ENERGY DATA SCIENCE

Digital transformation of energy sector

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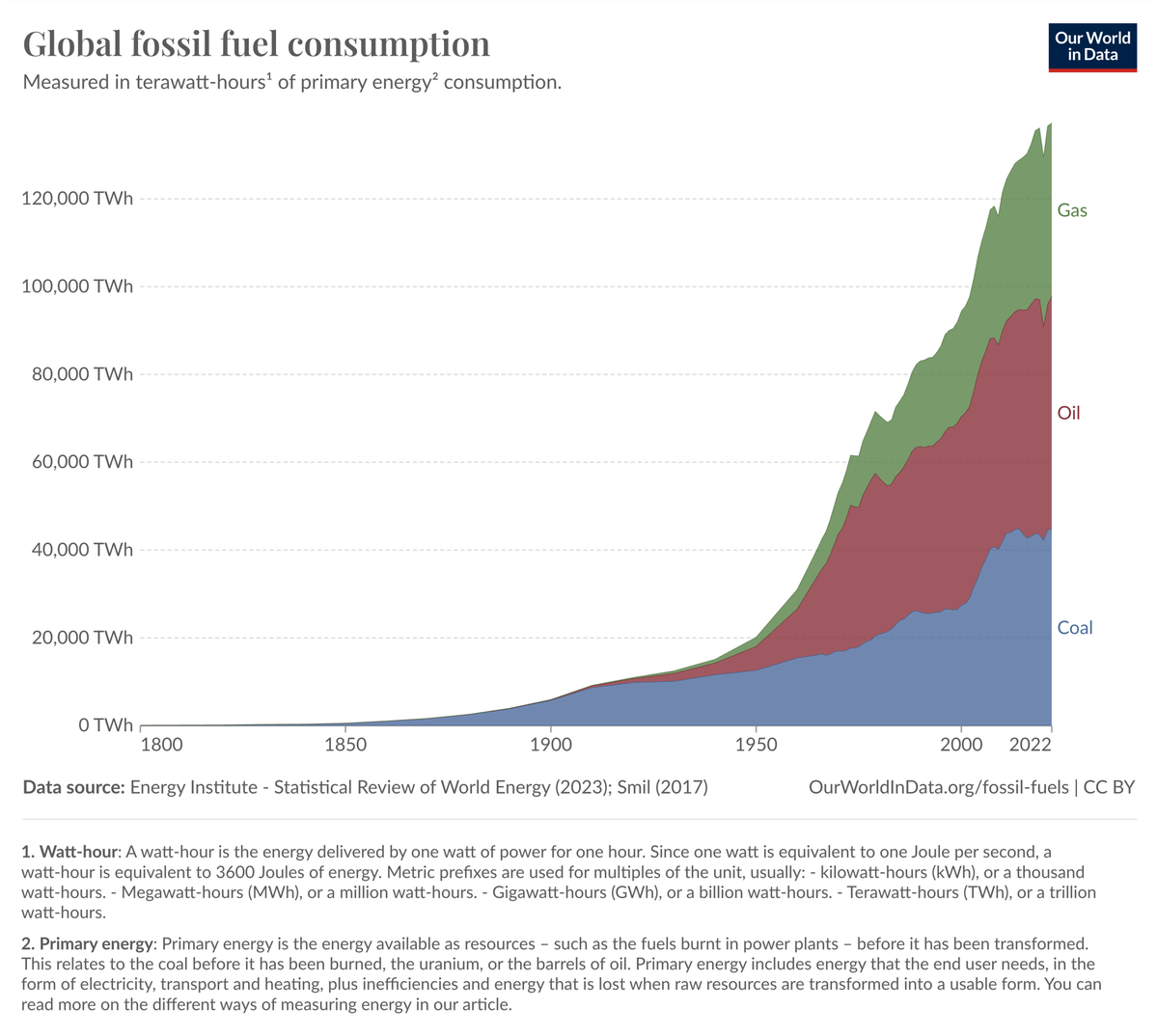
PREVIOUSLY IN COURSE …

Key takeaways:

- Energy and science
- Key challenges in energy domain
- Sustainability
- Energy policy

RECALL: HOW LONG?



https://ourworldindata.org/fossil-fuels

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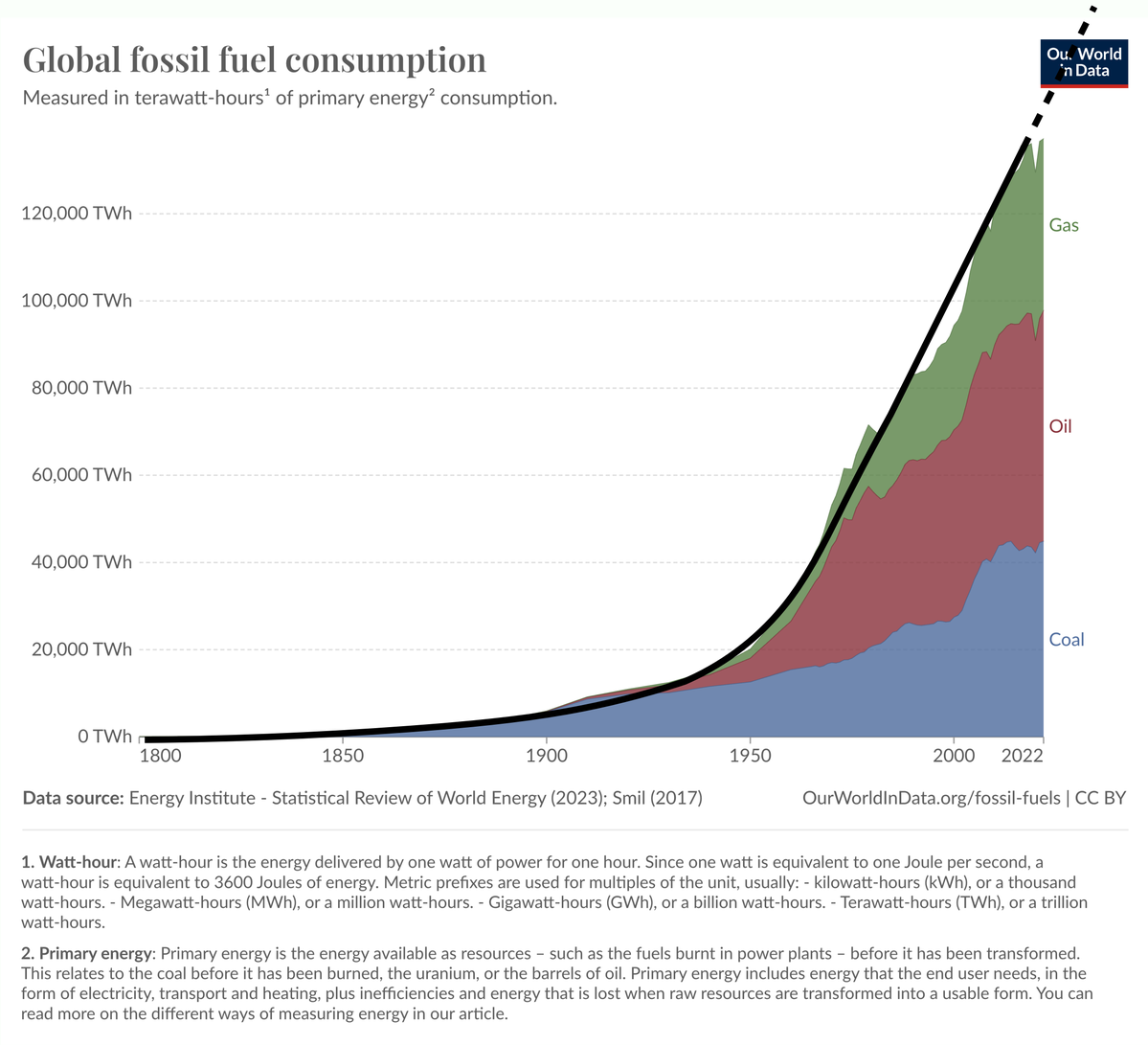
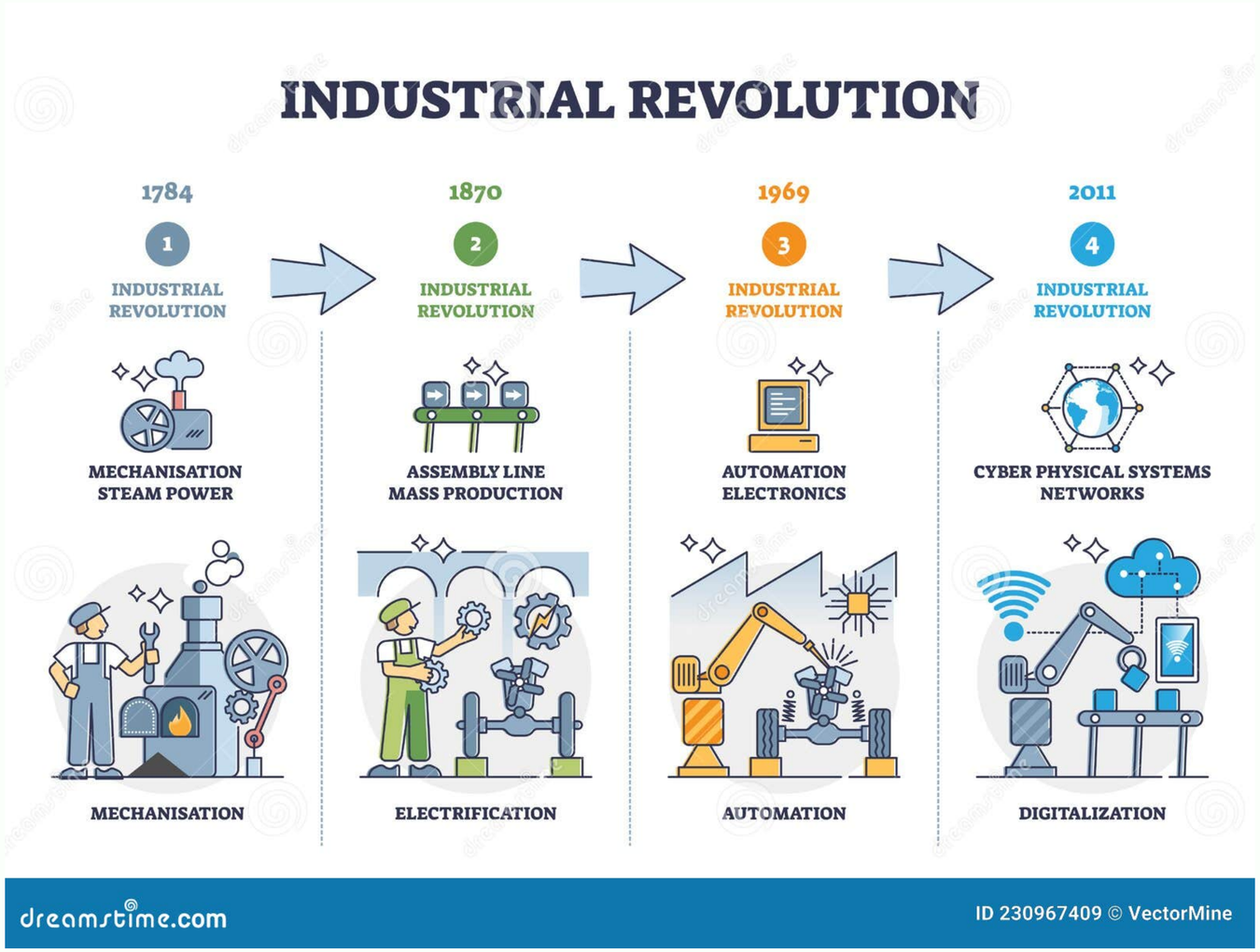


???

Such a growth is not sustainable and cannot last forever ...

https://ourworldindata.org/fossil-fuels

PROGRESS



[Accessed March 28, 2024], https://www.dreamstime.com/industrial-revolution-stages-manufacturing-development-outline-diagram-labeled-educational-timeline-mechanisation-image230967409

THREE MAIN STEPS TOWARDS DT

Digitisation

Digitise Information

Changing from physical to digital form.

Organise Information

Setting up database for storage and retrieval.

Digitalisation

Automate Processes

Eliminate human lapses through automation repetitive processes.

Streamline Processes

Redesigning processes to remove unnecessary steps.

Digital Transformation

Transform the business

Transform operations, strategic directions and value propositions.

Adopted from https://schweizer.pm/process-improvement/

DIGITAL TRANSFORMATION (2)

Digitisation

Process of converting analog information from the physical world into digital form.

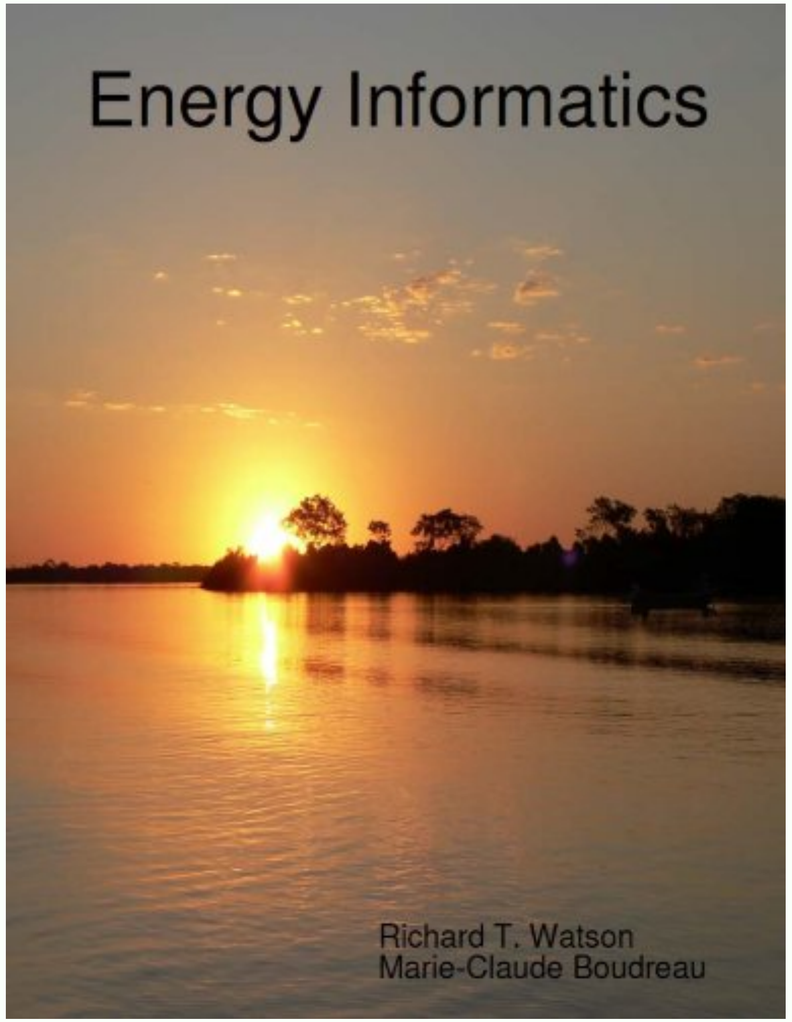
Digitalisation

Process of turning business functions into digital services by applying digital technology.

Digital Transformation

Process of using digital technologies to create new business processes, cultures and customer experiences, or to change existing ones.

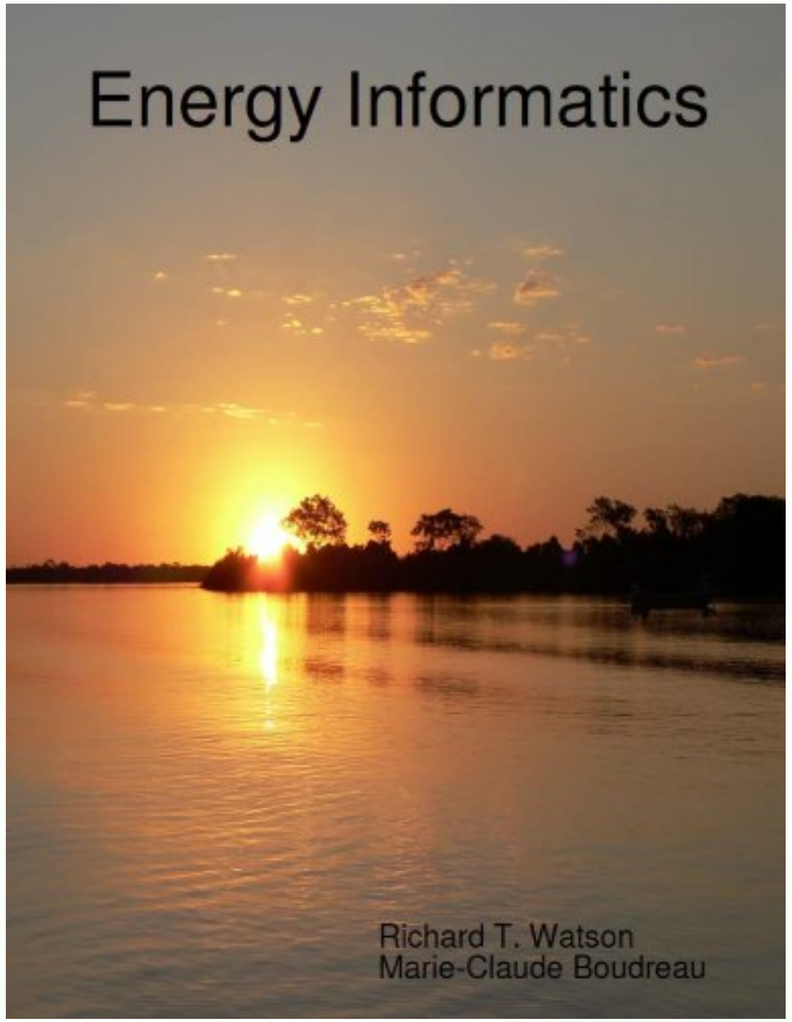
ENERGY INFORMATICS



"Energy Informatics"
by R. Watson and M.-C. Boudreau, eGreen Press, kindle edition, 2011

"According to Darwin, fire (a form of energy) and language (an information system) are the two most important human inventions."

ENERGY INFORMATICS



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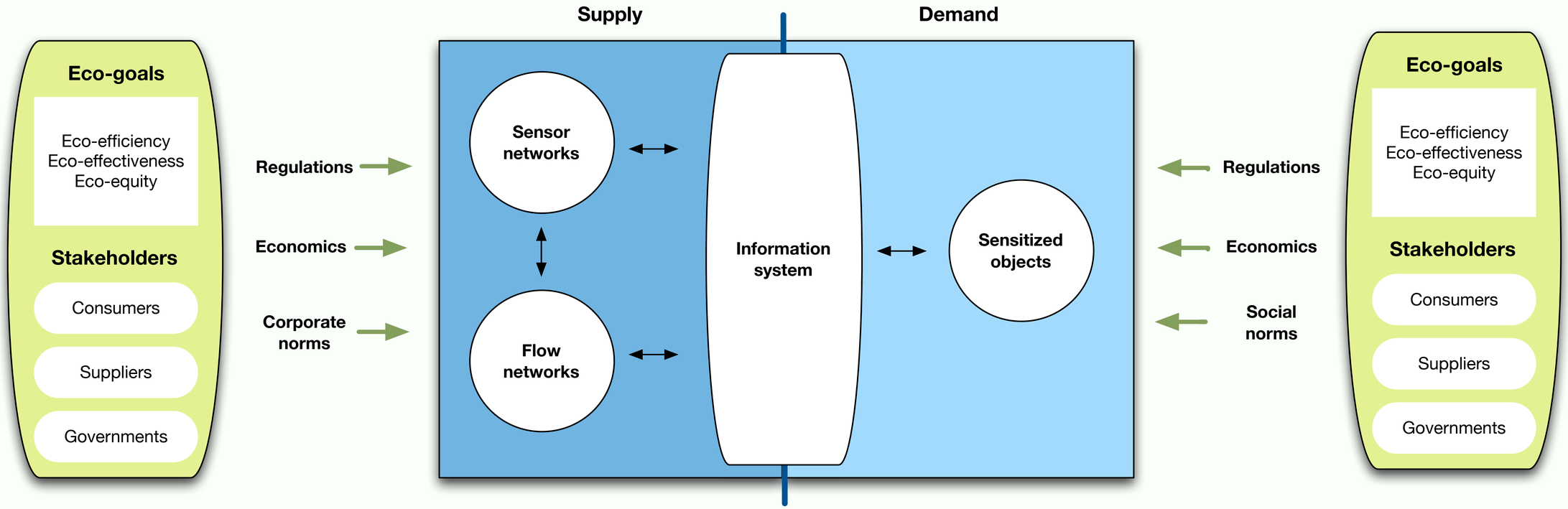
Fundamental principle:

Energy + Information < Energy

ENERGY INFORMATICS FRAMEWORK



ENERGY INFORMATICS ECOSYSTEM

SOCIETAL GOALS

- Energy end-use efficiency
- Green economic growth
- Renewable energy supply

SMART ENERGY RESEARCH THEMES

- Smart energy systems
- Smart energy business innovation
- Smart energy networks

SMART ENERGY ECOSYSTEMS

Energy end use		Service providers	Utility grids	Energy markets	Energy supply	Software suppliers	Hardware suppliers
Commercial buildings	Electricity mobility	Aggregators	Power	Electricity market	Renewable energy	SCADA	Systems & components
Residential buildings	Hydrogen mobility	Data HUBs	District heating	Gas market		BMS	
Factories	Data centres	ESCO	District cooling		Energy storage	EMS	Photovoltaic
		System integrators	Gas				Wind turbine

COMPUTER SCIENCE / INFORMATION SYSTEMS

- Artificial Intelligence
- Machine learning
- Distributed systems
- Big data
- Data analytics
- Software evolution
- Embedded systems

CONTROL & ELECTRICAL ENGINEERING

- FDD & Prognosis
- Control systems
- Control theory
- Power systems modelling & simulation
- Power electronics
- Systems dynamics & stability
- Optimisation

MECHANICAL & CIVIL ENGINEERING

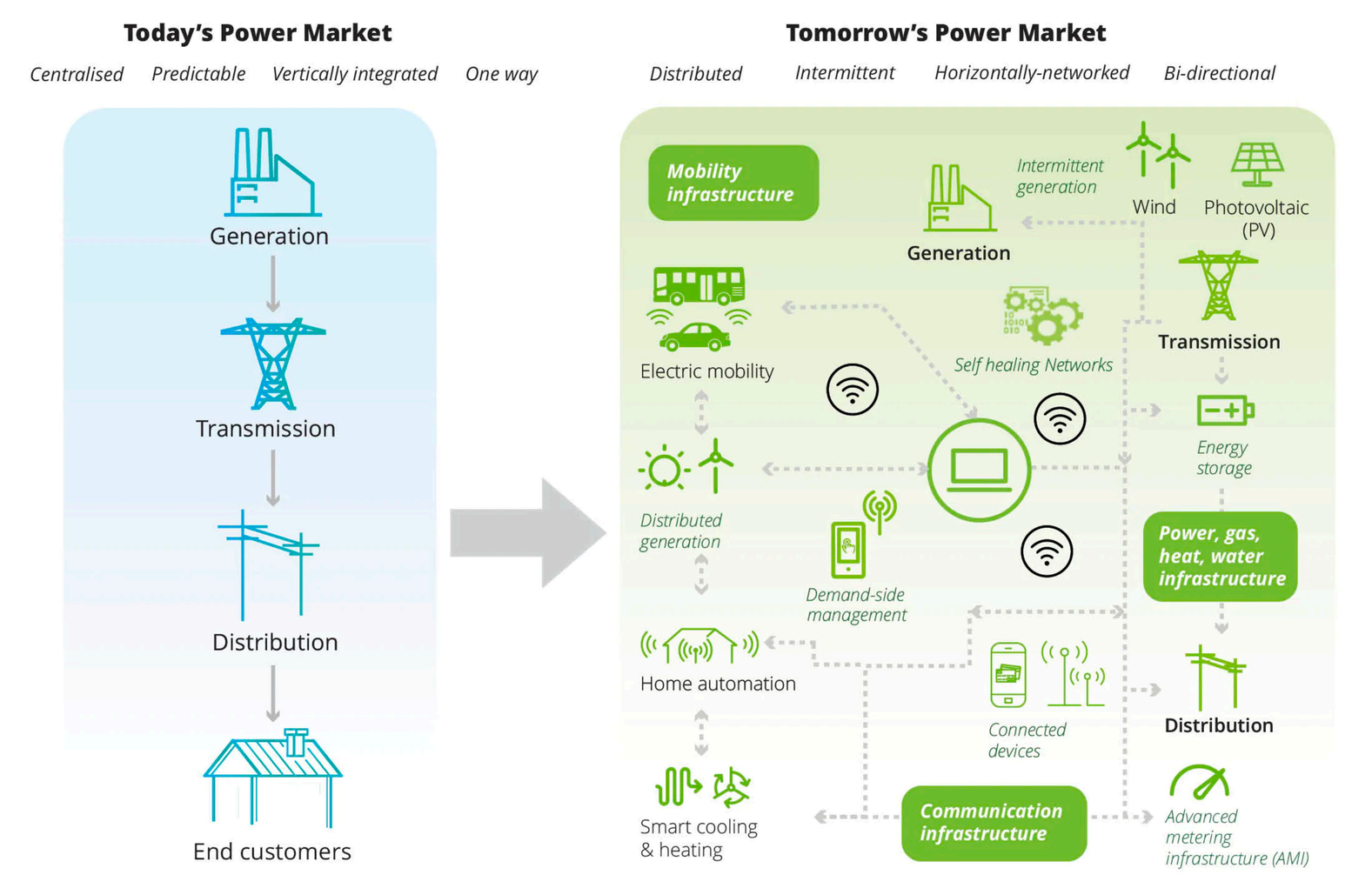
- Heat transfer
- Energy conversion
- Fluid mechanics
- Computer-aided design
- Mass transfer
- Thermodynamics
- Numeric methods

MANAGEMENT ENGINEERING

- Technology innovation management
- Business development
- Consumer engagement
- Globalisation & market analysis
- Energy economics & regulation
- Energy policy & strategies

Adopted from keynote speech by Prof. B. N. Jørgensen (University of Southern Denmark) at the Energy Informatics.Academy Asia 2021 PhD workshop

WHAT IS IN THE FUTURE?



[Accessed May 8, 2025], https://www2.deloitte.com/uk/en/pages/energy-and-resources/articles/energy-as-a-service.html

Smart Grids

SMART GRIDS: LONG STORY SHORT

Q: What is a Smart Grid?

Short Answer: Smart Grid = IT + Electric Grid

DEFINITION OF A SMART GRID

There are numerous definitions of smart grids available that may differ by reflecting regional or national system development needs:

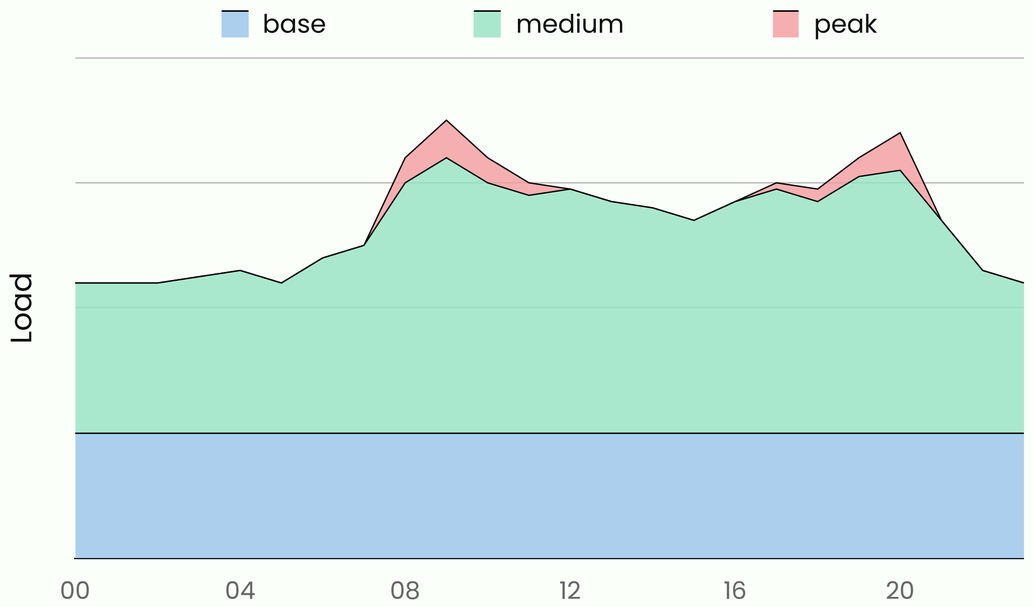
https://unece.org/fileadmin/DAM/energy/se/pdfs/geee/News/Smart_Grids_Overview_05-19-15.pdf

The principal smart grid functional characteristics are:

- Self-healing
- Enabling active participation by consumers
- Resilient
- Power quality
- Generation and storage
- Enabling new products, services, and markets
- Operating efficiently

POWER GRID CHALLENGES: ENERGY MIX

Load	Cost	Responsiveness to load variations	Examples
Base	cheap	low	coal, oil shale
Medium	medium	moderate	combined gas and steam
Peak	high	high	gas turbines, diesel generators



Adopted from the lecture “Introduction to smart grids”, Summer School 2019 "Smart Grid: Systems and Technologies", A. Berl

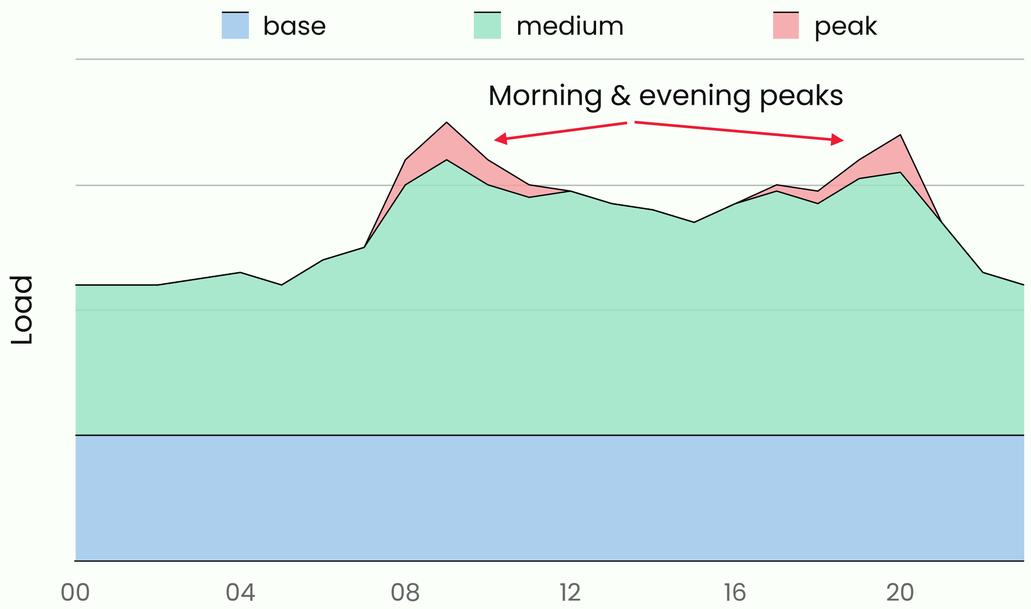
POWER GRID CHALLENGES

Problem: Peaks in energy demand

The grid must be balanced at all times:

Production needs to meet demand

- Often prediction models use simple static energy demand profiles
- Unforeseen changes
- Peak load energy compensation

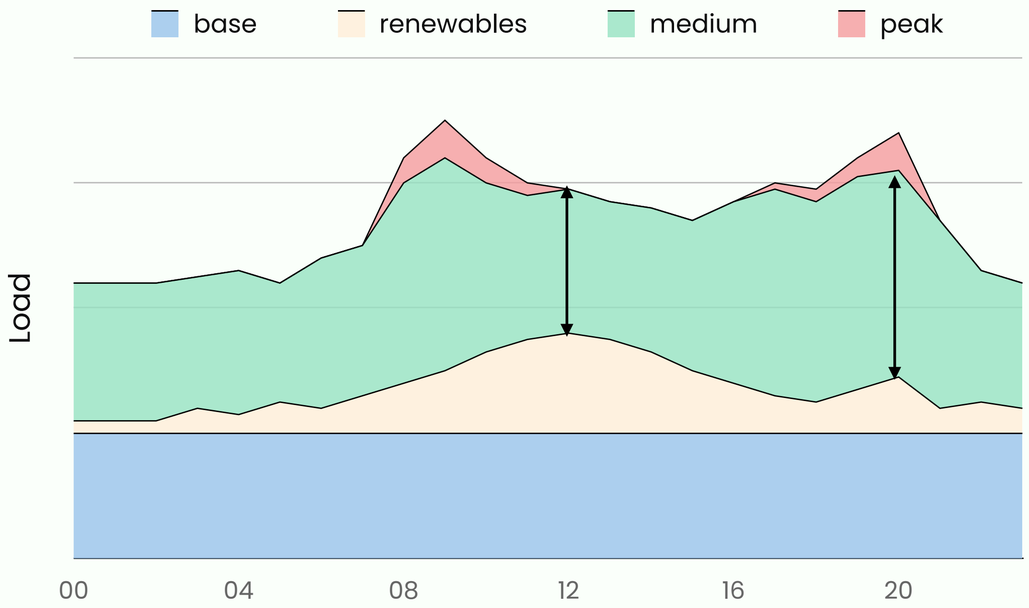


POWER GRID CHALLENGES (2)

Problem: Volatility of renewable energy production

The grid accommodates more renewable energy sources

- Generation/demand prediction becomes very complex
- In the future renewable energy may replace base energy generation



POWER GRID CHALLENGES (3)

Problem: Current models become inaccurate and need to be extended

Past:

- Centralised approach

Future:

- Decentralised production
- Consumer becomes a prosumer (locally generates electricity, eg. PV panels)

POWER GRID CHALLENGES (4)

Problem: Temporal and spatial diversity of energy supply and demand

Temporal:

- Solar energy is generate in the summer (Estonia)
- There are peak hours for solar energy production

Spatial:

- PV farms are located in suburban or rural areas
- Energy is mostly consumed in industrial areas or cities

SMART GRID IDEA

Increase the intelligence of the power grid

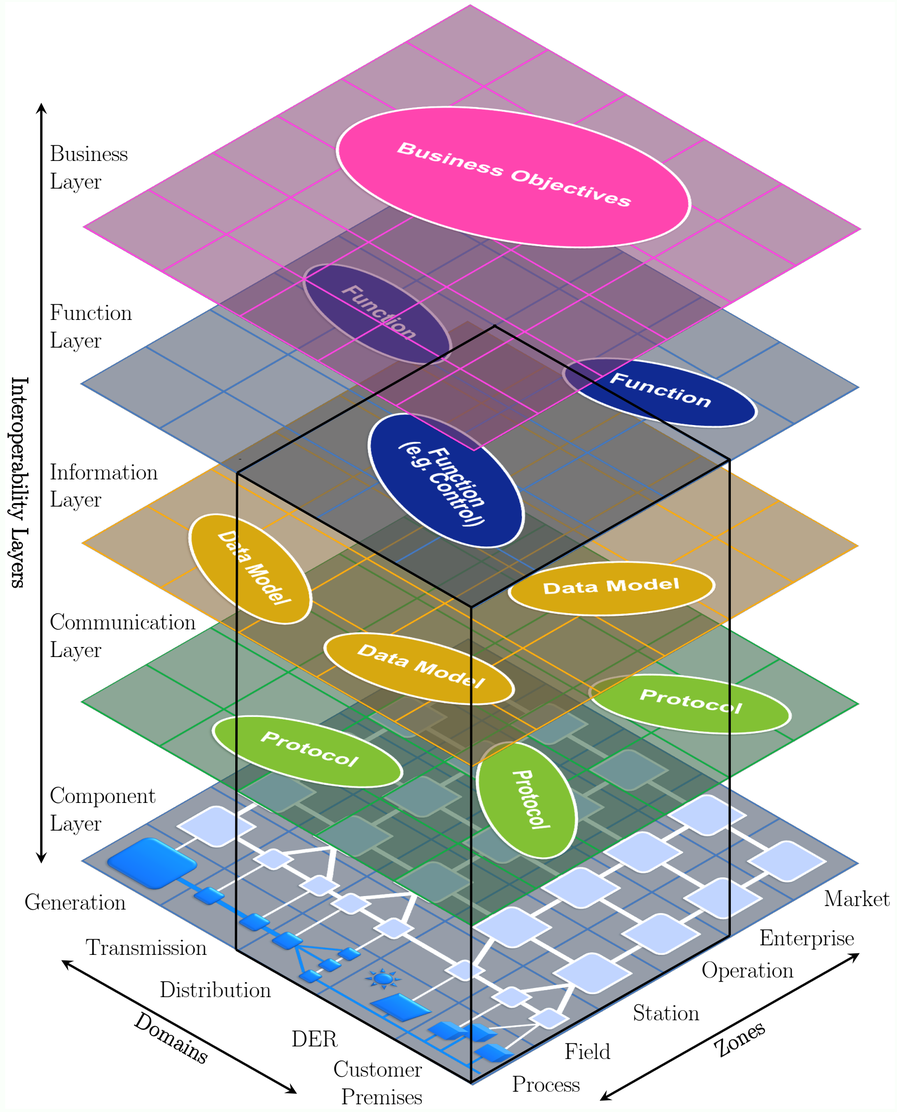
- Energy production: predict demand and shape production accordingly
- Energy demand: reshape demand to fit current availability of energy

- Power reliability and quality
- Resilience to disruptions
- Expand deployment of RES
- Reduce fossil fuel demand
- End-consumer engagement

Where is IT and how IT can help?

SMART GRID ARCHITECTURE MODEL

Smart Grid Architecture Model (SGAM) with the smart grid plane (spanned by zones and domains) as the bottom layer and further interoperability layers on top.

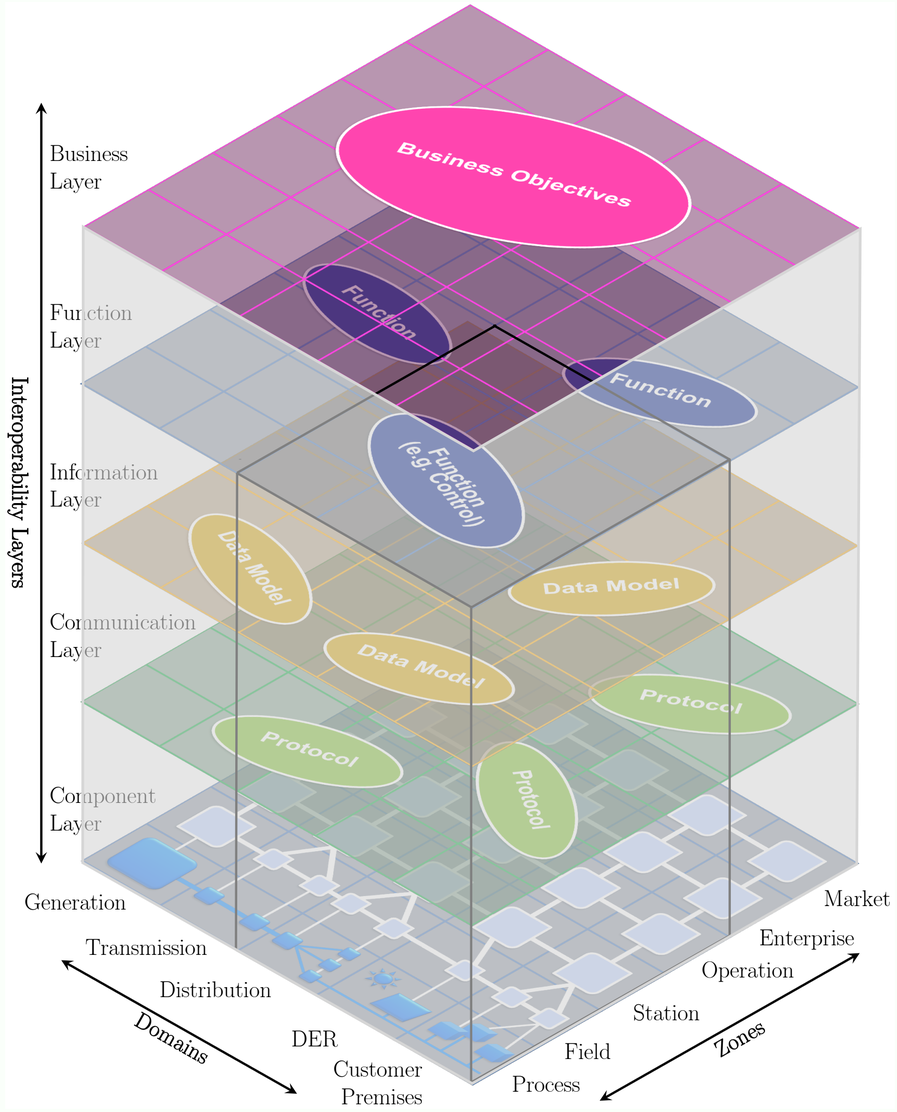


Faschang, M. (2015). Rapid control prototyping for networked Smart Grid systems based on an agile development process, Dissertation, Technische Universität Wien https://repositum.tuwien.at/handle/20.500.12708/4869

BUSINESS LAYER

Business view on information exchange:

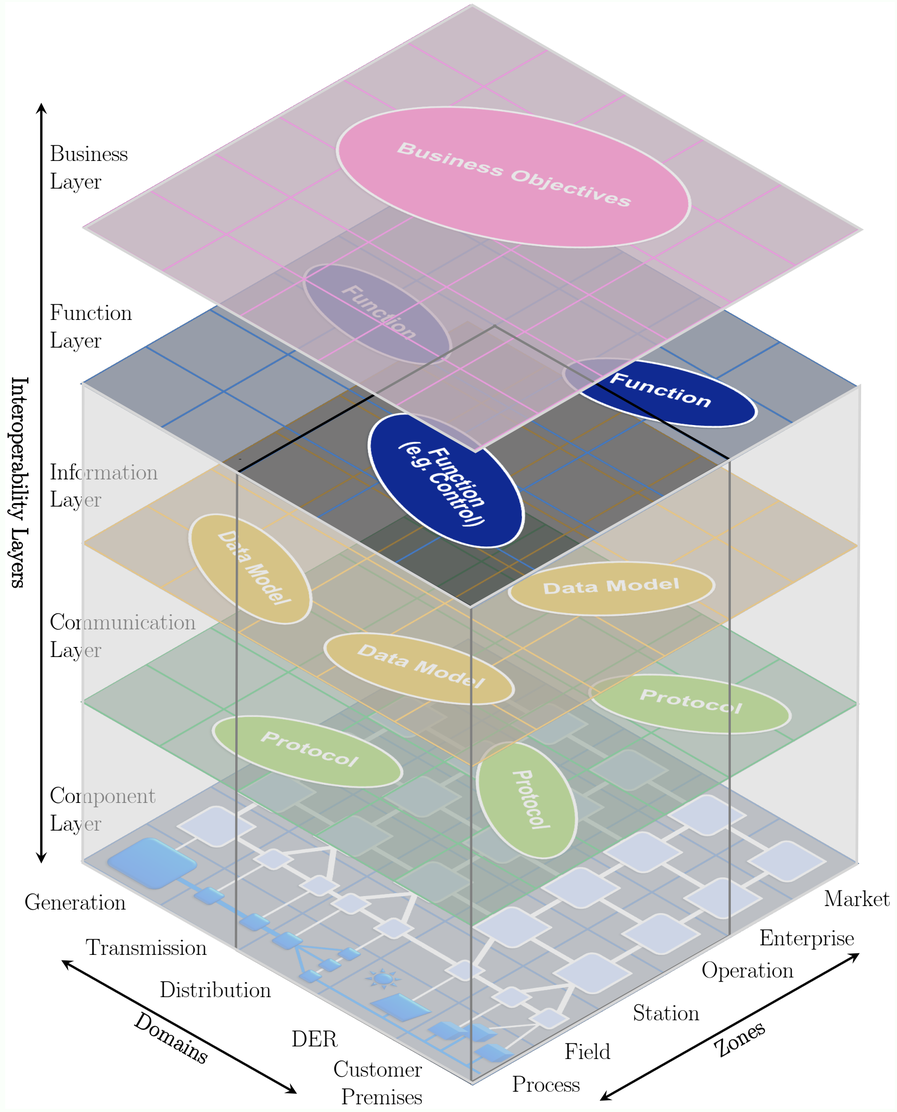
- Map regulatory and economic (market) structures and policies, business models, business portfolios
- Map business capabilities and business processes
- Supports business executives and regulators in decision making



FUNCTION LAYER

Function smart grid is energy (secure, etc)

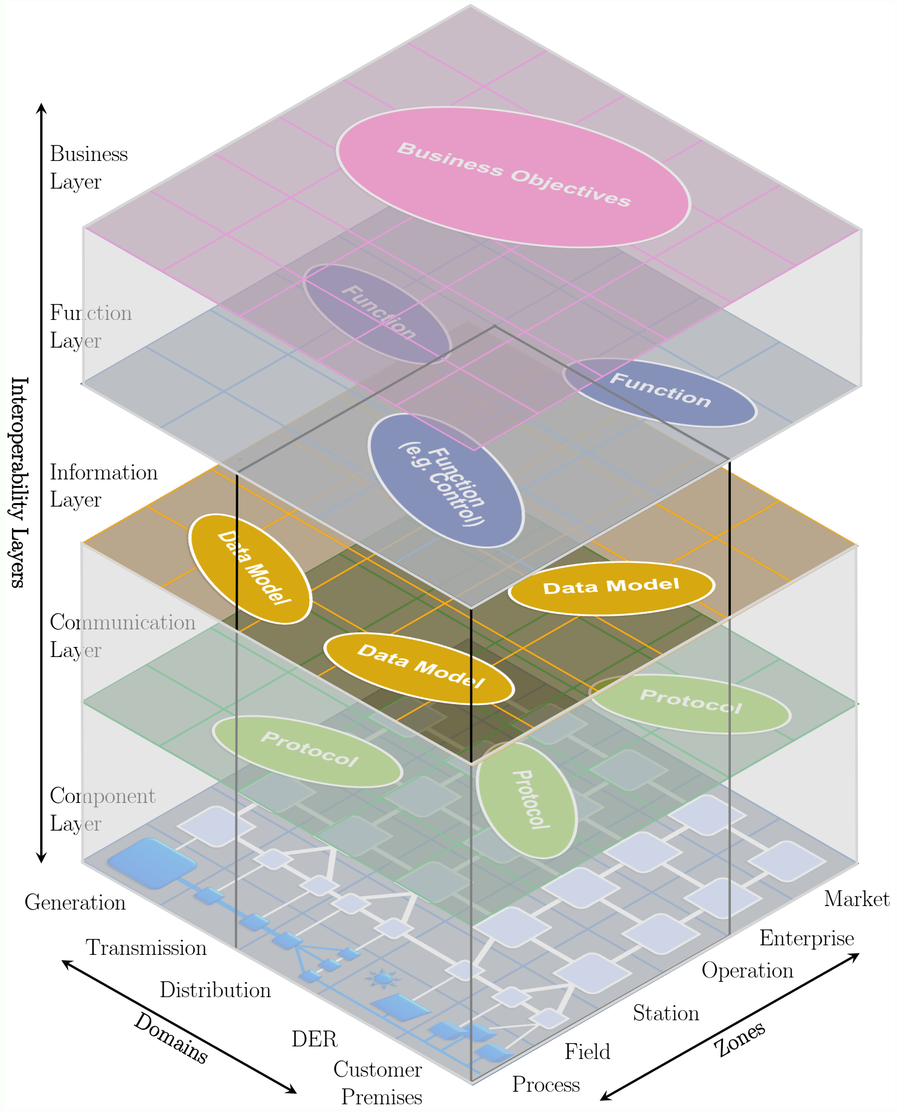
- In the function layer, you control for example voltage of the network



INFORMATION LAYER

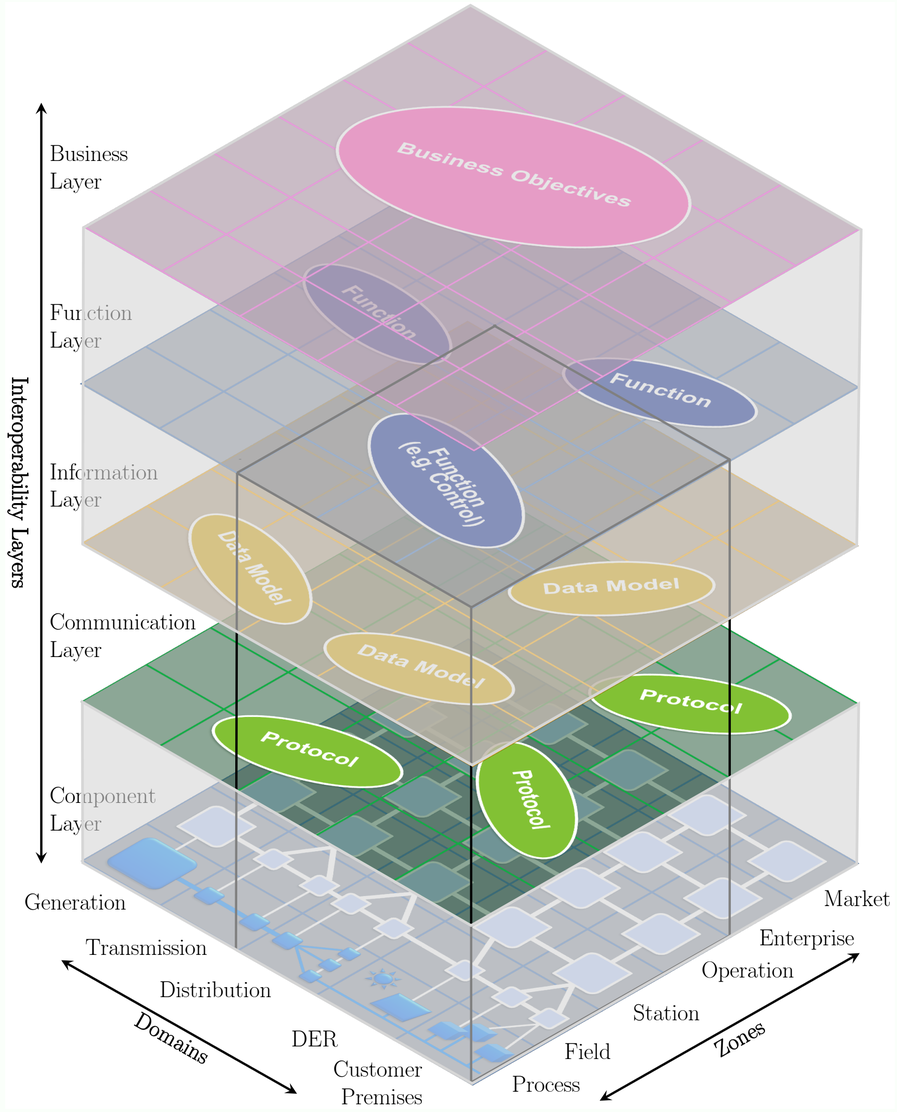
Transforms data into useable information:

- Describes how functions (energy) and services talk to each other
- Think about production, business, performance etc.



COMMUNICATION LAYER

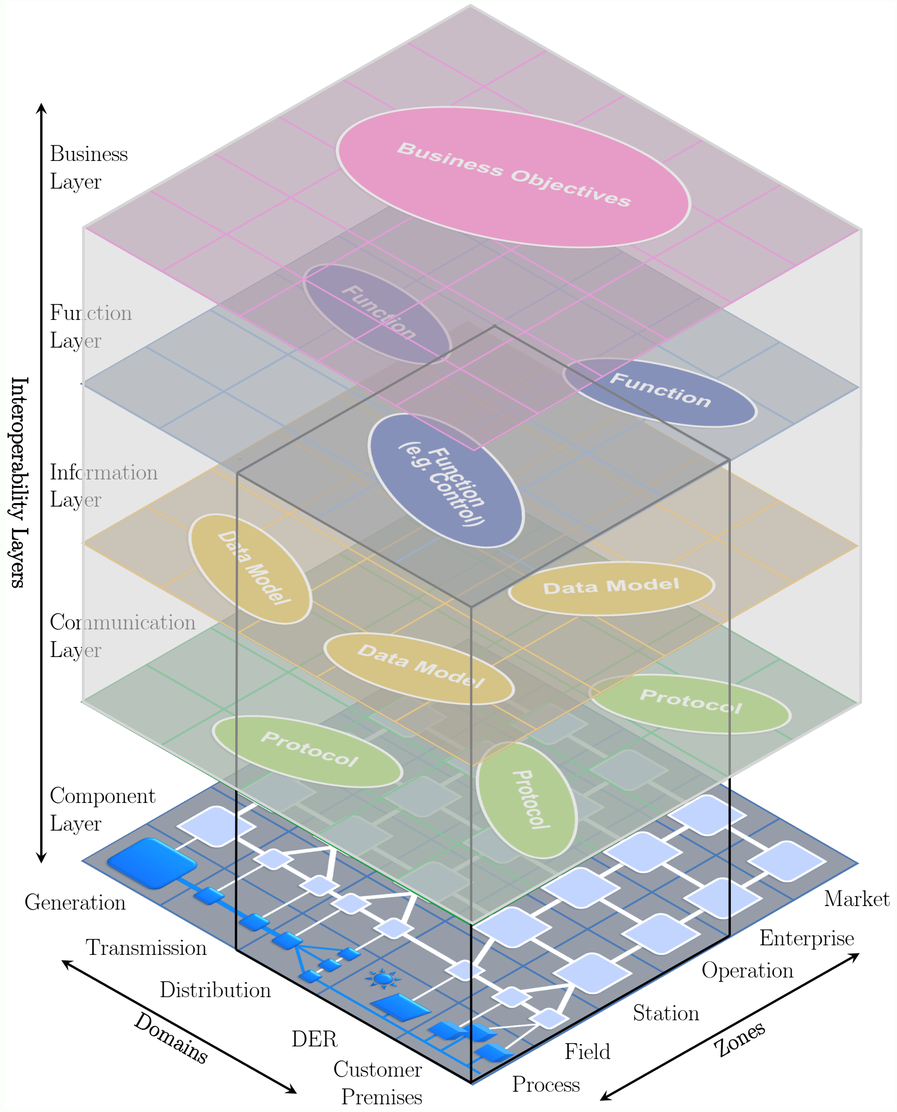
Protocols and mechanisms for interoperable info exchange between components (physical infra) depending on function or service



COMPONENT LAYER

Physical distribution of components:

- system actors
- applications
- power system equipment
- protection
- tele-control devices
- network infrastructure
- computers

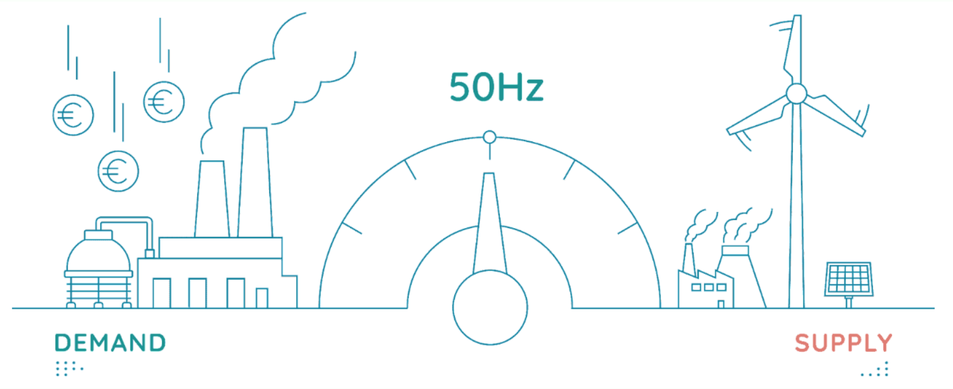


IT IN SMART GRIDS

- Advanced metering infrastructure (AMI)
- SCADA (Supervisory Control and Data Acquisition)
- Demand Response (DR)
- Grid Analytics and Data Management
- Renewable Energy Integration
- Energy Storage Management
- Cybersecurity Solutions
- Predictive Maintenance
- Distributed Energy Resources (DER) Management

DEMAND RESPONSE (DR)

DR is a change in consumer energy demand in response to grid conditions to balance the supply and demand of electricity.



Increase in demand:

- Special events
- Unusual weather conditions
- Emergency plan:
  - Use reserve power plants
  - Electricity curtailment

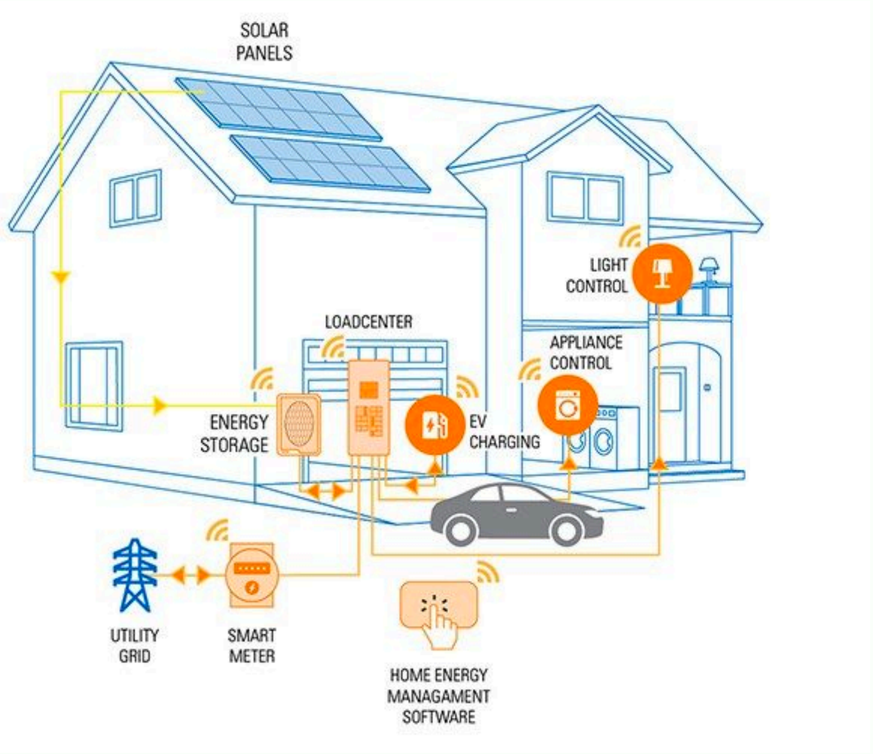
Surplus in production:

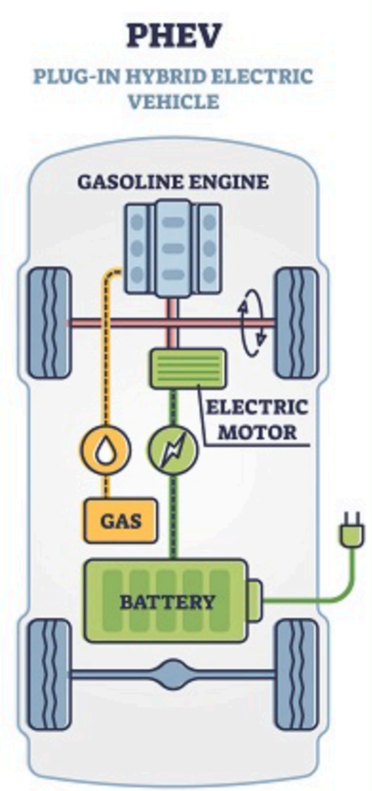
- Sudden increase of renewable energy
- Lower demand
- Emergency plan:
  - Pay neighbours
  - Turn off generation plants

https://sympower.net/what-is-demand-response/

ENERGY STORAGE MANAGEMENT (ESM)

Energy storage such as battery is used to store excess energy during periods of low demand and release it during peak demand.





R. Machlev, N. Zargari, N.R. Chowdhury, J. Belikov, Y. Levron. A review of optimal control methods for energy storage systems-energy trading, energy balancing and electric vehicles. Journal of Energy Storage, 32, 101787, 2020

CYBERSECURITY IN SMART GRIDS

Smart grids rely heavily on digital communication and data exchange.

Robust cybersecurity measures are needed to protect against cyber threats and ensure the integrity and confidentiality of grid data and operations.

BUSINESS

FUNCTION

INFORMATION

COMMUNICATION

COMPONENT

- Prevent
- Detect
- Identify
- Isolate

Ukraine Claims Hackers Caused Christmas Power Outage

By Thomas Brewster, Forbes Staff. Senior writer at Forbes covering...

Follow Author

Jan 04, 2016, 12:15pm EST

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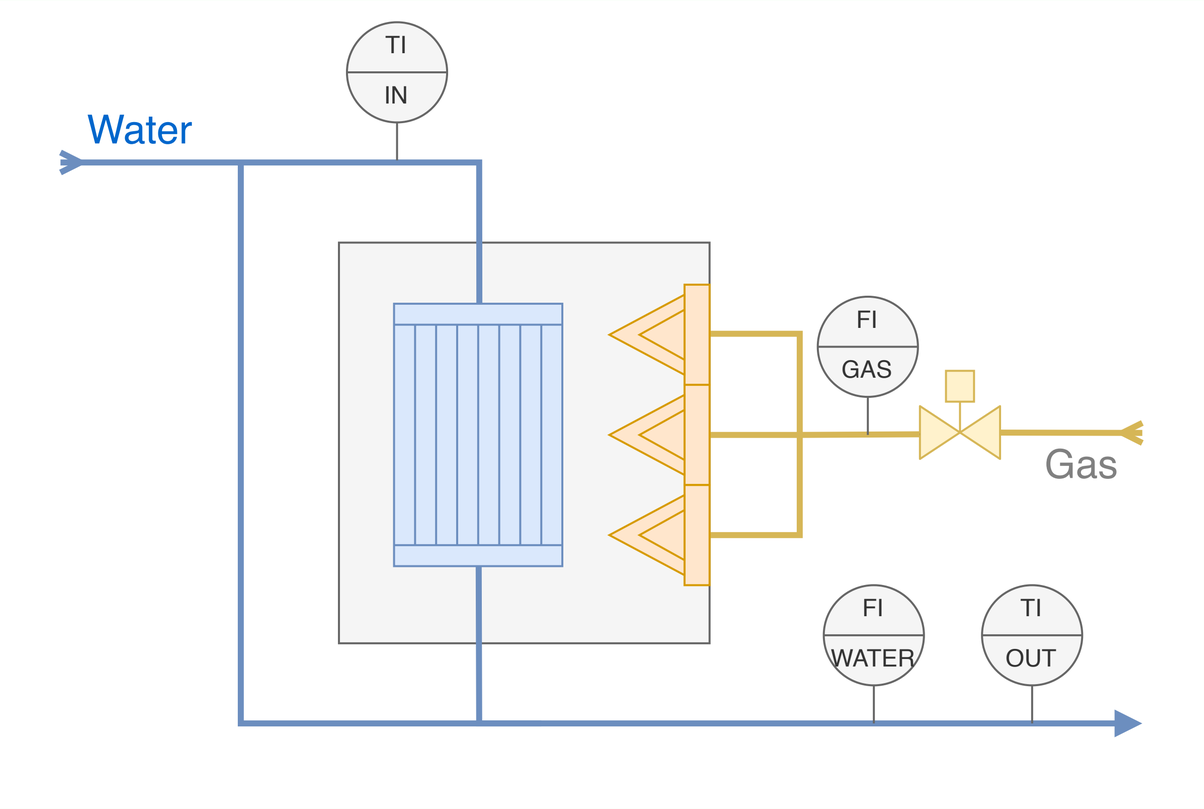
This article is more than 9 years old.

Just before Christmas, power went out across western Ukraine. Soon after, the energy ministry confirmed it was exploring claims a cyber attack disrupted local energy provider Prykarpattyaoblenergo, causing blackouts across the Ivano-Frankivsk region on 23 December. The SBU state intelligence service said Russian attempts to disrupt the country's power grid had been deflected, but did not comment on any specific attack.

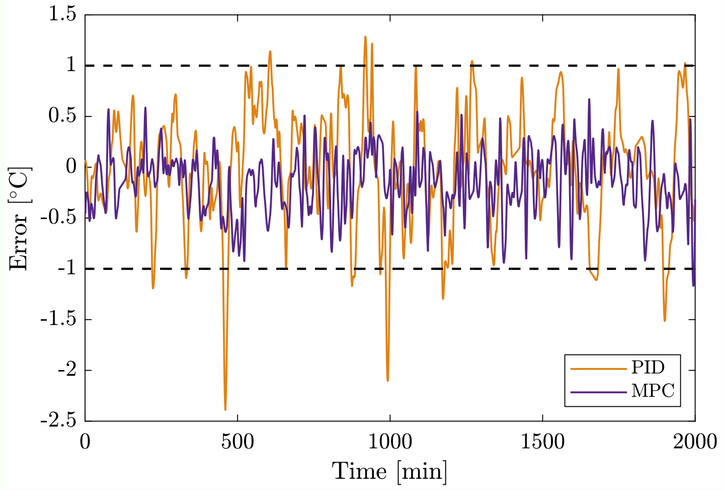
[Accessed May 19, 2025], https://www.forbes.com/sites/thomasbrewster/2016/01/04/ukraine-power-out-cyber-attack/

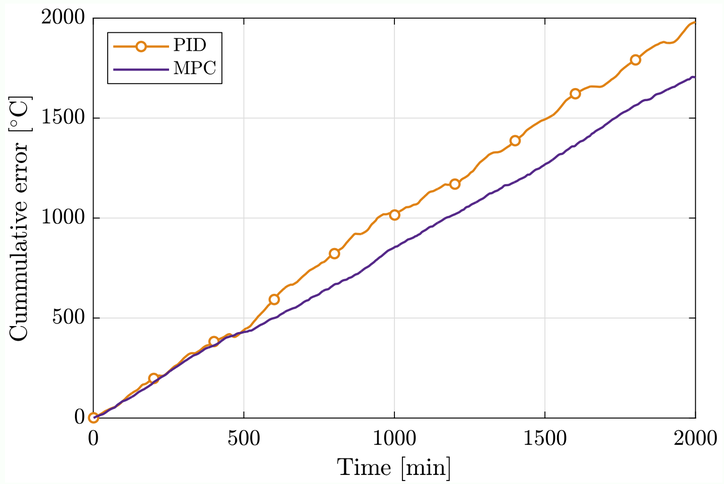
Some practical use cases

DISTRICT HEATING PLANT



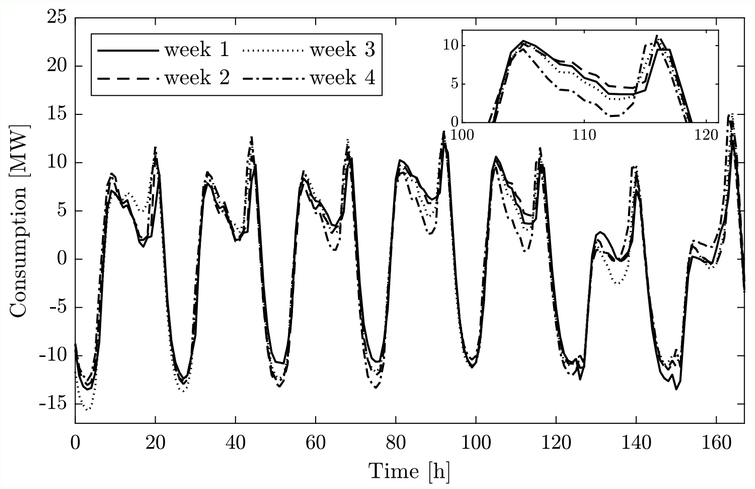
Reactive vs proactive

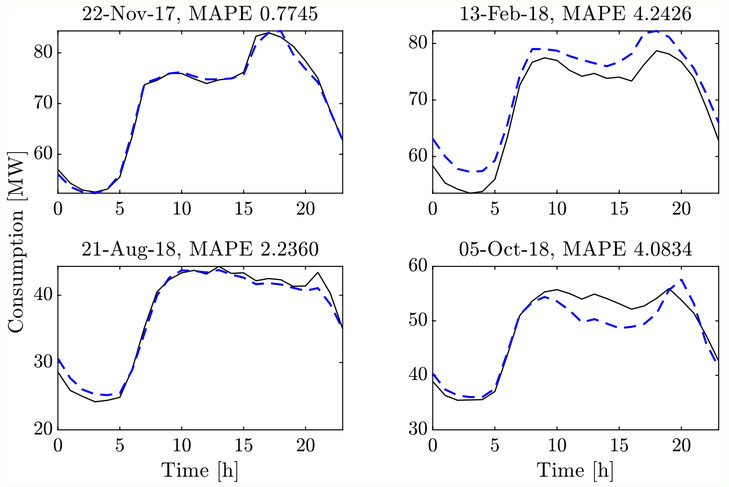


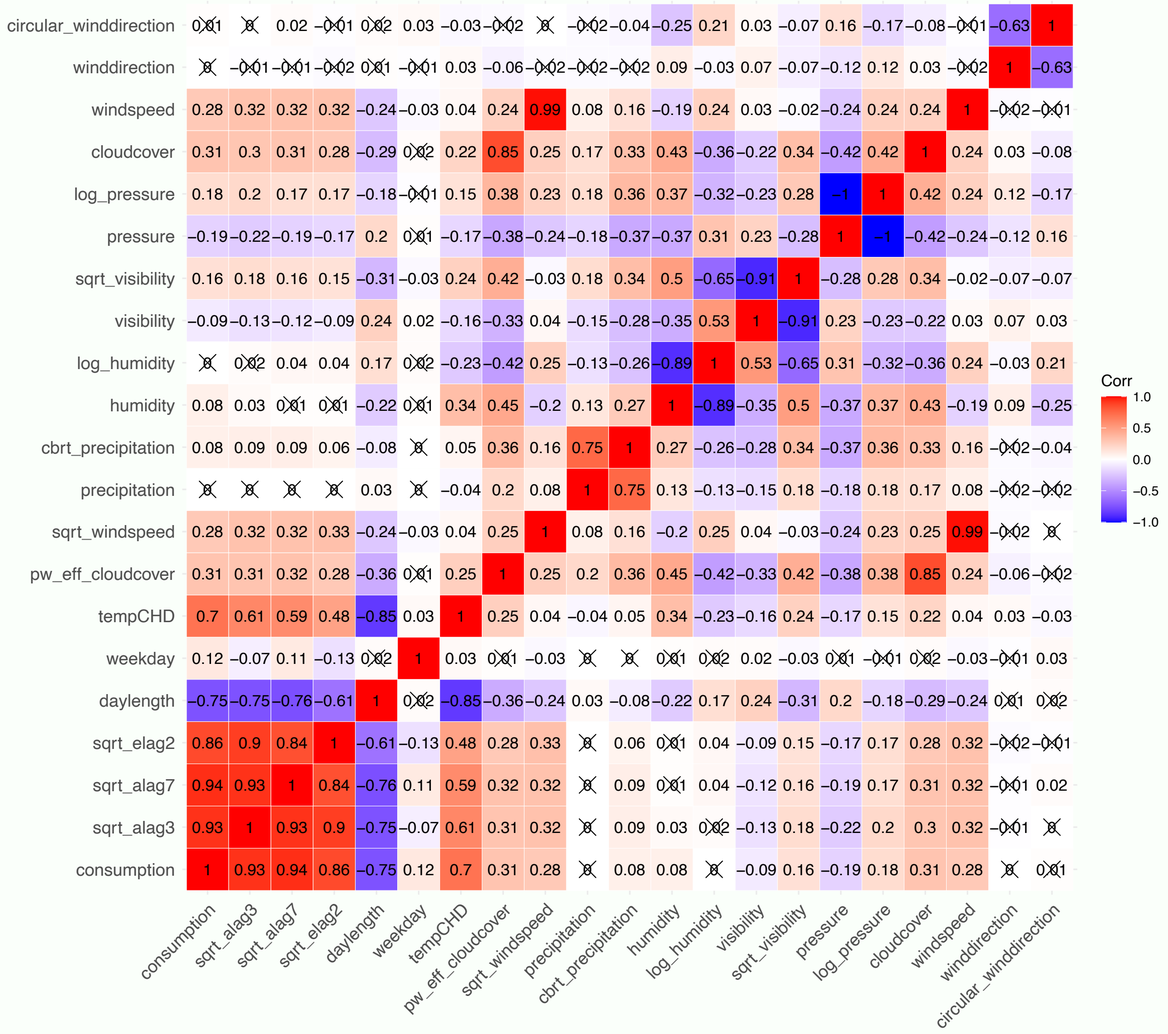


Vansovits, V.; Petlenkov, E.; Tepljakov, A.; Vassiljeva, K.; Belikov, J. Bridging the Gap in Technology Transfer for Advanced Process Control with Industrial Applications. *Sensors* 2022, *22*, 4149.

FORECASTING ELECTRICITY DEMAND

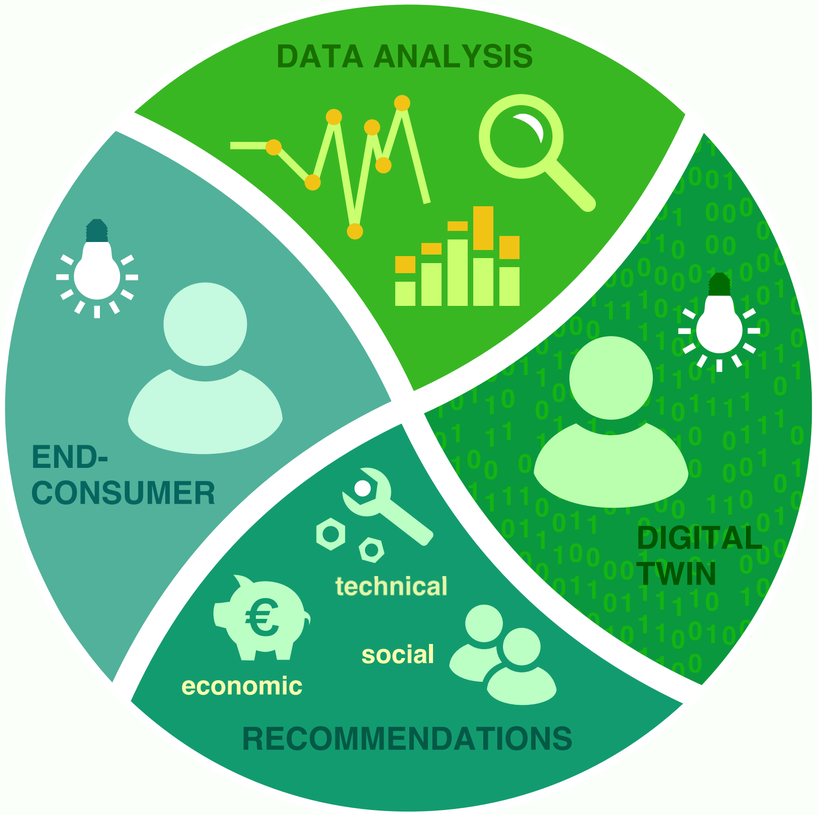


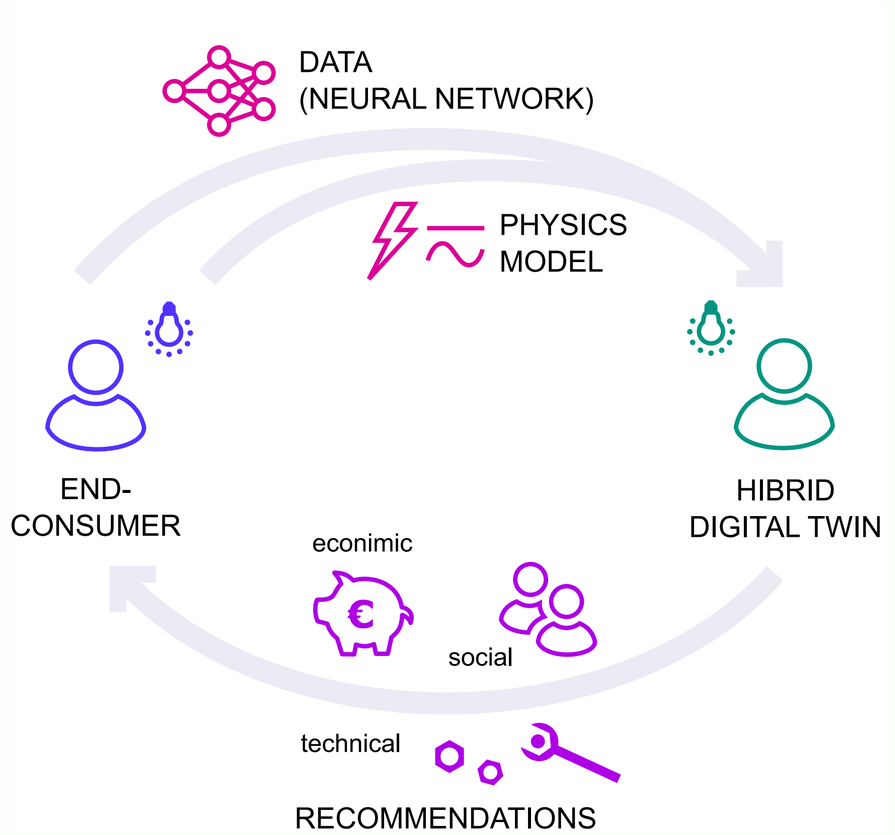




M. Sinimaa, M. Spichakova, J. Belikov, and E. Petlenkov. Feature engineering of weather data for short-term energy consumption forecast. *IEEE Madrid PowerTech,* June 28th - July 2nd, 2021, Madrid, Spain.

DT & INTELLIGENT ENERGY SERVICES





A. E. Onile, J. Belikov, Y. Levron, and E. Petlenkov Energy efficient behavior modelling for demand side recommender system in solar microgrid applications using multi-agent reinforcement learning model. Sustainable Cities and Society, 90, 104392.

Forbes

FORBES > SMALL BUSINESS

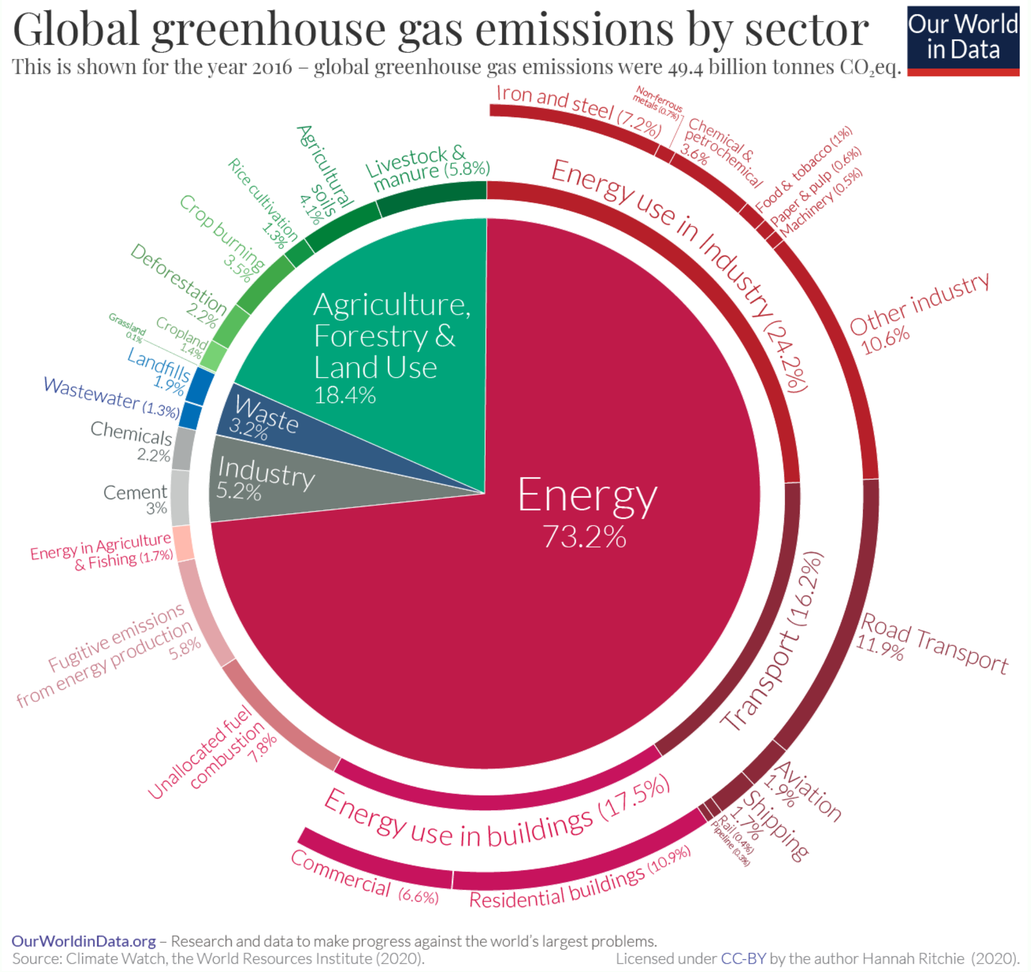
Confronting Commercial Real Estate's Biggest Challenges With Technology

Jeri Frank Former Forbes Councils Member
Forbes Business Council COUNCIL POST | Membership (Fee-Based)

Aug 4, 2022, 09:00am EDT

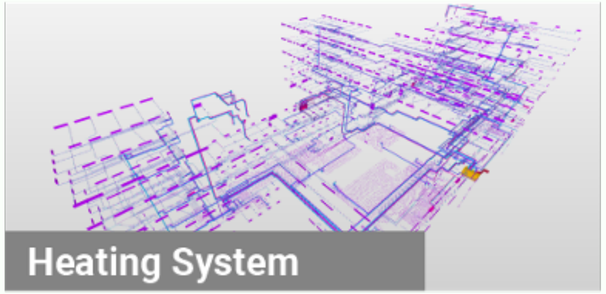
Climate Change And The Impact On Technology

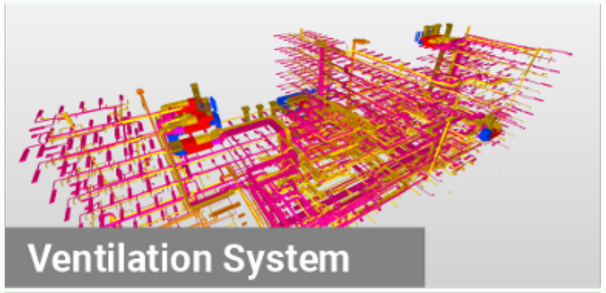
First, let's talk about climate technology and how it is affecting the real estate industry. Nearly half of all greenhouse gas emissions are generated from real estate. Approximately 27% of annual CO2 emissions come from building operations and another 20% come from building materials, construction and other construction-related causes. Concrete, steel and aluminum for new construction are particularly large contributors to carbon emissions. Existing buildings are contributing to the climate crisis due to a lack of energy efficiency. Even though upgrades are available, many real estate developers and owners are slow to embrace sustainable solutions.

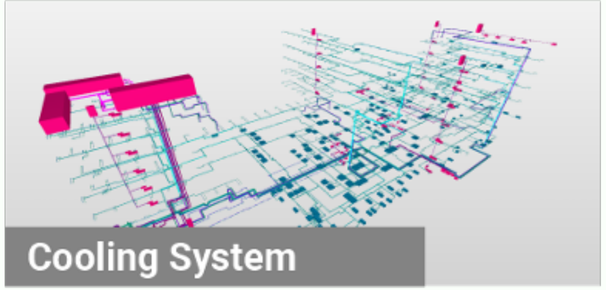


[Accessed February 27, 2025], https://www.forbes.com/sites/forbesbusinesscouncil/2022/08/04/confronting-commercial-real-estates-biggest-challenges-with-technology

SMART BUILDINGS







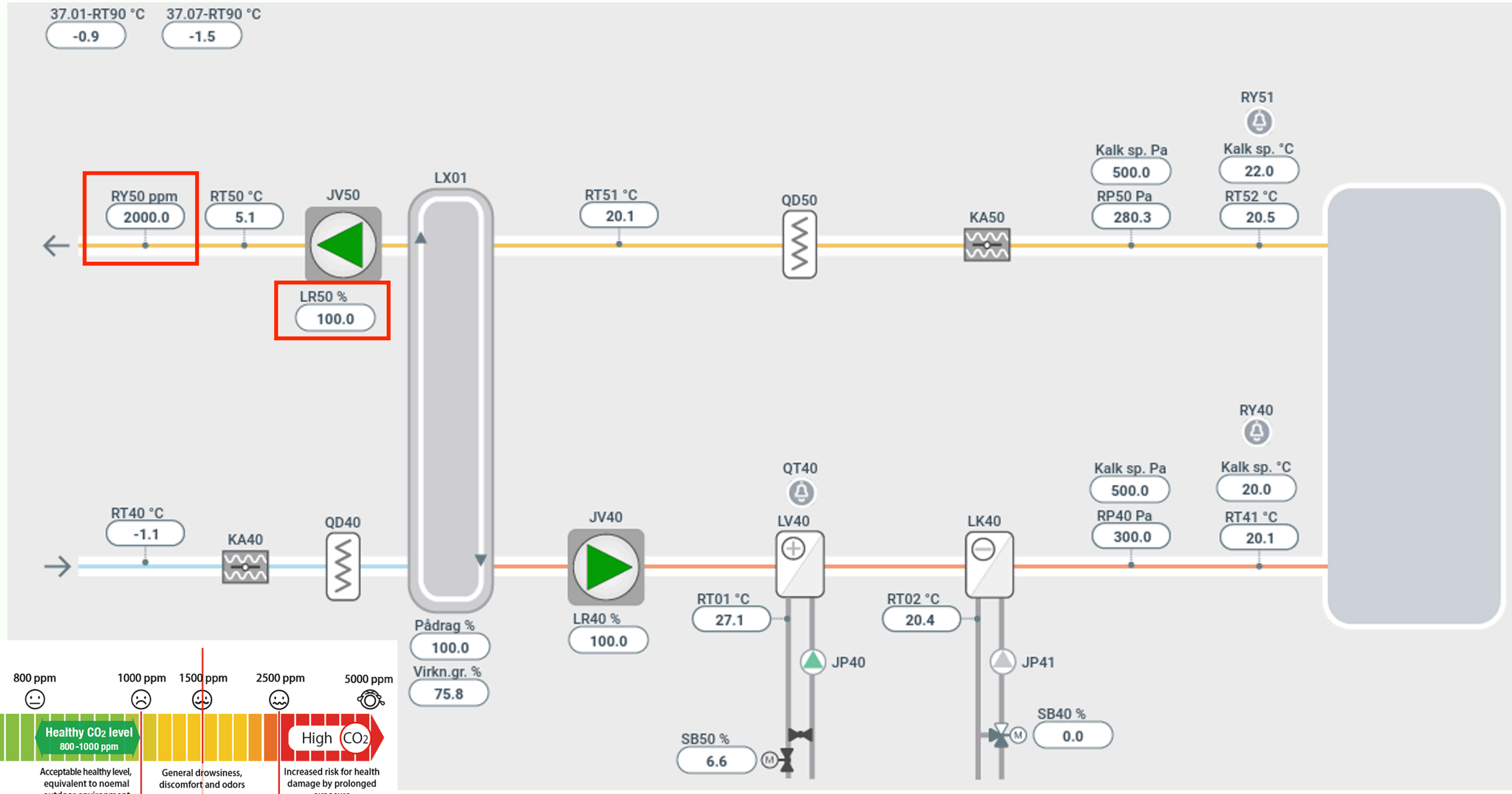
constructed 2018

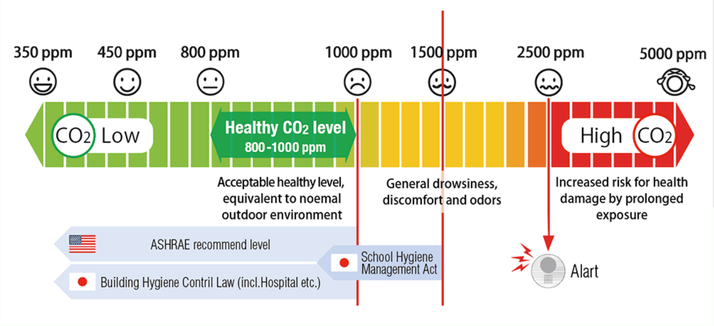
25 304 m² office building

48 813 datapoints

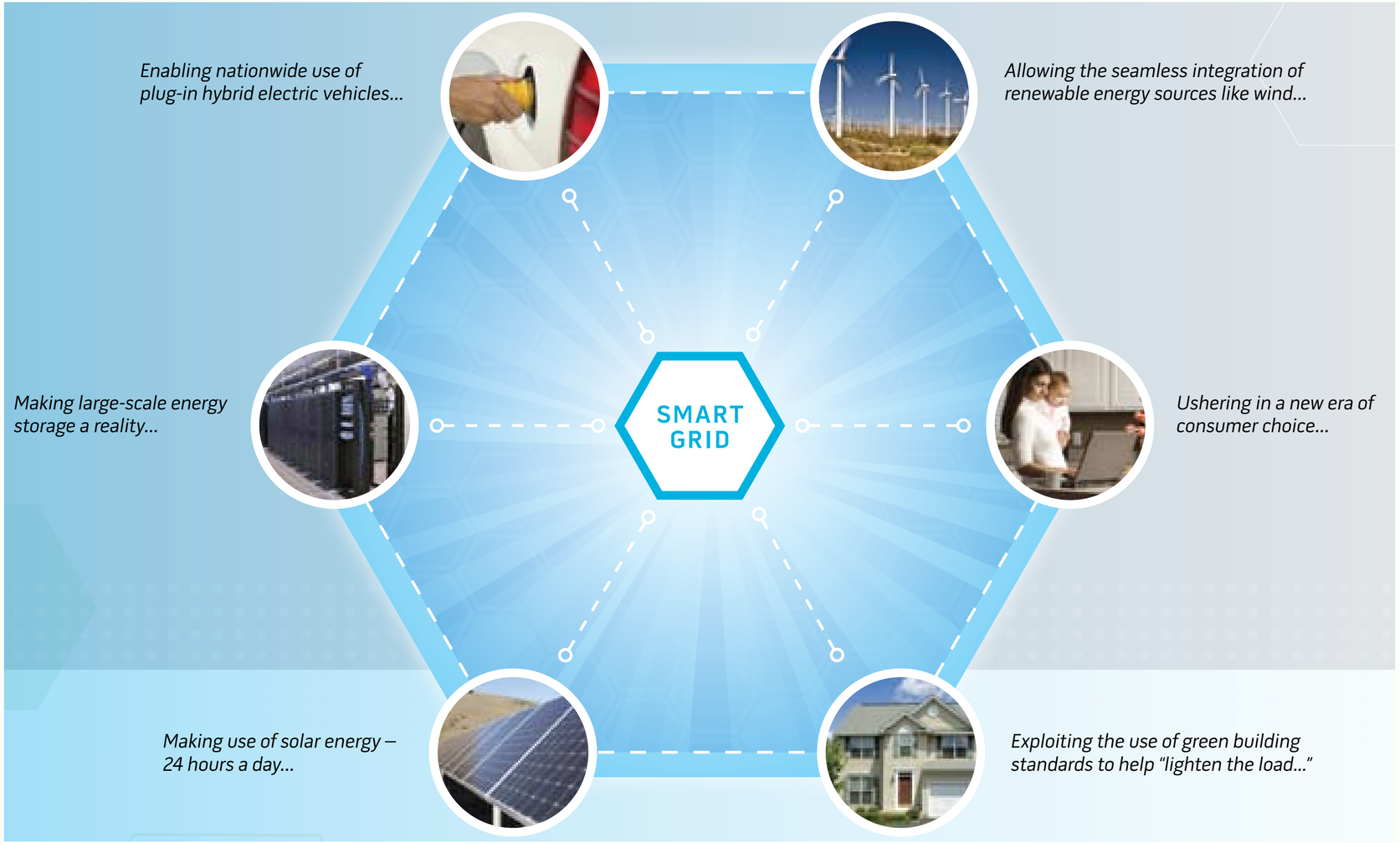
2 898 controllable HVAC components

FAULTY CO2 SENSOR



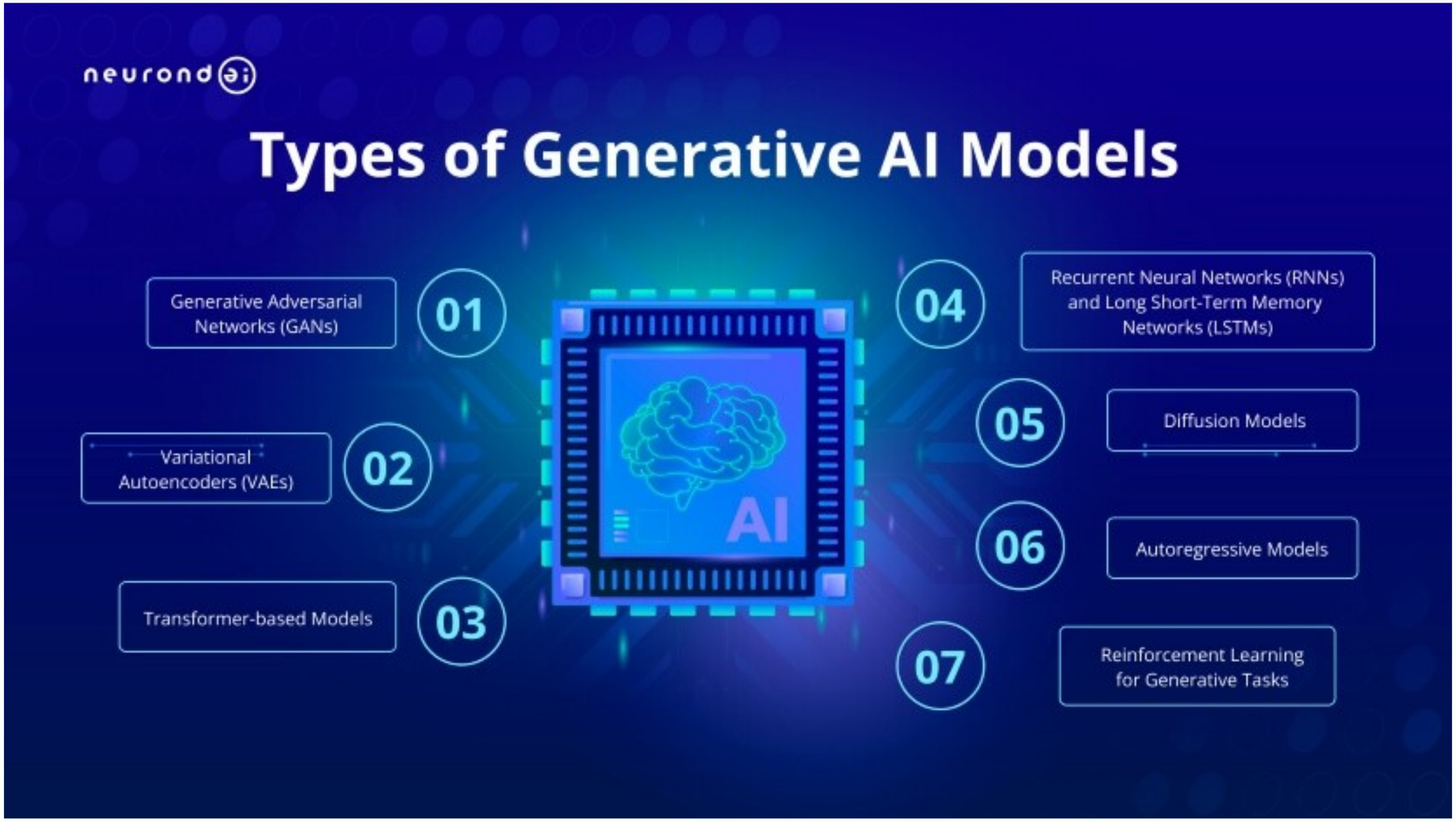


OPPORTUNITIES IN SMART GRIDS



[Accessed May 19, 2025], https://www.energy.gov/oe/articles/smart-grid-introduction-0

GOING DISRUPTIVE



[Accessed May 19, 2025], https://www.neurond.com/blog/generative-ai

MAKING THE CONTEXT

DECARBONISATION

- Renewable energy resources and integration with the existing grid
- Electric vehicles and charging infrastructure
- Green and zero emission buildings
- H2 technologies and storage

DECENTRALISATION & DIGITALISATION

- Microgrids
- Smart Grids
- ICT, ML, AI
- Internet of Things
- Cybersecurity

DEREGULATION & DEMOCRATISATION

- Blockchain technology
- Flexibility management
- Virtual power plants
- Network stability
- Peer to peer energy trade
- Demand side management

MAKING THE CONTEXT (2)

Estonian Research and Development, Innovation and Entrepreneurship (RDIE) Strategy 2021—2035

- [EST] https://www.hm.ee/korgharidus-ja-teadus/teadus-ja-arendustegevus/taie-arengukava-2021-2035
- [ENG] https://www.hm.ee/en/media/1614/download

The RDIE focus areas are:

- digital solutions across all areas of life
- health technologies and services
- valorisation of local resources
- smart and sustainable energy solutions
- viable Estonian society, language and cultural space

MAKING THE CONTEXT (3)

Three major changes to achieve the objective of the Strategy:

1. RDIE addresses society's development needs. RDIE helps to achieve societal and economic objectives.
2. Increasing impact and influence of science and researchers.
3. Business is becoming more RDI-intensive.

THE WORLD NEEDS INNOVATIONS

Challenges = Opportunities

FURTHER READING

https://elering.ee/en/smart-grid-development

https://www.entsoe.eu/news/2017/06/26/study-data-exchange-in-electric-power-systems-european-state-of-play-and-perspectives/

https://eu-sysflex.com/wp-content/uploads/2022/02/WP9-Demo-Fact-Sheet_Estonian_Final.pdf

https://eu-sysflex.com/wp-content/uploads/2021/11/EU-SysFlex-D5.1-Data-exchange-model-v.1.pdf

http://www.interrface.eu/sites/default/files/publications/INTERRFACE_D5.5_vPUBLIC.pdf

https://onenet-project.eu/wp-content/uploads/2023/04/D6.2-OneNet-v1.0.pdf

https://op.europa.eu/en/publication-detail/-/publication/0ff50c6e-ac1d-11ed-b508-01aa75ed71a1/language-en

Thank you!
Questions?