sustainability into their core strategy. STEM careers are gaining prominence with the innovation and digitalising of our economy. We need to promote these opportunities to the public more. Before youths decide what they like to study, we can educate them about the potential career paths and the level of flexibility that they can enjoy in such careers. Another important aspect is seeking the right mentor. For example, we organised a Lead for Sustainability Mentorship Programme with the World Economic Forum Global Shapers. We aim to expose more undergraduate and postgraduate students to careers related to sustainability, empowering the younger generation to pursue STEM careers.

Q4. Would Ms CHUNG and Prof SEPAROVIC share with us, what is the biggest challenge to providing an opportunity for women in the engineering field?

Ms Natalie CHUNG: The most significant challenge is the lack of support circles and tracks record in the field. I believe it is crucial to building a mentorship network to support the younger generation, especially women in engineering. We can also rely on professional coalitions to offer support for women in STEM.

Prof. Frances SEPAROVIC: We have to raise the visibility of women. If we don't see women in the field, we don't tend to attract them and it is also why the people at the top make better business decisions when they have diverse teams.

(iv) Session 4 - New and renewable energies, and innovative technologies applications for data centres (moderated by Prof. XU Zhao, Chairman of IEEE Hong Kong Joint Chapter of PES/IELS/IAS/PELS; Professor from The Hong Kong Polytechnic University)

Q1. Would Prof ZHAO highlight some location criteria that can favour the data centres to be more energy efficient?

Prof. Junhua ZHAO: We should try to consider the locations, which have a higher percentage of renewable energy. The Western region in China, Gansu, and Qinghai have a very high proportion of wind power. In the Southwest region, Sichuan, Yunnan, they have hydrogen power. Recently, the trend is ready to launch a large-scale offshore wind power project. For example, in Fujian, there is a large-scale offshore wind power schedule. They are suitable sites for improving efficiency and reducing carbon emissions for data centres.

Q2. Since was introduced the data centre to provide the frequency services, would Prof. YU share with us what other grid services can be provided by data centres?

Prof. Nanpeng YU: Demand-response services, machine learning requests, and some loads could be delayed.

Q3. Would Prof. DONG share with us what is the main challenge of the green data centre power supply?

Prof. Joe DONG: Contradictory objective of data centre services and the upgrading capital cost from the network are the main challenges. Given data centres have been the major growth factor, we can consider more renewable energy potential for distribution generation of data centres.

(v) Session 5 - Best practices of energy efficient, renewable and resilient data centres (moderated by Prof. XU Zhao, Chairman of IEEE Hong Kong Joint Chapter of PES/IELS/IAS/PELS; Professor from The Hong Kong Polytechnic University)

Q1. Would Prof. Rabih BASHROUSH share what are the biggest opportunities to increase energy efficiency in data centres?

Prof. Rabih BASHROUSH The biggest opportunities are going to be holistic thinking. For instance, how to optimise the delivered digital services? The opportunity could be anywhere. Significant energy savings could be achieved by this holistic thinking. The architecture and the system use this redundancy and resilience in only limited infrastructure sites. Redundancy means inefficiency because the application is underutilization. Another focus is to get the most out of the IT infrastructure. Last but not least thing is the modularizing and right-sizing of the infrastructure

Q2. There are many reviews on how we count the total energy consumption of data centres, would Prof. Rabih BASHROUSH share your views on this issue?

Prof. Rabih BASHROUSH: There are a lot of misconceptions. One misunderstanding is that the energy consumption of data centres did not go up when workloads went up one hundred and thousands of times. There are quite a few major mistakes or misunderstandings in this. The energy consumption for bitcoin, blockchain, etc. is not counted. Another misunderstanding was that the assumptions were not realistic. For instance, it was assumed the utilization of servers and data centres was around 30%. It was also assumed that all workload was going to be in large efficient data centres. It was not true that smaller data centres were getting closed. That's why many different estimations were completely different. My perception is that the consumption was about 450 terawatt in 2018 or 2019. Now it would be over 500 terawatts.

Q3. Would Prof. Rabih BASHROUSH share your views on the track forward and the biggest challenges facing data centres?

Prof. Rabih BASHROUSH: The use of renewables would be one thing. But the biggest challenges are the trend of the edge facilities for 5G and IoT. The facilities are going to be highly volatile. It is key to make sure these facilities are going to be energy proportionate, otherwise serious problems would happen.

Q4. Would Mr VAN GENNIP share with us what can the Government do to support and steer the industry in the right direction?

Mr Arno VAN GENNIP: The Government could support the sustainability efforts of the industry by forcing companies to operate at ASHRAE allowable temperature levels inside data centres at levels where the IT equipment can easily perform. That will allow more access to free cooling. Most data centres are operating to the ASHRAE recommended thermal envelope, which means somewhere between 18-27℃. IT equipment can easily do with higher temperatures. With higher temperatures, far more free cooling could be used in almost every environment around the world.

5. Conclusion

In this workshop, various international scholars and engineers share their professional points of view and investigation of the Data centre. From their expertise in analysing the data centre development in the APEC region, they introduced the background of data centres and emphasized the importance of the data centre. At the same time, they pointed out the problems and challenges that data centres are currently facing and envisioned future goals. Female experts also play indispensable roles in data centre research, and some experts shared the contributions and opportunities of women in the development of data centres.

This workshop provided an opportunity for APEC member economies to learn about energy efficiency, resilience, and green data centres standards, guidelines, and certification schemes. APEC member economies shared best practices for converting knowledge into practical action. The workshop is for promoting energy efficiencies of data centres in the APEC regions and provides a platform for fostering energy-efficient and resilient data centres. APEC economies consume approximately 60% of the world's energy. As the region becomes increasingly developed, the population shifts from rural to urban areas. Consumption will continue to increase. In 2011, APEC leaders set a goal to reduce aggregate energy intensity by 45% by 2023, against the 2005 level. We are making enduring efforts to achieve energy efficiency and conservation goals in addressing the climate crisis.

In the workshop, several key points were shared and discussed. The main conclusions could be summarised in five sections.

(1) The guidelines, standards, and certification schemes of data centres.

The FEMP data centre program of the U.S. with the implementation plan and applied actions/policy in private and public sectors for EE&C of DC were introduced. In addition, the difference between DC and other commercial buildings is identified. A designated guideline for the DC is needed according to the launched Good Practice Guide and BEAM plus (DC) in Hong Kong, China.

(2) Energy data collection and analysis of data centres.

The energy used details in Data centres were shown, and the difficulties in data collection for energy surveys in DC and seeking collaboration from the DC industry are highlighted.

(3) Women's contribution and opportunity in Data Centre Development.

The impact of the pandemic on gender inequality and also the same situation in the DC industry with highlighted solutions were proposed and analysed. It was found that the pandemic had led to the rise of common social changes across all economies and as such global solutions are required. Some action suggestions are proposed, such as "leverage existing domestic strategies that address gender equity in STEM and use them as a blueprint to extend their reach throughout the region".

(4) New and renewable energies, and innovative technologies applications for data centres.
The applicable Renewable Energy in DC was discussed. It is recommended that locating data centres in regions where there is a higher percentage of renewable energy could reduce carbon emissions significantly. In addition, innovative technologies, such as the provision of grid services by data centres, could reduce data centre operating costs.

(5) Best practices of energy efficient, renewable and resilient data centres.
Some excellent cases of the Alibaba green DC solutions and the Huawei green DC solutions were shared in the workshop. Also, a good practice by Equinix in considering EE&C and balance with the resilience of DC was introduced and discussed. The DC supports for power grid frequency regulation and grid resilience enhancement are also discussed. The measures for DC industries to follow for energy efficiency, resilience and green energy adoption are summarised.

The energy demand in data centres continues to grow, which is driven by the wide adoption of advanced technologies, such as artificial intelligence, and virtual realities. The growing energy footprint and the mental impact that goes along with it are important issues. A concerted effort is required to ensure that data centres are designed and operated efficiently, reliably, and with no carbon emission to support the sustainable digital transformation in the APEC region. Increasing energy efficiency is essential to improve the competitiveness and growth of businesses for a long time. The wisdom shared by experts on data centres to reduce carbon efficiency is helpful for energy efficient and environmentally sustainable data centres. Integrating data centres with the grid offers cheaper opportunities for data centres to modernize existing access in conjunction with improving grid reliability and resilience. More collaboration between data centre operators and Government agencies is expected to enhance sustainability in the next generation of data centres.

Annex A – Agenda

Day 1 Workshop on 28 June 2022 09:30am-12:30pm (GMT+8)

Time slot (HKT)	Sessions / Topics	Speaker and Organisation
09:30-10:00	Registration	
10:00-10:08	Opening Remarks	Mr WONG Kam-sing, GBS, JP Secretary for the Environment The Government of the Hong Kong Special Administrative Region
10:08	Photo Taking	
10:10-10:15	Project Summary	Ms Elaine YIP Engineer, Electrical and Mechanical Services Department, The Government of the Hong Kong Special Administrative Region, Hong Kong, China
Session 1: Guidelines, Standards, Certification Schemes of Data Centres		
10:15-10:35	Energy Efficiency for U.S. Data centres: Distributed And Evolving Regulation	Dr Christopher PAYNE Research Scientist Lawrence Berkeley National Laboratory, The United States
10:35-10:55	BEAM Plus Data Centres & Green Data Centres Practice Guide	Ir CS HO General Manager BEAM Society
10:55-11:10	Discussion	Ms Jovian CHEUNG EGEE&C Secretariat
11:10-11:20	Break	
Session 2: Energy Data Collection and Analysis of Data Centres		
11:20-11:35	Data Centre Energy Use in APEC	Mr Glen SWEETNAM Senior Vice President Asia Pacific Energy Research Centre
11:35-11:45	Energy Survey of Data Centre in HKC	Ms Becky CHIM Engineer, Electrical and Mechanical Services Department, The Government of the Hong Kong Special Administrative Region, Hong Kong, China

11:45-12:00	Discussion	Ms Jovian CHEUNG EGEE&C Secretariat
Section 3: Women's contribution and opportunity in Data Centre Development		
12:00-12:10	Impact of COVID-19 on women in the STEM workforce: Asia-Pacific	Prof. Frances SEPAROVIC Foreign Secretary, Australian Academy of Science, Australia
12:10-12:20	Empowering Young Women in APEC for Climate and Energy Innovation	Ms Natalie CHUNG Members of the Council for Sustainable Development and the Green Tech Fund Assessment Committee, Hong Kong, China
12:20-12:30	Discussion	Ms Christine TSE Senior Engineer, Electrical and Mechanical Services Department, The Government of the Hong Kong Special Administrative Region, Hong Kong, China
12:30	Summary of day 1	

Day 2 Workshop on 29 June 2022 09:30am-12:30pm (GMT+8)

Time slot (HKT)	Sessions / Topics	Speaker and Organisation
09:30-10:00	Registration	
10:00-10:05	Event start	
Session 4: New and renewable energies, and innovative technologies applications for data centres		
10:05-10:20	China's Strategy for Adopting Renewable Energy and Carbon Emission Reduction for Data Centre	Prof. Junhua ZHAO Associate Professor The Chinese University of Hong Kong (SZ), China
10:20-10:35	Provision of Grid Services by Data centres	Prof. Nanpeng YU Associate Professor Department of Electrical and Computer Engineering, University of California, Riverside, The United States
10:35-10:50	Internet Data centre – Grid Planning	Prof. Joe DONG Professor School of Electrical and Electronics Engineering, Nanyang Technological

		University, Singapore (formerly with the School of Electrical Engineering and Telecommunications, University of New South Wales Sydney, Australia)
10:50-11:00	Discussion	Prof. XU Zhao Chairman of IEEE Hong Kong Joint Chapter of PES/IELS/IAS/PELS; Professor from The Hong Kong Polytechnic University
11:00-11:10	Break	
Session 5: Best practices of energy efficient, renewable and resilient data centres		
11:10-11:20	Recent digital strategies of Alibaba Cloud data centre to reduce carbon emissions	Dr Xin FANG Business Director, Data Centre, Alibaba Cloud, China
11:20-11:30	Zero Carbon Transformation Experience Sharing from Huawei - Boosting energy transition towards a net zero carbon future	Mr Patrick PAN Planning and Consulting Expert, Electric Power Digitalisation Department, Huawei Technologies Co., Ltd., China
11:30-11:50	Operation Best Practice of energy efficiency in data centres	Mr Arno VAN GENNIP VP of Operation Engineering, Equinix
11:50-12:10	Best practices for energy efficient and environmentally sustainable data centres	Prof. Rabih BASHROUSH Global Head, IT Infrastructure Advisory, Uptime Institute
12:10-12:20	Discussion	Prof. XU Zhao Chairman of IEEE Hong Kong Joint Chapter of PES/IELS/IAS/PELS; Professor from The Hong Kong Polytechnic University, Hong Kong, China
12:20	Photo Taking	
12:20-12:30	Closing Remarks	Mr Barry CHU Project Overseer Hong Kong, China
12:30	End of workshop	