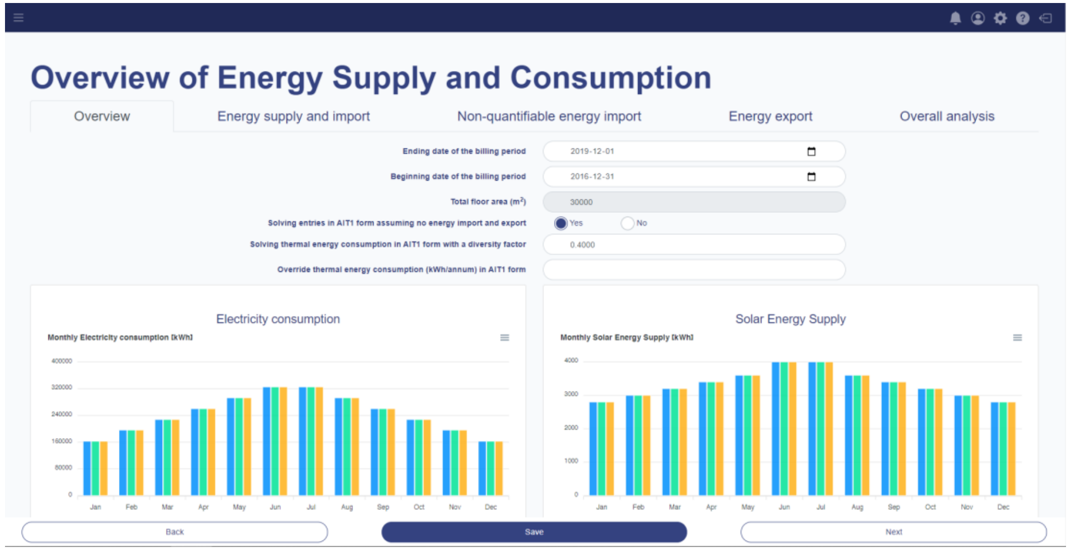
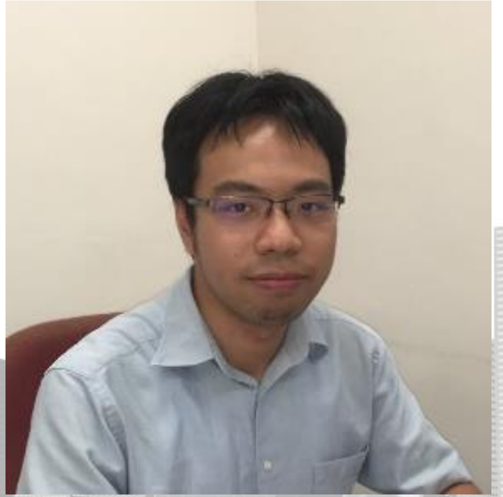
Energy Management with Data Analytics in the Era of Carbon Neutrality

Dr. Howard Cheung



Who am I?

- **Dr. Howard Cheung**
- Assistant Director at Carbon Exchange (Hong Kong) Limited
- PhD from Purdue University in 2014 on Smart HVAC Systems
- Current research in smart energy & city solutions
- Worked on > 400 energy efficient and green building certification projects
- Published more than 40 journal and conference papers on energy efficiency improvement practices



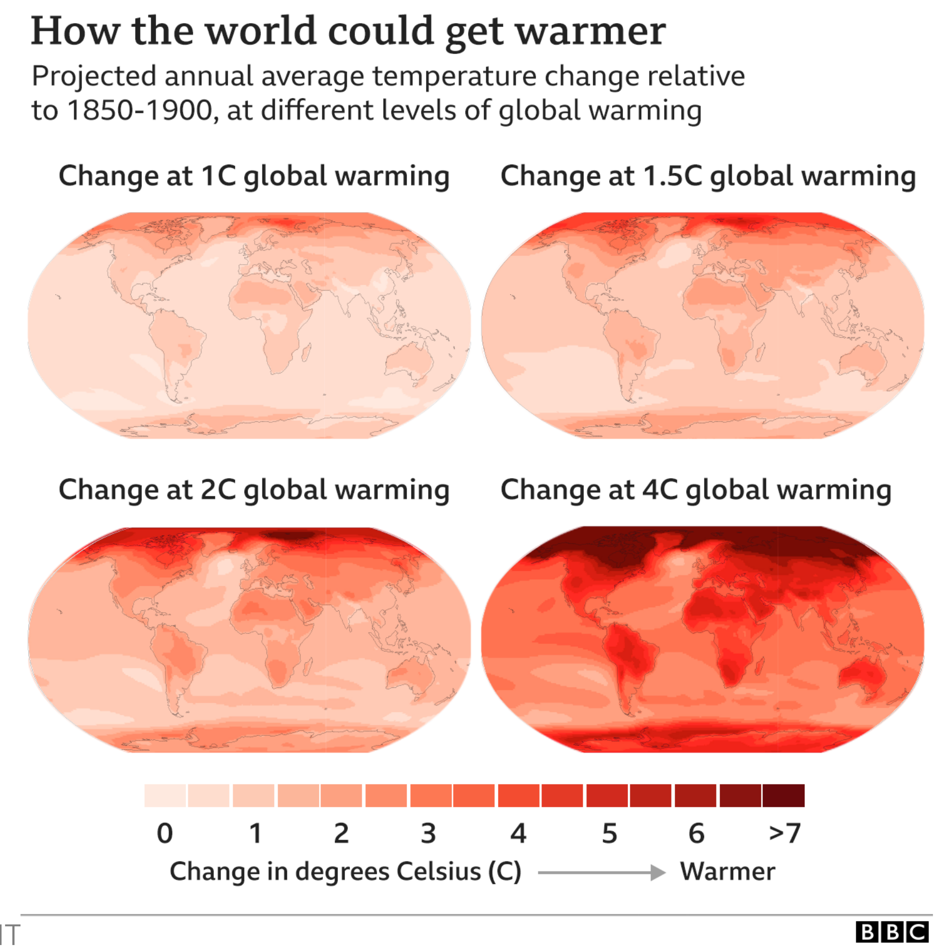
Agenda

- What is carbon neutrality and why do we care?
- Is data analytics important for energy management?
- Current technology implementation in Hong Kong
- What are we getting in the future?

Carbon Neutrality

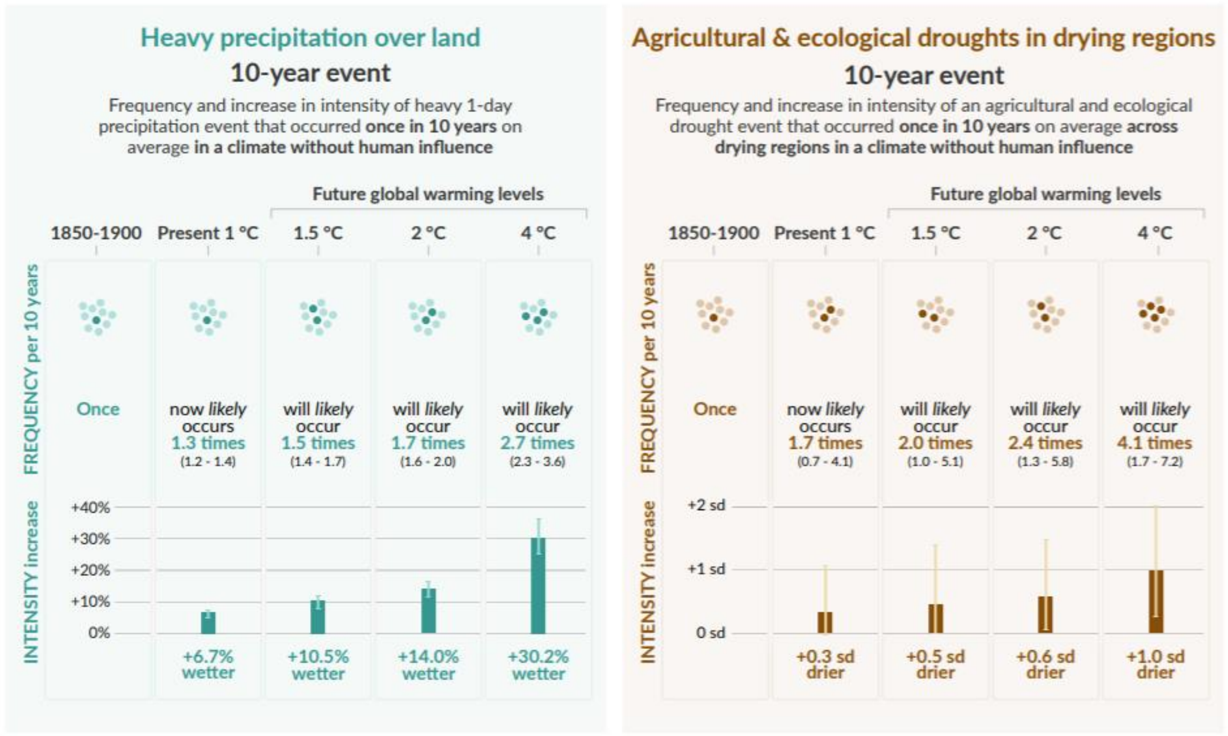
- **Carbon Neutrality** means net-zero emissions of greenhouse gases to the atmosphere, with quantification measured by the global warming potential of these gases.
  - From IPCC (Intergovernmental panel on Climate Change) (2018)
  - To limit the global average temperature rise by 1.5°C
- More than 160 nations committed to be carbon neutral by 2040 to 2060
- But why do we care?

Climate change due to human greenhouse gas emission

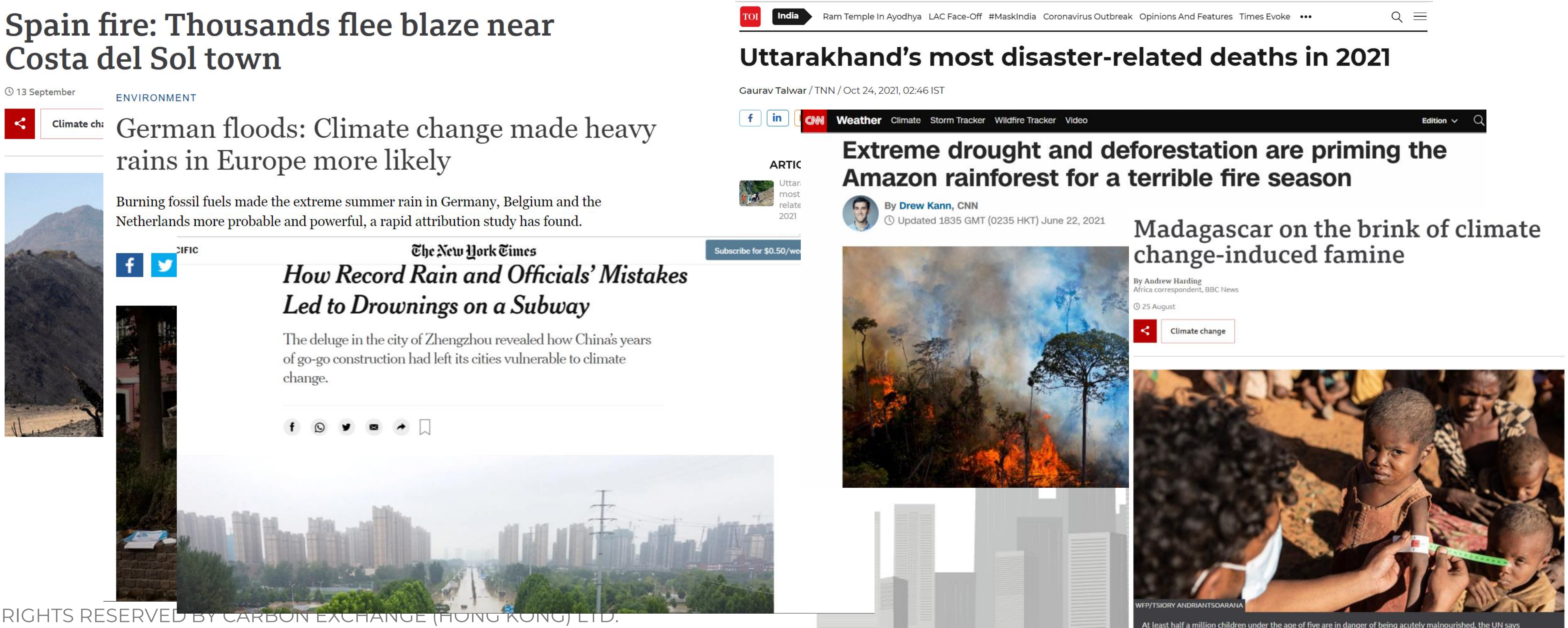


(2021)

IPCC (2021)



Climate change due to human greenhouse gas emission



Spain fire: Thousands flee blaze near Costa del Sol town

13 September

Climate cha

ENVIRONMENT

German floods: Climate change made heavy rains in Europe more likely

Burning fossil fuels made the extreme summer rain in Germany, Belgium and the Netherlands more probable and powerful, a rapid attribution study has found.

The New York Times

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The deluge in the city of Zhengzhou revealed how China's years of go-go construction had left its cities vulnerable to climate change.

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Gaurav Talwar / TNN / Oct 24, 2021, 02:46 IST

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By Drew Kann, CNN

Updated 1835 GMT (0235 HKT) June 22, 2021

Madagascar on the brink of climate change-induced famine

By Andrew Harding
Africa correspondent, BBC News

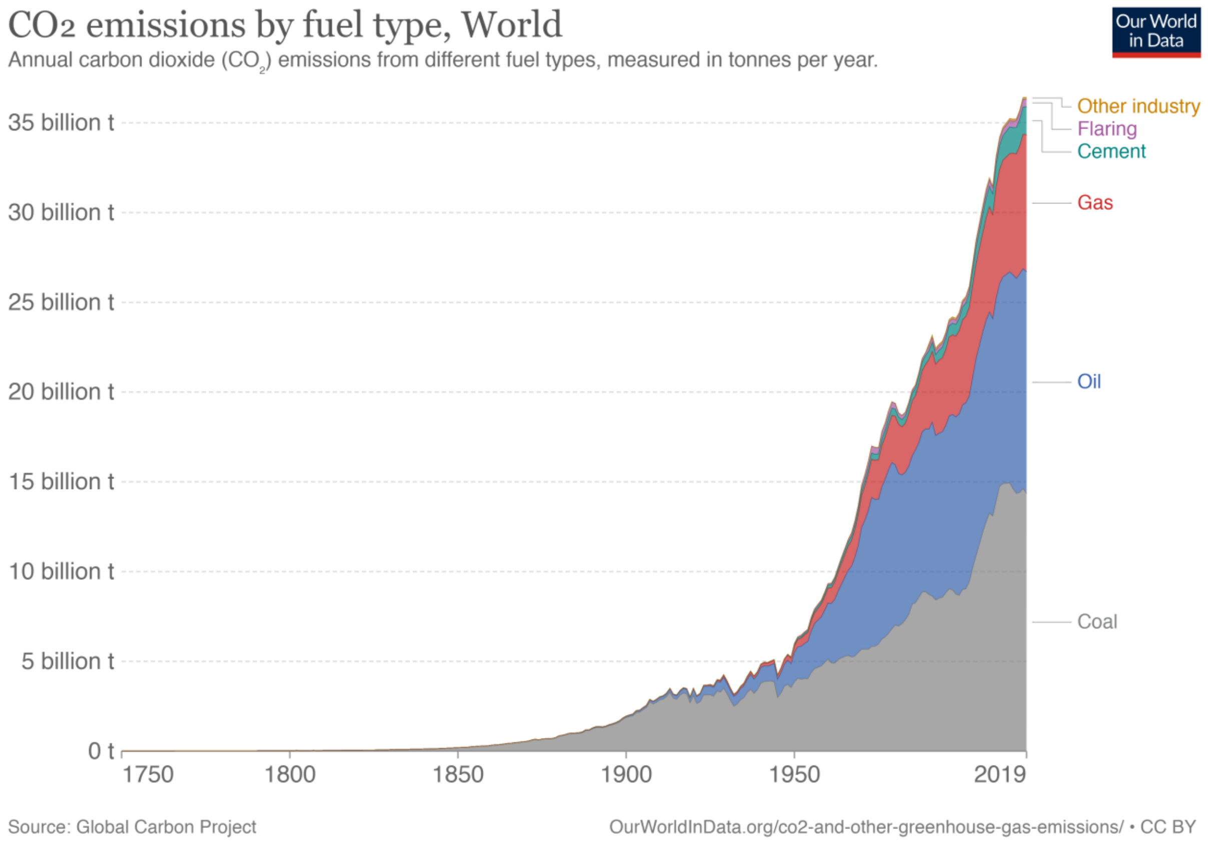
25 August

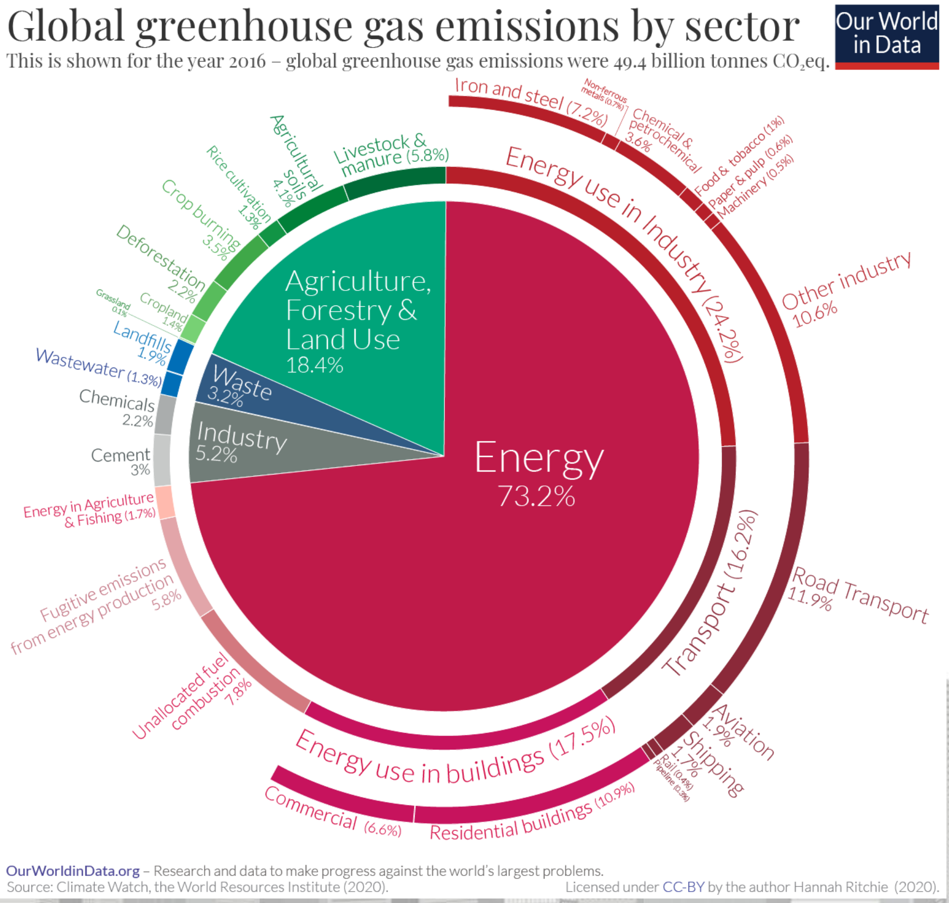
Climate change

WFP/TSIORY ANDRIANTSOARANA

At least half a million children under the age of five are in danger of being acutely malnourished, the UN says

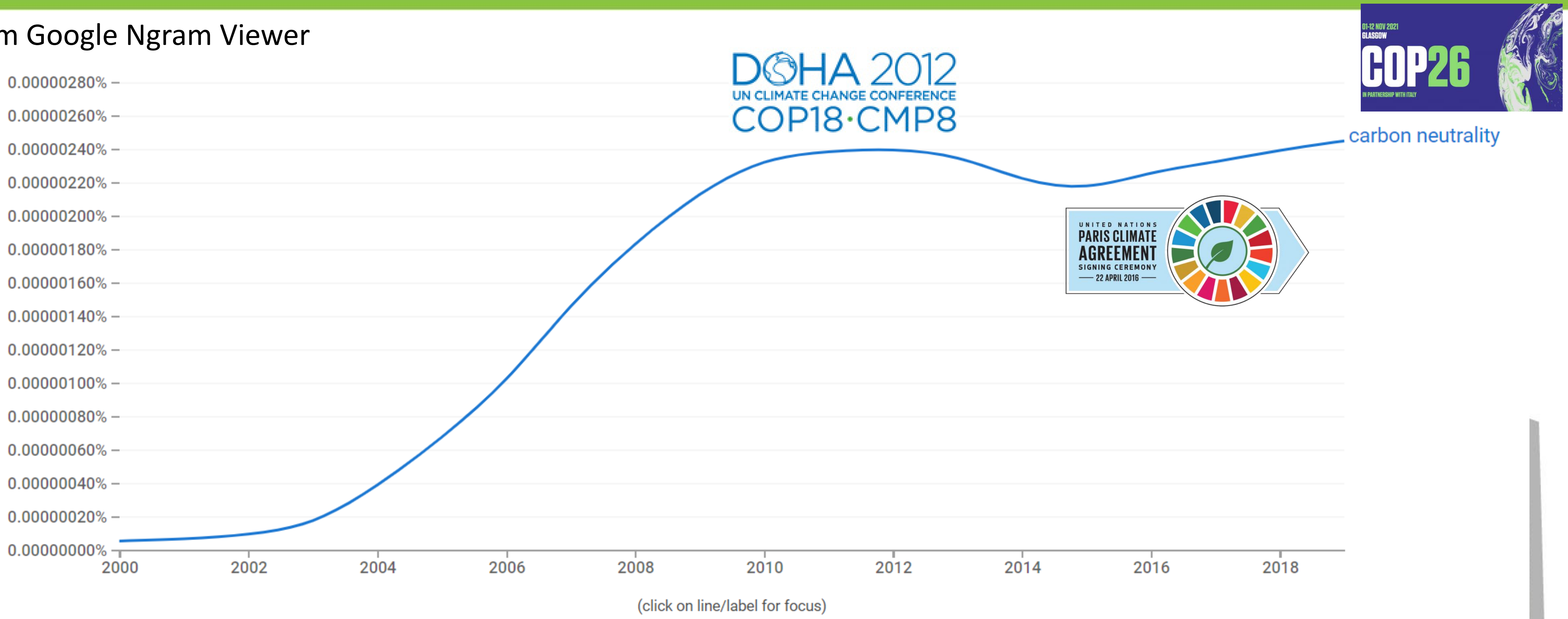
Carbon emission by the energy sector worldwide



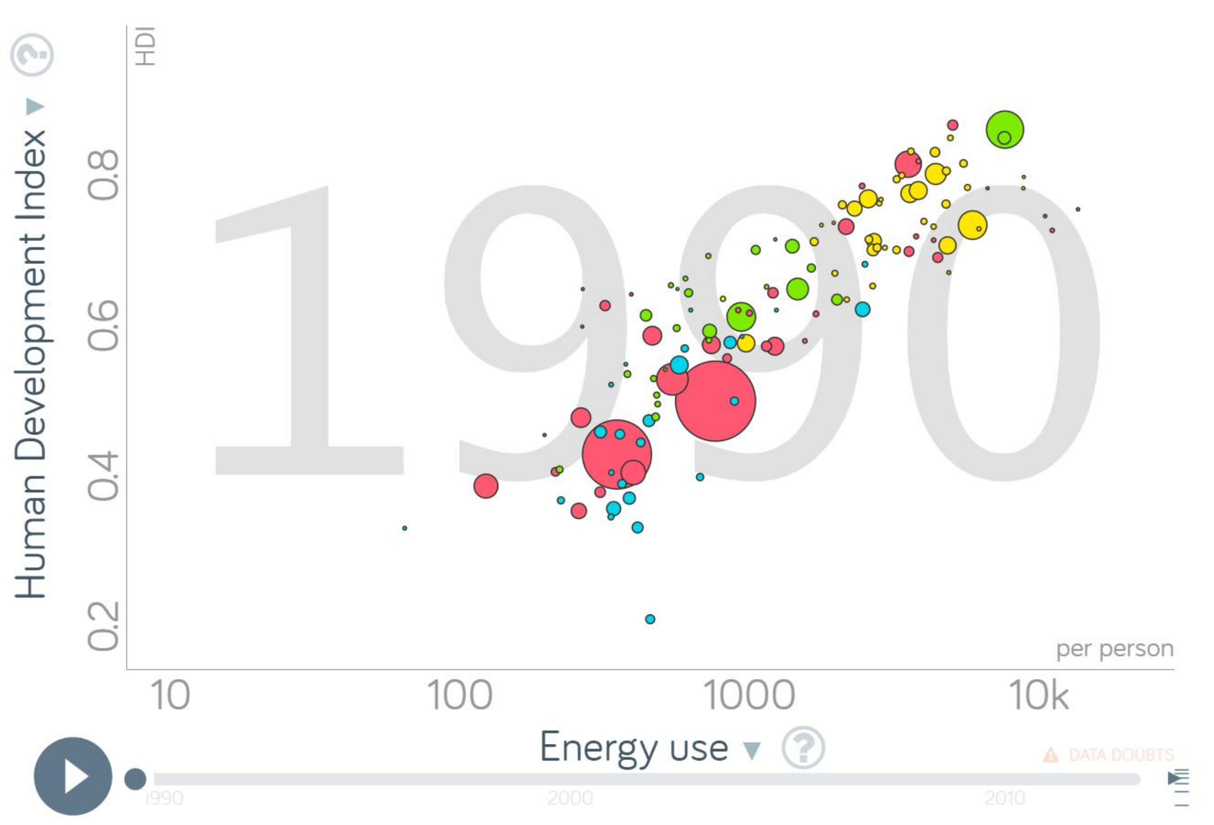


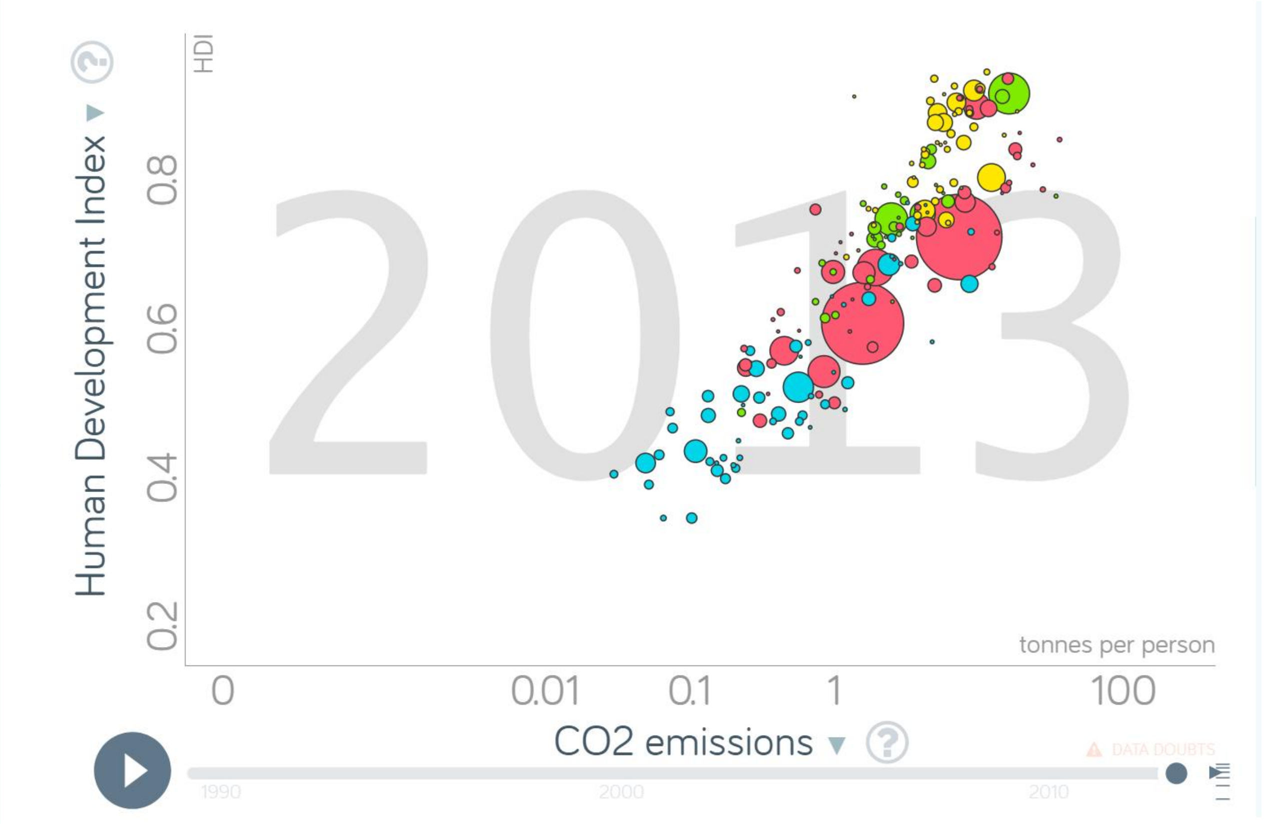
Did we care?

From Google Ngram Viewer



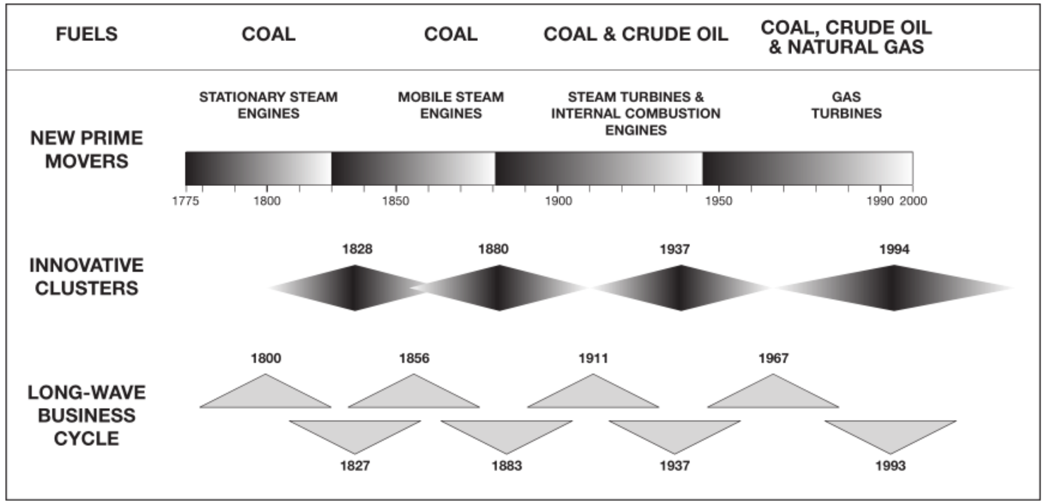
But will it be easy?





But will it be easy?

(Smil, 2017)



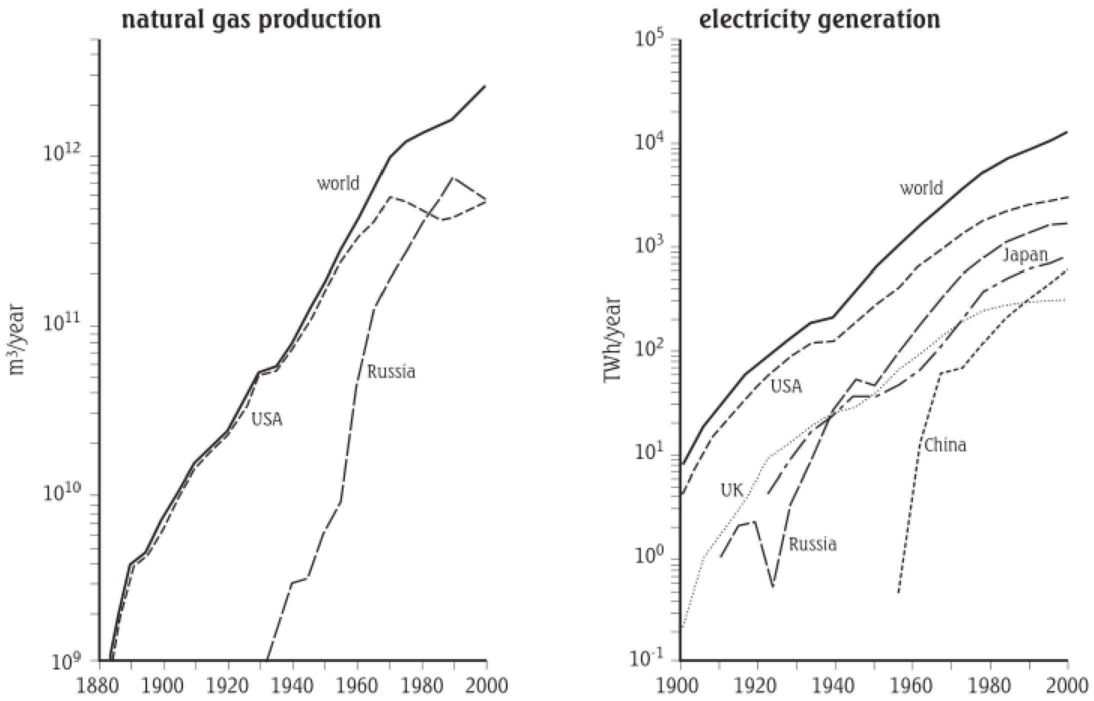
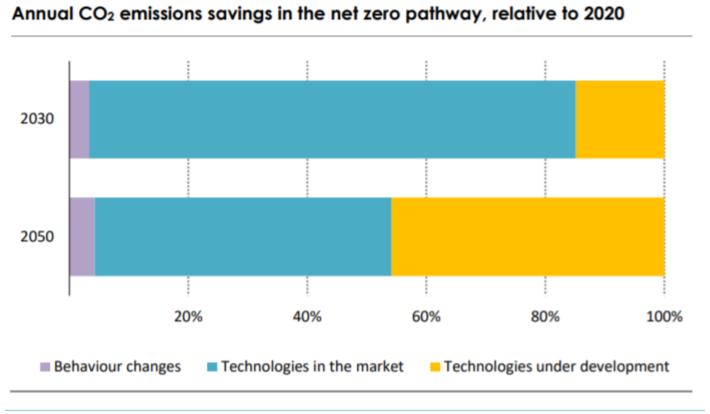


Figure 18 *Global coal, crude oil, and natural gas production, and electricity generation*

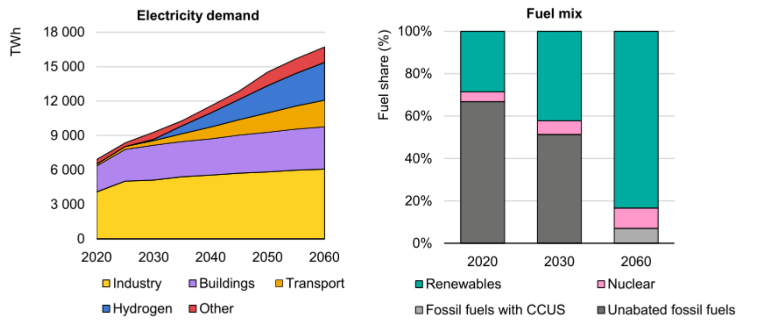
Can we meet all demand by zero-carbon emission energy sources?



(IEA, 2021)

We need to depend on the **non-commercialized** technologies to reach carbon neutrality in 2060!

Figure 3.2 Electricity demand by sector and generation by fuel in China in the APS



IEA, 2021.

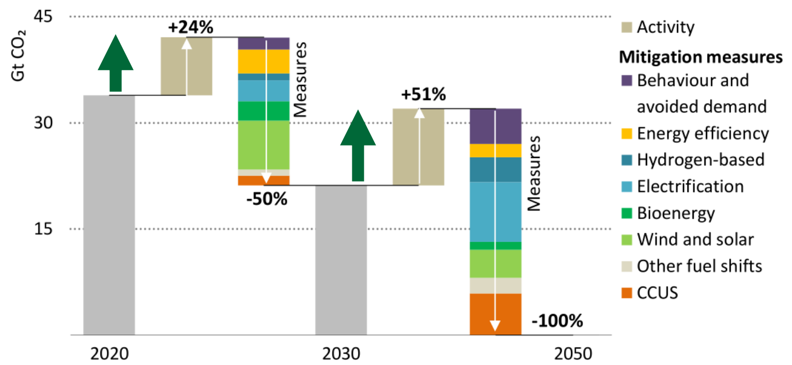
Note: CCUS = carbon capture, utilisation and storage.

Electricity demand grows briskly, driven by industry, EVs and later by hydrogen production, with renewables displacing fossil fuels in generation

(IEA, 2021)

Can we meet all demand by zero-carbon emission energy sources?

Figure 2.12 ▹ Emissions reductions by mitigation measure in the NZE, 2020-2050



Solar, wind and energy efficiency deliver around half of emissions reductions to 2030 in the NZE, while electrification, CCUS and hydrogen ramp up thereafter

Notes: Activity = energy service demand changes from economic and population growth. Behaviour = energy service demand changes from user decisions, e.g. changing heating temperatures. Avoided demand = energy service demand changes from technology developments, e.g. digitalisation. Other fuel shifts = switching from coal and oil to natural gas, nuclear, hydropower, geothermal, concentrating solar power or marine.

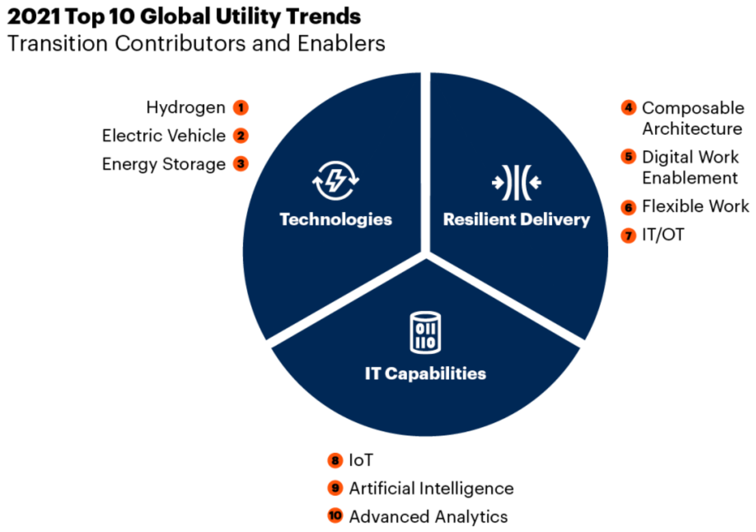
We cannot depend on energy generation technologies to reduce all CO2 emission for us

We need to keep monitoring energy demand and adapt them to avoid unnecessary CO2 emissions

(IEA, 2021)

But why data? Let's look at national technology roadmaps

- Globally
- Use of AI, IoT, analytics, digitization, etc. that are all based on data are booming in utility and building industries



Sumic et al. (2021)

Trend Profiles

Technologies Trends	Resilient Delivery Trends	IT Capabilities Trends
Hydrogen Holds Promise, but Challenges Are Still Ahead	Composable Architecture Provides Resilience and Agility Required During Turbulent Times	Utilities Accelerate IoT Initiatives to Aid Operations Improvements
Electrification of Transportation Will Invigorate the Energy Transition, but Not Without Pain to Utilities	Digital Worker Enablement Improves Utility Operations Resilience	Enterprise Advanced Analytics Drives the Peak Wave of Utility Digitalization
Storage Comes in to Save the Day by Tempering Intermittency and Firming Energy Availability	Flexible Work Improves Performance and Builds Utility Resilience	Scale in Utility AI Investment Expands Benefits and Value
	Accelerated IT/OT Convergence Improves Utility Asset and Network Performance	

But why data? Let's look at national technology roadmaps

- National Energy Administration in PRC (2021)
- Digital and Smart Energy System as one of the 5 big missions under energy technology innovation in the 14th Five-Year Plan

"十四五"能源领域科技创新规划

2021 年 12 月

专栏 6 能源系统数字化智能化技术重点示范

01 基础共性技术示范

① 开展发电装备、油气田工艺设备、输送管道、柔性输变电等能源关键设备数字孪生技术示范应用；

② 开展电力人工智能一站式服务系统、智能调度指挥平台等应用示范；

③ 开展区块链技术在可再生能源电力消纳、分布式发电市场化交易、电力批发市场、电力零售市场、安全生产等能源电力业务的示范应用；

④ 开展能源大数据中心安全开放平台开发与示范应用；

⑤ 开展电力云平台异构云组件兼容适配平台开发与示范应用；

⑥ 开展具备接入和管理各类物联设备及规约的物联网管理支撑平台示范。

02 行业智能升级技术示范

⑦ 开展智能油气田建设项目示范；

⑧ 依托已投运的高坝大库开展智能水电站大坝管理平台示范；

⑨ 开展智能光伏发电示范应用；

⑩ 开展基于主配网协同的新一代智能调度系统示范；

开展基于输电线路的异构融合组网通信智能输电示范；

基于数字孪生和全景感知的输变电工程智能运维综合示范；

开展基于云-边-端一体化智能量测系统及增值服务示范；

选择不同区域、不同地质条件的井工和露天煤矿，开展智能化开采、智能化选煤、矿山物联网等工程示范；

开展设计、建造、运维、检修、决策等全生命周期智能电厂示范。

03 智慧系统集成与综合能源服务技术示范

开展工业园区可再生能源冷热电联供以及电冷热气氢多能转换工程示范；

开展省级大规模可调资源聚合调控示范。

But why data? Let's look at national technology roadmaps

- **Department of Energy in USA (2020)**
- Research and Development Opportunities Report for Emerging Technologies for 2030 targets

Table ES-1. Technical Barriers for Priority Research Areas and Associated Goals for 2030[2]

Focus Area	Technical Barriers	Relevant ECM	Sector	Installed Cost Target[3]	Energy Savings Goal	Technical Potential[4]
Multifunctional Wireless Sensor Networks	• Enhanced wireless communications • Operational power lifetime • Accuracy and reliability • Modular design and materials cost reduction • IT system expansion • Automated calibration • Automated recognition and configuration • Flexible placement methods.	Plug-and-play sensors	Residential[5]	$29/node	17% (HVAC); 35% (Lighting)	1.14 quads
			Commercial	$57/node[6]		0.99 quads
Advanced Monitoring and Data Analytics	• High-accuracy hardware • Enhanced wireless communications • Modular design and materials cost reduction • Load disaggregation and nonintrusive monitoring • Automated fault detection and diagnostics (AFDD) • Long-term accuracy and calibration • Automated configuration with existing or new building automation infrastructure • Occupant/operator engagement and feedback.	AFDD and submetering	Commercial[7]	$0.14/ft² floor	30% (HVAC)	1.18 quads

Focus Area	Technical Barriers	Relevant ECM	Sector	Installed Cost Target[3]	Energy Savings Goal	Technical Potential[4]
Adaptive and Autonomous Controls	• Whole-building, coordinated controls • Predictive and adaptive capabilities • Automated fault correction, tolerance, and resilience • Automated configuration and implementation • Continuous commissioning.	AFDD				
Occupant-Centric Controls	• Occupancy detection and comfort • Adaptive models and control algorithms • Long-term accuracy and calibration • Occupant engagement and feedback • Automated recognition and configuration with existing building automation infrastructure.	Occupancy detection and comfort	Residential[8]	$92/occupant	40% (HVAC); 60% (Lighting)	3.14 quads
			Commercial[9]	$49/occupant		1.49 quads

But why data? Let’s look at national technology roadmaps

- **European Commission**
- ERA industrial technology roadmap for low-carbon technologies in energy-intensive industries (2022)

Figure 17 Estimate of the progression of P4P innovation area level

Innovation area	Progress up until milestone year[1,2] 2024	2030	2040	2050
Integration of renewable energy and circular feedstocks as energy source				
Heat reuse				
Electrification of thermal processes				
Electrically-driven processes				
Hydrogen integration				
CO_2 capture for utilisation				
CO_2 utilisation in minerals				
CO_2 & CO utilisation in chemicals and fuels				
Energy and resource efficiency				
Circularity of materials				
Industrial-Urban symbiosis				
Circular regions				
Digitalisation				
Non-technological aspects				

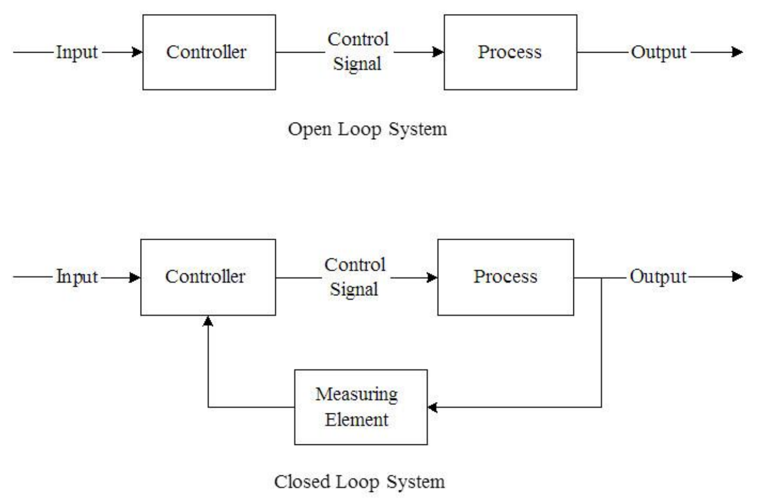
[1] Progress is depicted here as % of total TRL9 projects programmed in each area, and for circular regions, digitalisation, and non-technological aspects % of total investment needs until 2050.

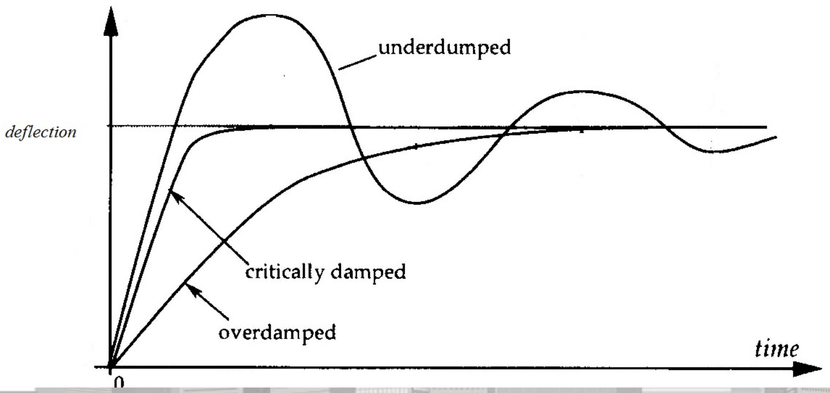
[2] It is extremely difficult to foresee future technological developments and related innovation opportunities over a 5- to 10-y horizon. This Table outlines the foreseeable progress of each innovation area based on best available knowledge about technologies under development.

Considered to be mature enough for use

But why data digitization and visualization?

- **Data enables us to**
- Conduct closed-loop controls on energy systems rather than open-loop controls
  - Not only with engineering systems but with policies and corporate business and policy cycles (i.e. System Dynamics)
- Speed up response time through more and easier-to-understand data
  - How can you achieve carbon neutrality by 2050 when half of the technologies are still not commercial?
  - You want to control it to achieve targets as quick as you want
- Median Annual Energy Saving by 3% just by monitoring system only without any automated feedback (Kramer et al. 2020)





What are the current commercial technologies & solutions in Hong Kong?

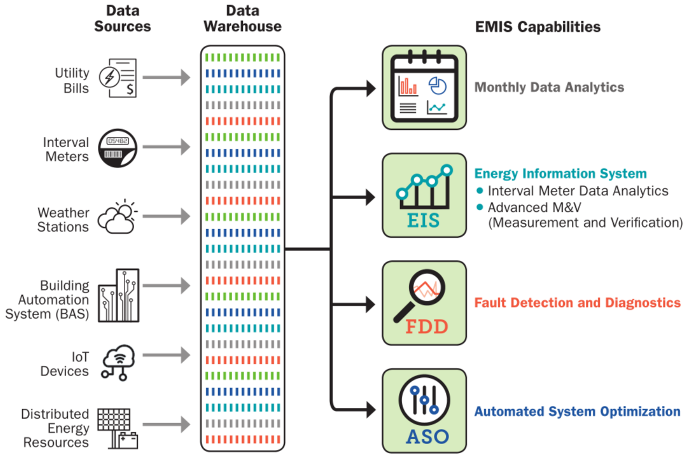
Data-driven Air-conditioning Automated Fault Detection & Diagnostics (AFDD)

- Sensor Fault
- Energy Efficiency Degradation
  - Undercharging
  - Fouling

Data-driven Smart Chiller Plant and Energy System Management

- Chiller and pump sequencing at part-load
- Temperature set-point reset
- Automated Variable speed adjustment

Data-driven Automation of Retro-commissioning Practices



What are the current commercial technologies & solutions in Hong Kong?

Behavioural Management by CBSI FCU and Lighting Data

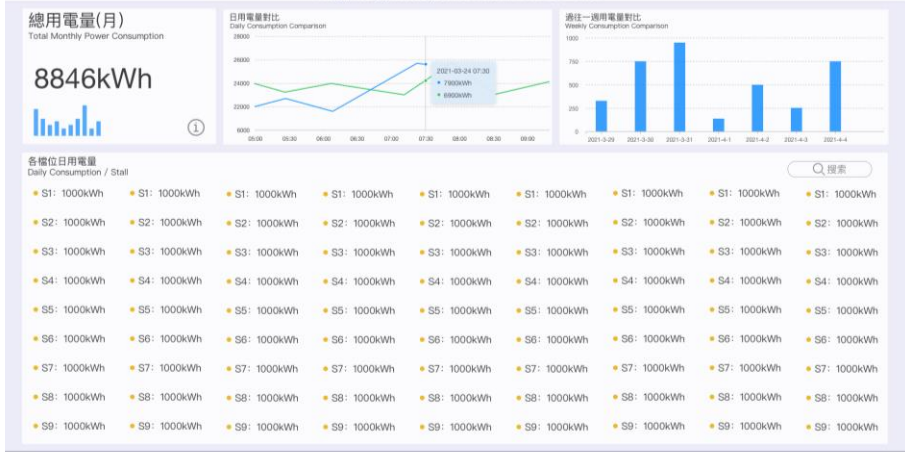
- Visualize energy usage by tenants and building occupants in various zones by IoT and dashboards
- Encourage energy use reduction behaviour
- Similar to Green Lease

Smart Energy Audit Tool

- Perform energy audits with buildings for large population
- Generate energy audit report automatically
- Explore their large energy consumers

Smart Home

- Energy monitoring through smart plugs
- Auto-on/off for plugload management



How do they work?

- **Machine learning (or AI)**
- Chiller Measurement Data (experience) associated with COP (performance) to provide cooling (tasks) collected to know how to
  - Optimize COP under different operating conditions
  - Diagnose causes of faults for chiller optimization

Machine Learning Definition by Tom M. Mitchell:
A computer program is said to learn from **experience E** with respect to some class of **tasks T** and **performance P** if its performance at tasks in T, as measured by P, improves with E.

(Zhang et al. 2021, Jordan & Mitchell 2015)

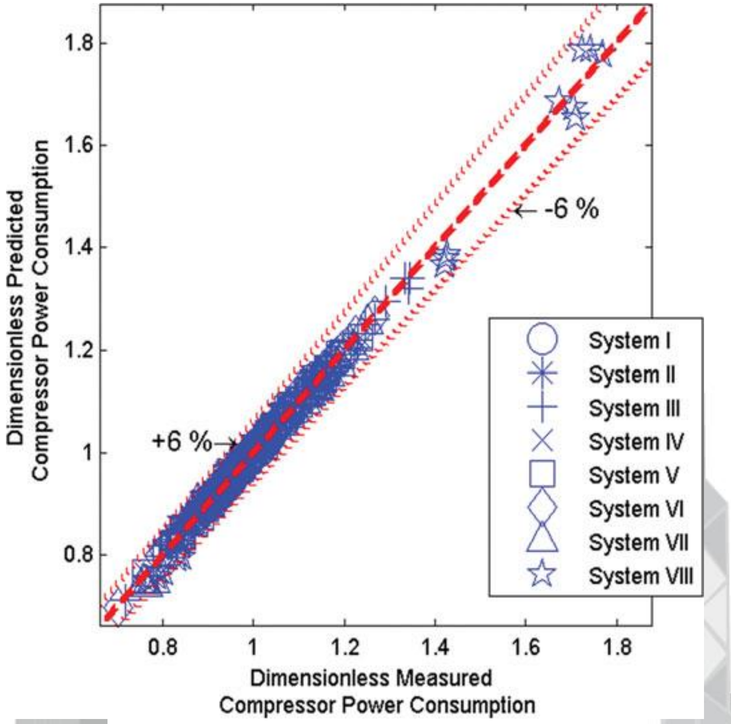
- **Systematic data digitization visualization to support management**
- Visualize multiple scenarios of chiller sequencing options
- Let management choose the best option

Example of a data-driven energy management approach

- **Example on chiller fault detection**
- Preparation
- You acquire data for chillers of different models under various normal operating conditions
- You normalize the data to show have parameters representing normal chiller operation
- You perform regression or machine learning algorithms with Coefficient of Performance, etc.
  - Example: Comstock et al. 2001

$$y = a_0 + a_1\mathrm{TEO} + a_2\mathrm{TCI} + a_3 EvapTons + a_4\mathrm{TEO}\cdot EvapTons + a_5\mathrm{TCI}\cdot EvapTons + a_6\cdot EvapTons^2$$

- You store the model on the cloud and keep updating it with incoming data



Cheung and Braun (2013)

Example of a data-driven energy management approach

- **Example on chiller fault detection**
- <u>Execution</u>
- You measure the data during actual operation of a chiller
- You use the specification of your chiller and data from BMS to use the <u>adaptive normalized model</u>
- You check for discrepancy between the estimation and the actual operation (i.e. COP)
  - Don't forget filtering with fluctuating data!
- When the discrepancies are too large for a continuous time, you know there is <u>an energy efficiency improvement opportunity</u>
  - Fouling, undercharging, unexpected part-load, etc.
- <u>Time to fix it to maintain high energy efficiency!</u>

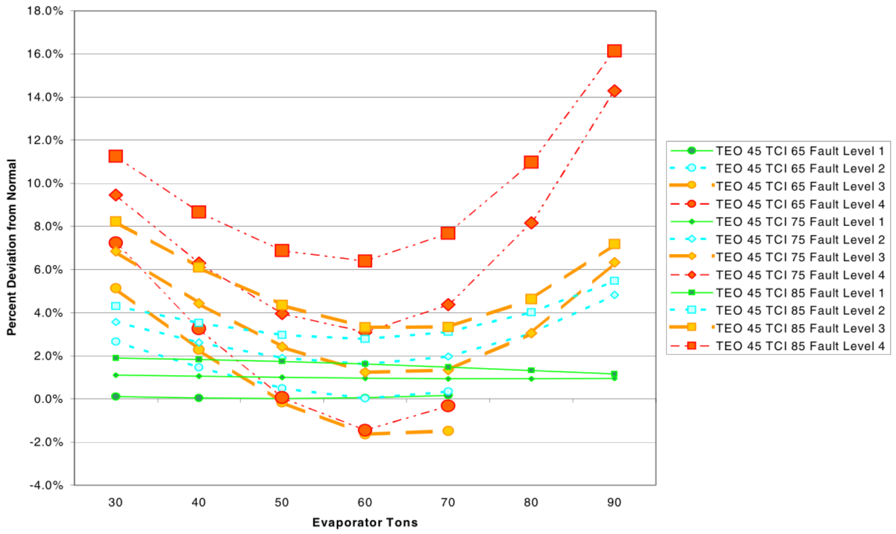
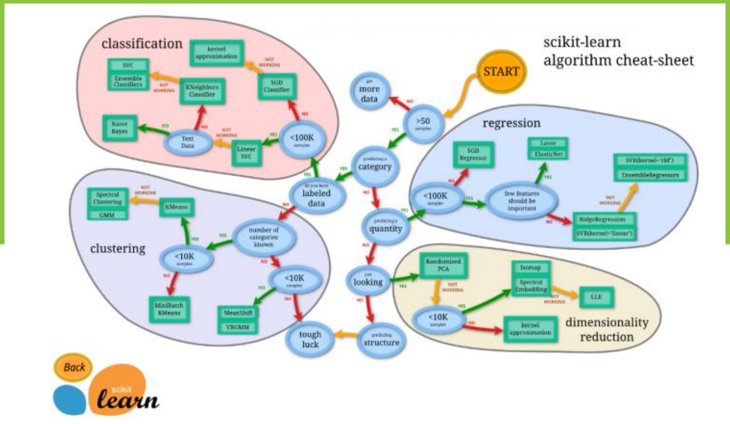


Figure 5. Deviation in kW/ton for Reduced Condenser Water Flow

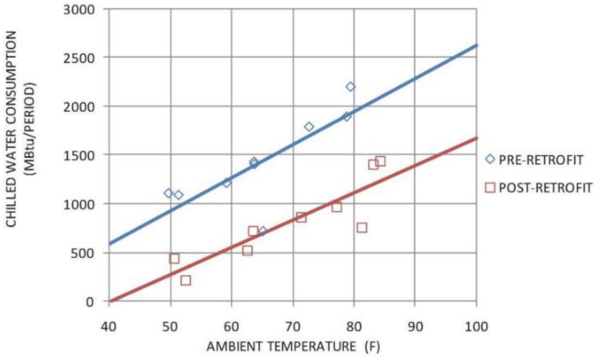
Comstock et al. (2001)

How can we adopt them?

- **Technically…….**
- Learning with data science and optimization
  - Python (i.e. scikit-learn, pandas, GEKKO)
  - Modelica (i.e. Modelica Buildings Library)
- Adopt data-driven procedures gradually (i.e. RCx for chillers)
- **Commercially……**
- Adopt methods described in standards (e.g. Inverse model toolkit following ASHRAE Guideline 14)
- Start with supporting and tender template documents on RFQ and procurement
  - US DOE provides materials like
    - EMIS Specification and Procurement Support Materials



(from https://scikit-learn.org/)

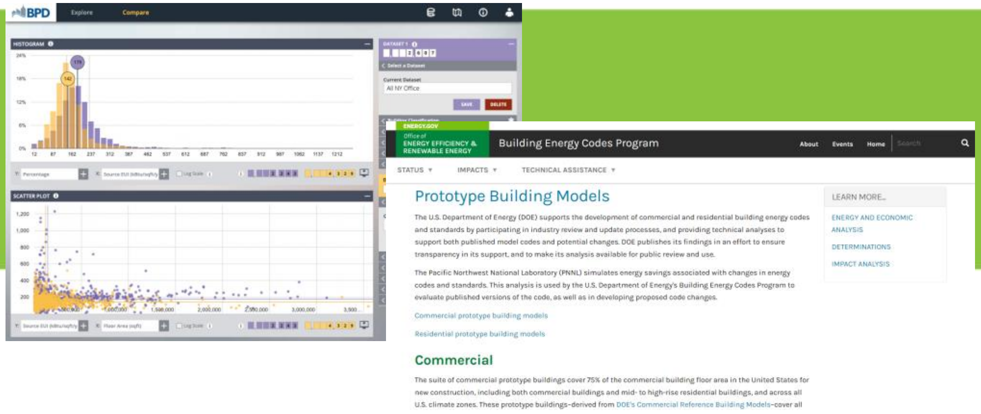


(ASHRAE 2015)

(U.S. DOE 2020)

What are we expecting in the future?

- **Building Energy Database, Standard Building Energy Model and Digital Twin**
  - Like BPD at LBNL, Commercial Prototype Building Model at PNNL and CBECS at EIA
  - Support energy system digitization with baseline buildings (e.g. quantification of improvement by ASHRAE 90.1, starting points for data-driven algorithms)
- **Multi-energy and grid-responsive (& smart grid) energy system management**
  - Energy procurement/management system as an energy-hub with dynamic energy pricing (A must to cater development in renewable energy)
- **Energy data transfer between cross-disciplinary applications**
  - Digital data schema formatting standard between BIM, energy simulation, etc.
  - Energy Internet (i.e. info. and energy flow between prosumers and AI systems)
- **Policy/ Business Management with Carbon Emission Data**
  - Carbon reporting is going to be required for not only listed corporates but their suppliers and clients for carbon neutrality
  - Simplification of their reporting by IoT/ cloud/ data technologies



(LBNL, PNNL)

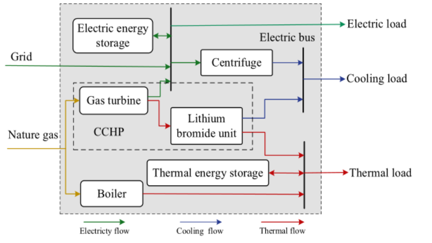


Figure 2. The MEMG architecture.

(Long et al. 2022)

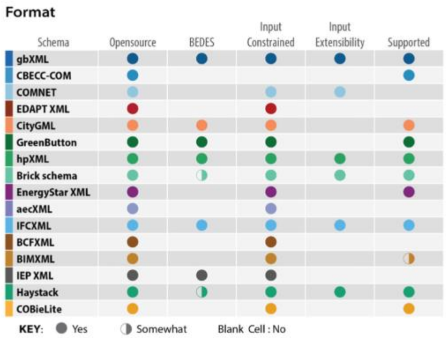
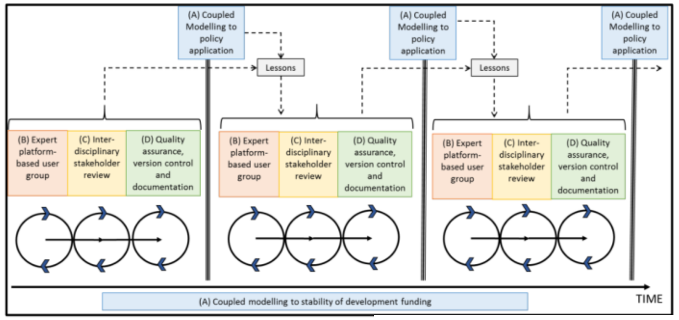


Fig. 5. Characteristics of common building data exchange schemas.

(Long et al. 2021)



(Strachan et al. 2016)

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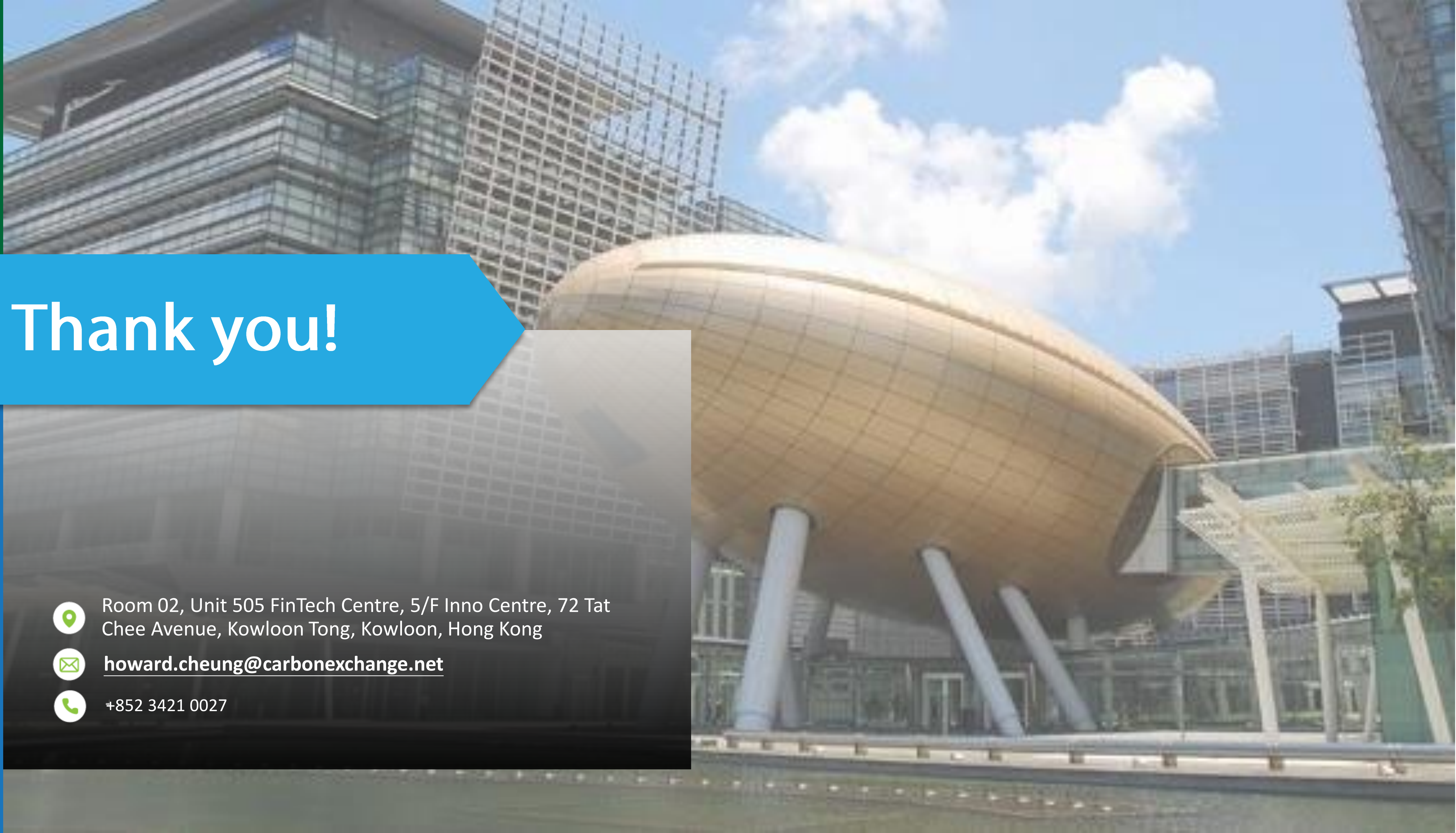

Thank you!

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