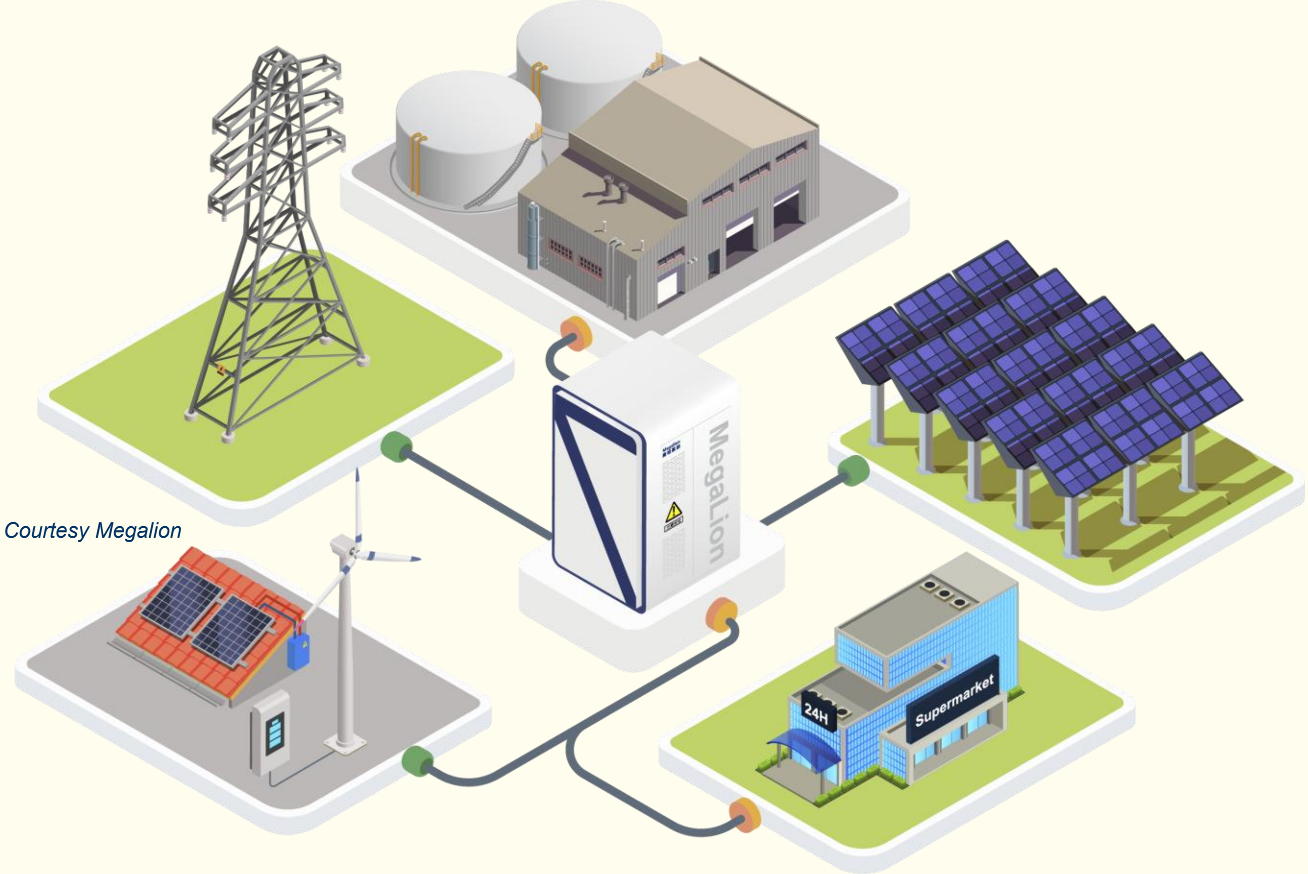


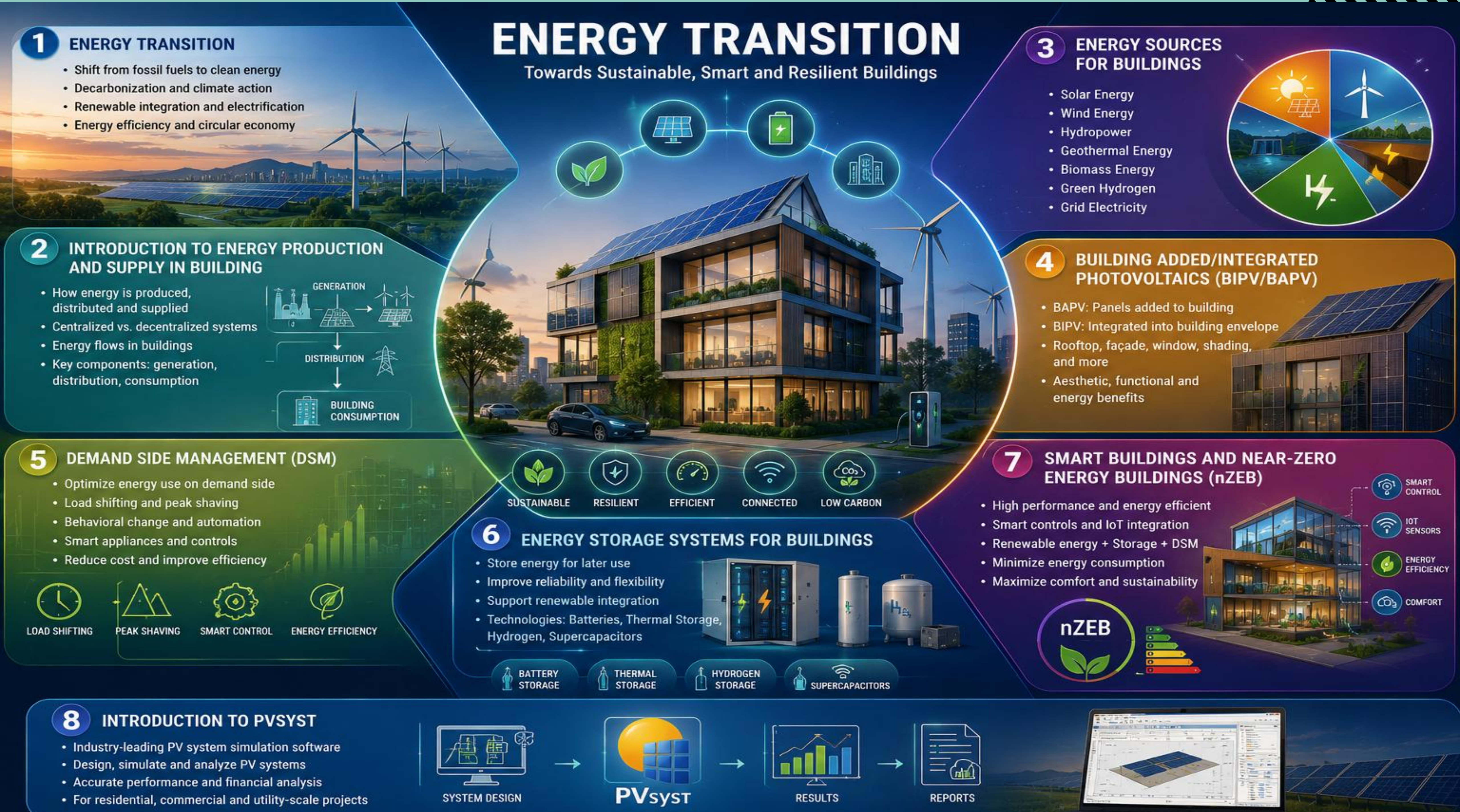
Courtesy Megalion

Module 4:

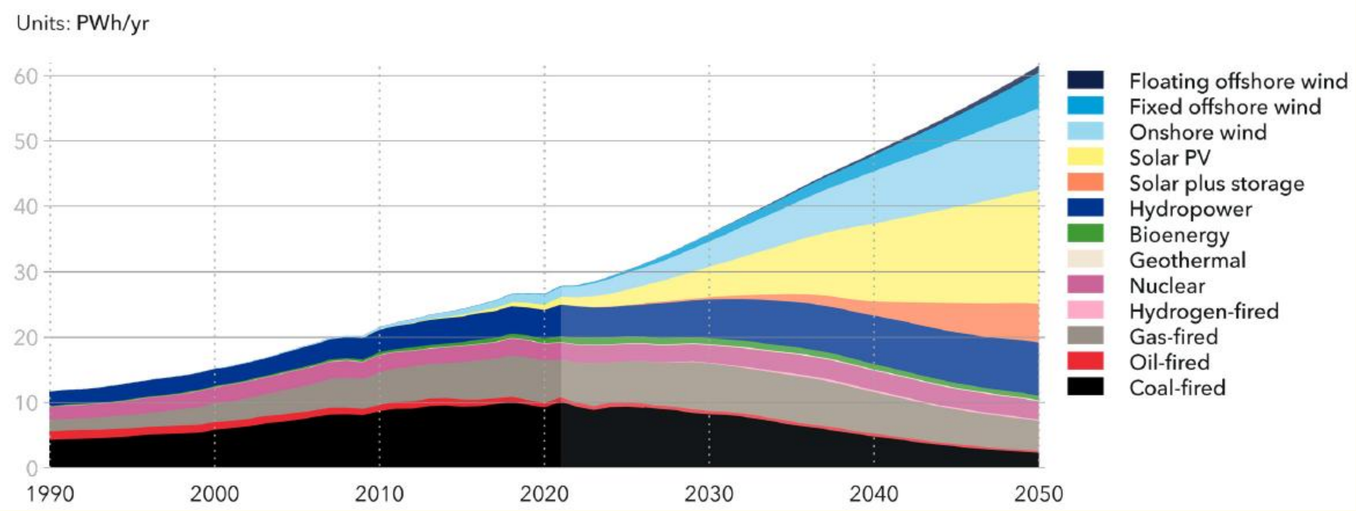
Energy and Building: Advanced Energy Management and Production

Prof. Dr.-Ing. Mohammadreza Aghaei

University of Freiburg


ENERGY TRANSITION
Towards Sustainable, Smart and Resilient Buildings
1 ENERGY TRANSITION
Shift from fossil fuels to clean energy
Decarbonization and climate action
Renewable integration and electrification
Energy efficiency and circular economy
2 INTRODUCTION TO ENERGY PRODUCTION AND SUPPLY IN BUILDING
How energy is produced, distributed and supplied
Centralized vs. decentralized systems
Energy flows in buildings
Key components: generation, distribution, consumption
GENERATION
DISTRIBUTION
BUILDING CONSUMPTION
3 ENERGY SOURCES FOR BUILDINGS
Solar Energy
Wind Energy
Hydropower
Geothermal Energy
Biomass Energy
Green Hydrogen
Grid Electricity
4 BUILDING ADDED/INTEGRATED PHOTOVOLTAICS (BIPV/BAPV)
BAPV: Panels added to building
BIPV: Integrated into building envelope
Rooftop, façade, window, shading, and more
Aesthetic, functional and energy benefits
5 DEMAND SIDE MANAGEMENT (DSM)
Optimize energy use on demand side
Load shifting and peak shaving
Behavioral change and automation
Smart appliances and controls
Reduce cost and improve efficiency
LOAD SHIFTING
PEAK SHAVING
SMART CONTROL
ENERGY EFFICIENCY
SUSTAINABLE
RESILIENT
EFFICIENT
CONNECTED
LOW CARBON
6 ENERGY STORAGE SYSTEMS FOR BUILDINGS
Store energy for later use
Improve reliability and flexibility
Support renewable integration
Technologies: Batteries, Thermal Storage, Hydrogen, Supercapacitors
BATTERY STORAGE
THERMAL STORAGE
HYDROGEN STORAGE
SUPERCAPACITORS
7 SMART BUILDINGS AND NEAR-ZERO ENERGY BUILDINGS (nZEB)
High performance and energy efficient
Smart controls and IoT integration
Renewable energy + Storage + DSM
Minimize energy consumption
Maximize comfort and sustainability
SMART CONTROL
IOT SENSORS
ENERGY EFFICIENCY
COMFORT
nZEB
8 INTRODUCTION TO PVSYST
Industry-leading PV system simulation software
Design, simulate and analyze PV systems
Accurate performance and financial analysis
For residential, commercial and utility-scale projects
SYSTEM DESIGN
PVsyst
RESULTS
REPORTS

Energy Transition
Introduction



World grid-connected electricity generation by power station type

Source: IEA WEB (2022), GlobalData (2022)

Energy transition refers to the **global energy sector's shift** from **fossil-based systems** of energy production and consumption — including **oil, natural gas and coal** — to **renewable energy sources** like **wind** and **solar**, as well as lithium-ion batteries.

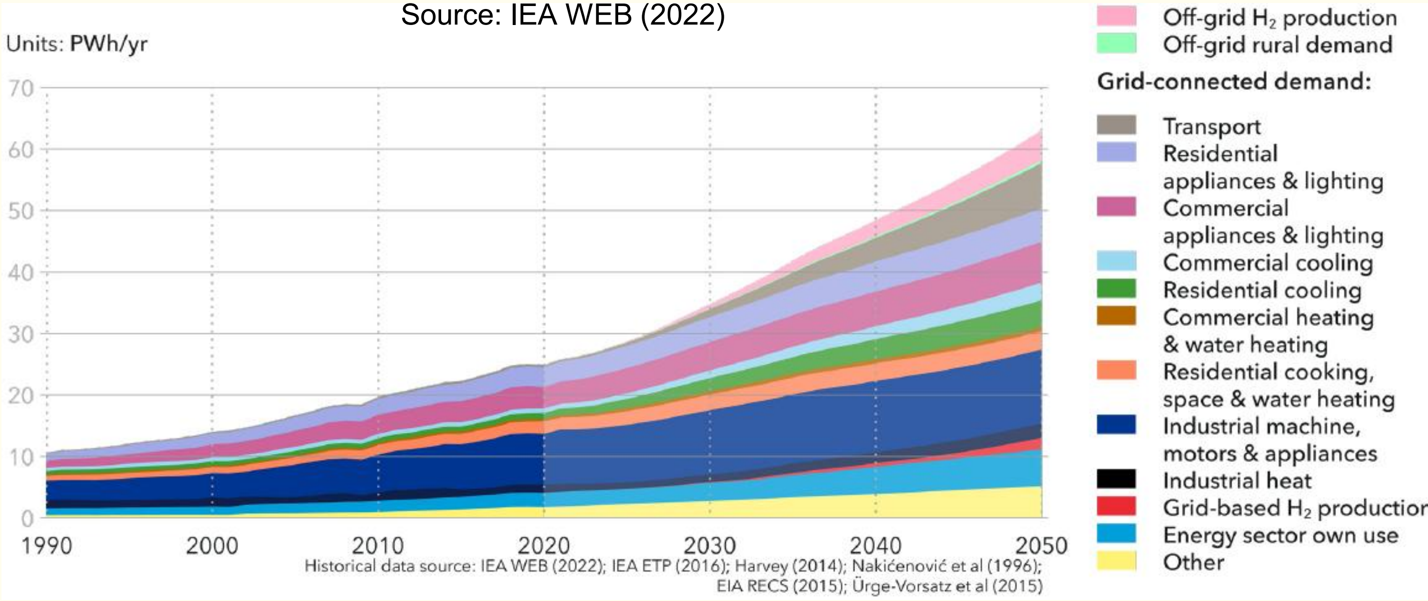
Source: IRENA, Energy Transition 2022

The success of the **Energy Transition** depends on a **transformation of the global energy sector** from fossil-based to **zero-carbon sources** by the second half of this century, reducing **energy-related CO2 emissions** to **mitigate climate change** and **limit global temperature to within 1.5°** of pre-industrial levels.

Source: IRENA, Energy Transition 2022

World electricity demand by sector

Source: IEA WEB (2022)



Energy Transition

Introduction

- One **clear goal**: «*move from fossil fuels to renewable energy production*».
- **Norway** has **98.7%** of energy generated covered by RES. However, in **EU** only reaches **65.8%** (including nuclear).
- **EU** aims to reduced emissions by **55%** in **2030**, **90%** in **2040**, and **climate neutrality** by **2050**.

https://safety4sea.com/dnv-energy-transition-outlook-2023/

- International Energy Agency. (n.d.). *Countries and regions*. Retrieved February 13, 2026, from https://www.iea.org/countries
- European Commission. (n.d.). *The European Green Deal*. Retrieved February 13, 2026, from https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

Energy Transition

Introduction

In 2020, the European Commission unveiled the **EU Strategy for Energy System Integration** serves as a framework for an **energy transition**, which comprises:

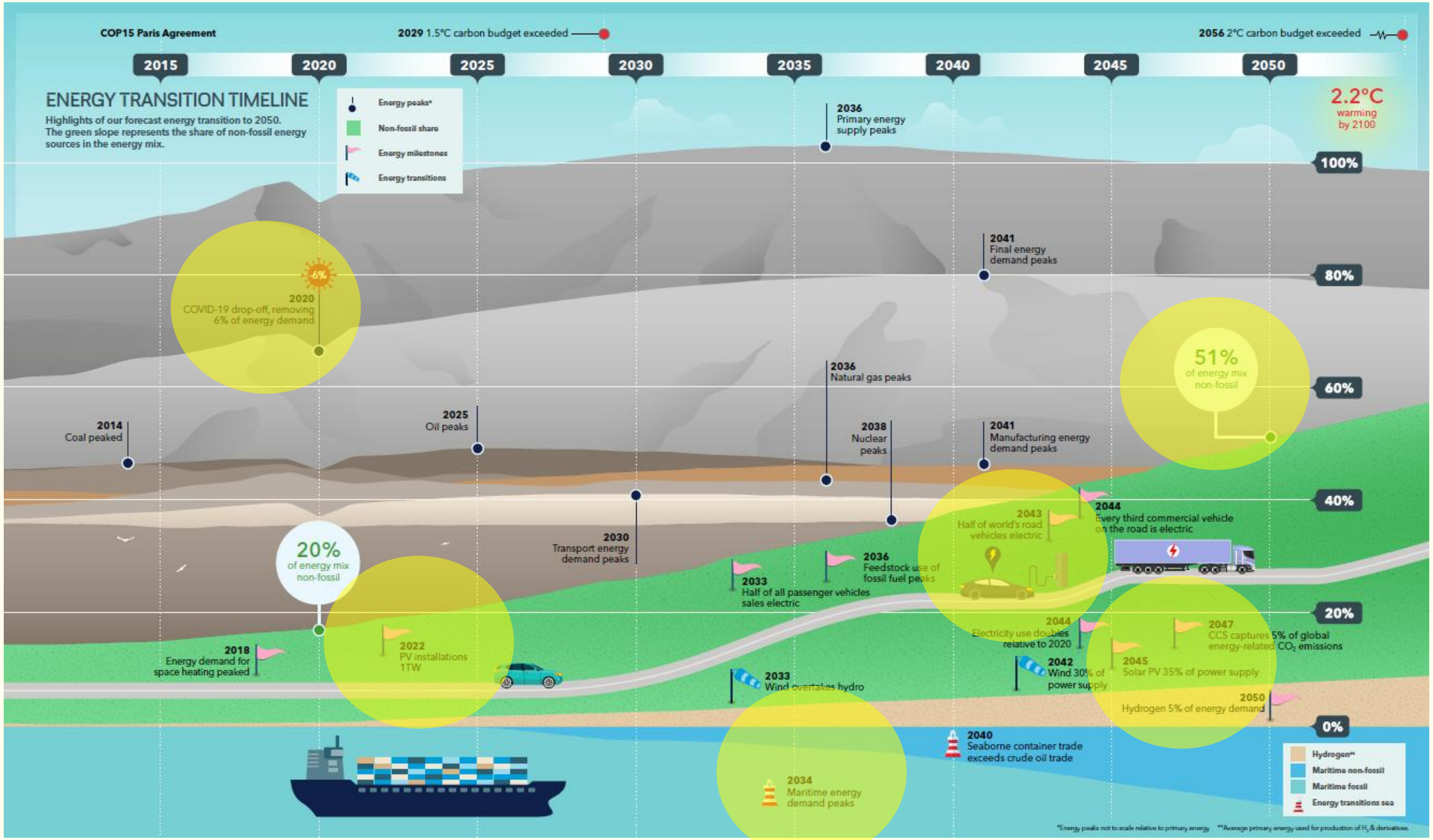
- **be more circular**, with energy efficiency at its core;
- **provide more and greener electricity** to sectors such as transport and industry;
- **promote low-carbon fuels** for sectors which are more difficult to decarbonise.

Source: Energi Media

European Commission, Directorate-General for Energy. (n.d.). Energy system integration. Retrieved February 13, 2026, from https://energy.ec.europa.eu/topics/eus-energy-system/energy-system-integration_en

Energy Transition

Timeline and achievement

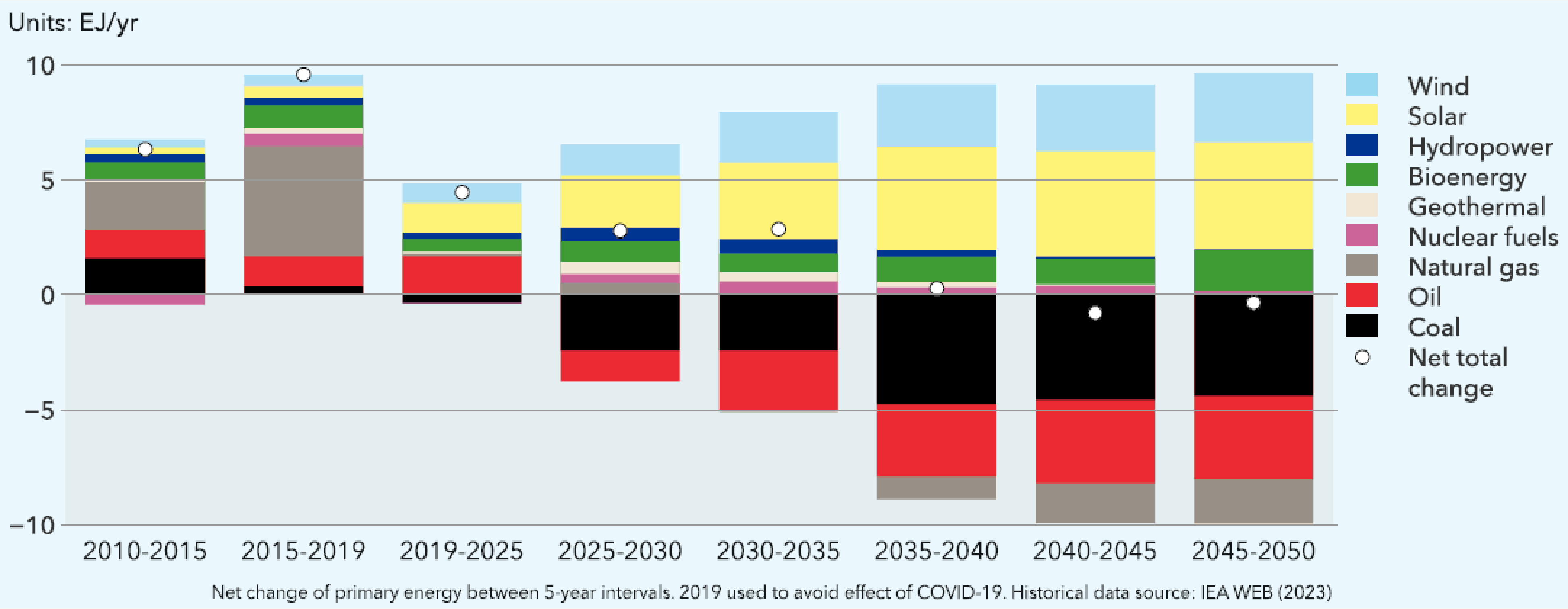


Source: Energy Transition Outlook, DNV, 2022

Energy Transition

Renewables outsprint fossils from the mid-2020s

- The transition involves both the **addition of renewables** and the **removal of fossil sources.**
- **Fossil primary energy** demand declines from **490 EJ** to **314 EJ** by **2050.**



Net change in primary energy supply by source
Source: DNV, 2023

7

Energy Transition

The Challenges

https://static.vecteezy.com/system/resources/previews/024/316/611/non_2x/green-hydrogen-h2-future-energy-transportation-to-city-concept-semi-trailer-gas-tank-on-the-road-isometric-cartoon-isolated-vector.jpg

The energy transition will carry **challenges**:

- **Producing** renewable and low-carbon energy and finding appropriate and publicly accepted production locations;
- **Storing** energy volumes over long periods, to match intermittent renewable supply with demand;
- **Transporting** energy from where it can be produced most efficiently to where it is consumed.

https://www.frontier-economics.com/media/jnjisrfx/decarbonising-europes-gas-system.pdf

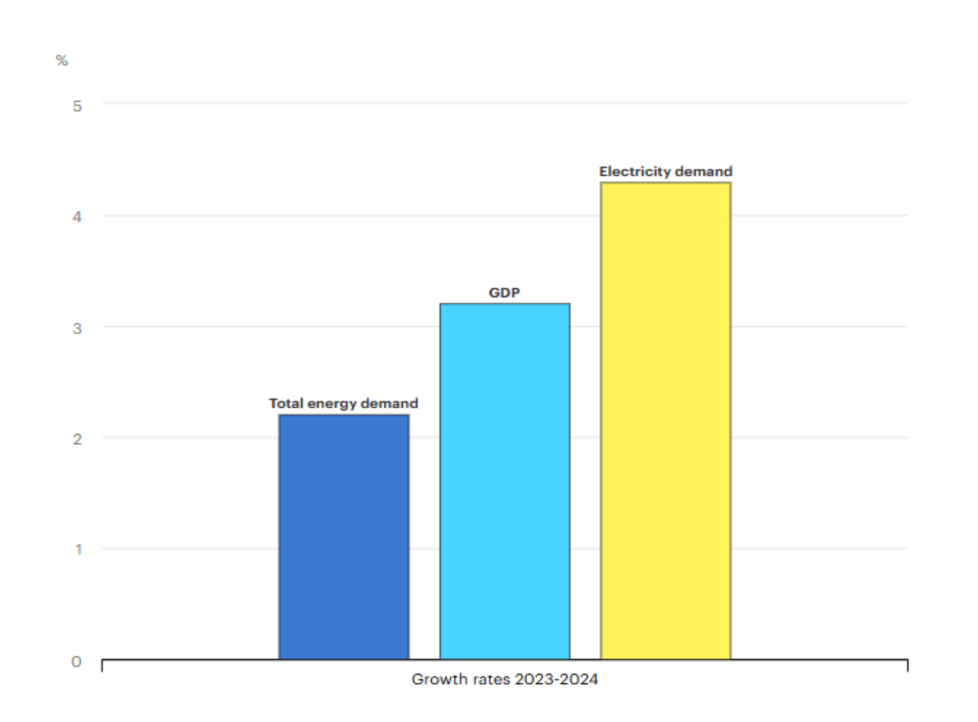
Energy Transition
The Challenges

Introduction to Energy Production and Supply in Building

Global Energy and Environmental Challenge

Growing Global Energy Demand

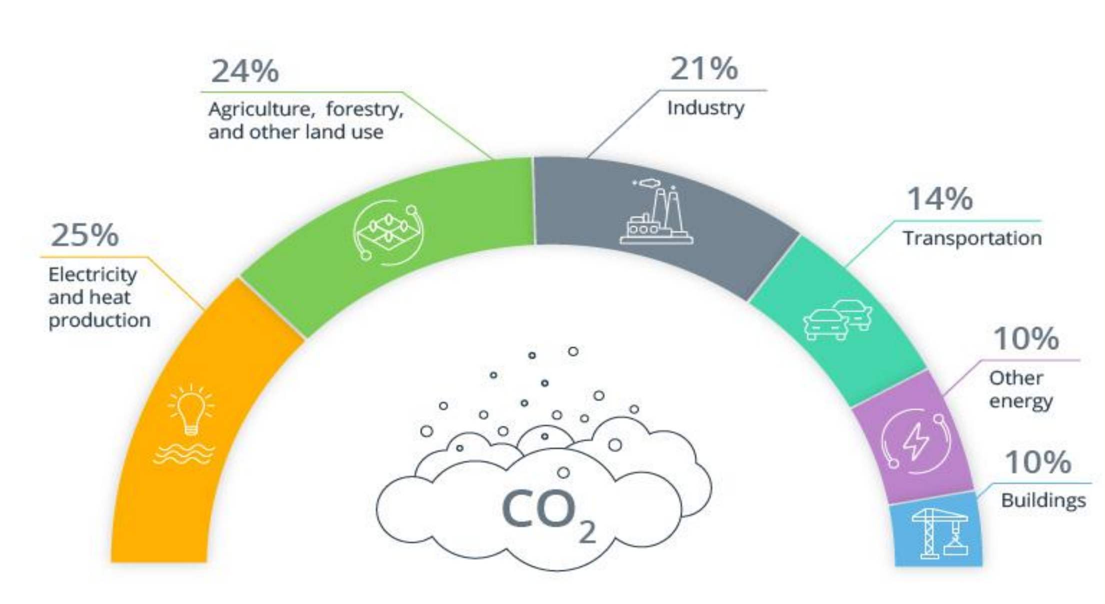
- Global energy demand has been rising steadily due to **population growth**, **urbanization**, and **economic development**.
- According to the International Energy Agency (IEA), **global final energy consumption** increased by about **4% between 2010 and 2020**, and is projected to continue rising.
- Urban areas are expanding rapidly: by 2050, nearly **70% of the world's population** will live in cities (UN, 2021).
- This urban growth places a heavy demand on building energy systems for **heating, cooling, lighting, and appliances**.



Source: IEA, *Key Global Growth Rates by Source*, 2024.

Climate Change and the Role of Energy Use

- Energy production (especially from fossil fuels) is the **largest contributor to greenhouse gas (GHG) emissions**.
- **Building operations** (heating, cooling, lighting, appliances) are responsible for approximately **28–30% of global CO_2 emissions**.
- Including construction materials (embodied carbon), the total building sector's share rises to **~40%**.
- Rising temperatures and climate change effects (heatwaves, extreme weather) further **increase building energy demands**, creating a feedback loop.



Source: Intellias, *How IoT, AI, and Big Data Can Help Save the Planet*, 2023

Urgent Call for Greener Buildings

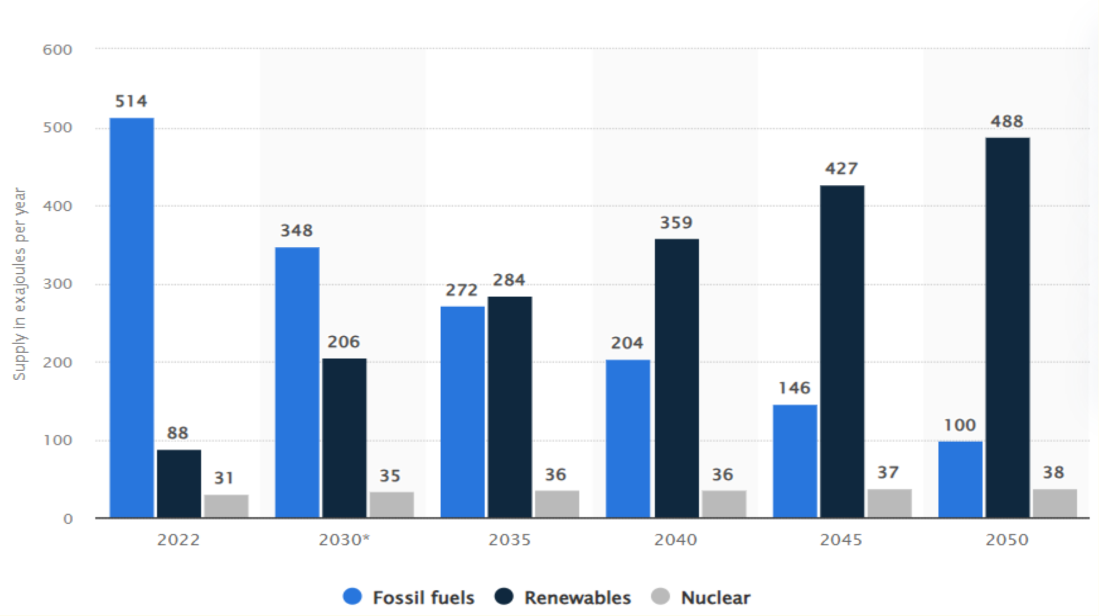
- Without strong action, building-related emissions are expected to **grow by another 50% by 2050**.

- **Net Zero Carbon Buildings** are essential to achieve the goals of the **Paris Agreement** (limit global warming to 1.5°C).

- New buildings must be **zero-carbon-ready** by **2030**.

- Existing buildings must be **deeply renovated** at a rate of **2–3% per year** (much higher than today).

- Energy efficiency, renewable energy integration, and smart management are **urgent and unavoidable** strategies.



Source: Statista, *Global Total Energy Supply by Source*, 2024.

Challenges in Current Building Energy Systems

Dependence on Fossil Fuels

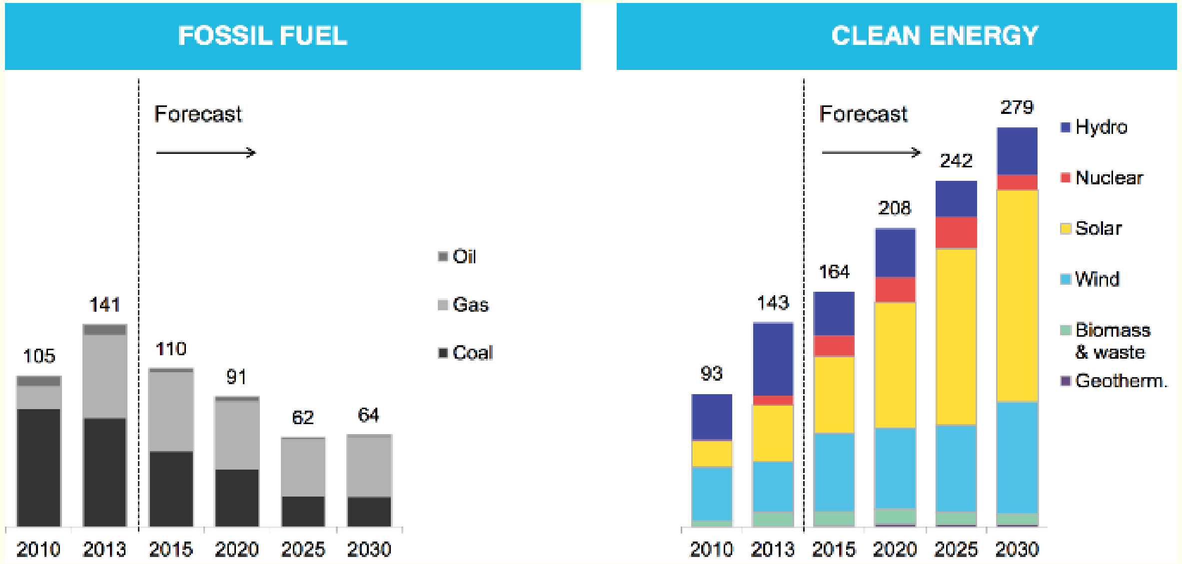
Many buildings still rely on **natural gas**, **oil**, and **coal** for heating, hot water, and cooking.

Over 50% of heating energy comes from fossil fuels globally (IEA, *Tracking Buildings 2023*).

Even electricity often comes from fossil-fuel-powered grids.

Consequences:

- High **CO_2 emissions** and contribution to climate change.
- Exposure to **energy price volatility** (e.g., gas crisis in Europe 2022).
- **Energy security risks** and vulnerability to supply disruptions.



Source: Renewable Energy World, *Fossil Fuels Just Lost the Race Against Renewables*, 2024.

Poor Energy Efficiency in Older Buildings

- Many existing buildings have **poor insulation**, **air leaks**, and **outdated HVAC systems**.
- **Over 75%** of European buildings are energy-inefficient (European Commission, *Renovation Wave 2020*).

Consequences:

- High **energy waste** (especially for heating and cooling).
- Increased **operating costs** for owners and tenants.
- Poor **indoor air quality** and **thermal comfort** (drafts, temperature swings).
- Slower progress toward **climate targets** without renovation.

High Operational and Environmental Costs

- Inefficient buildings have **high operational costs**: more energy needed for basic services.

Environmental costs include:

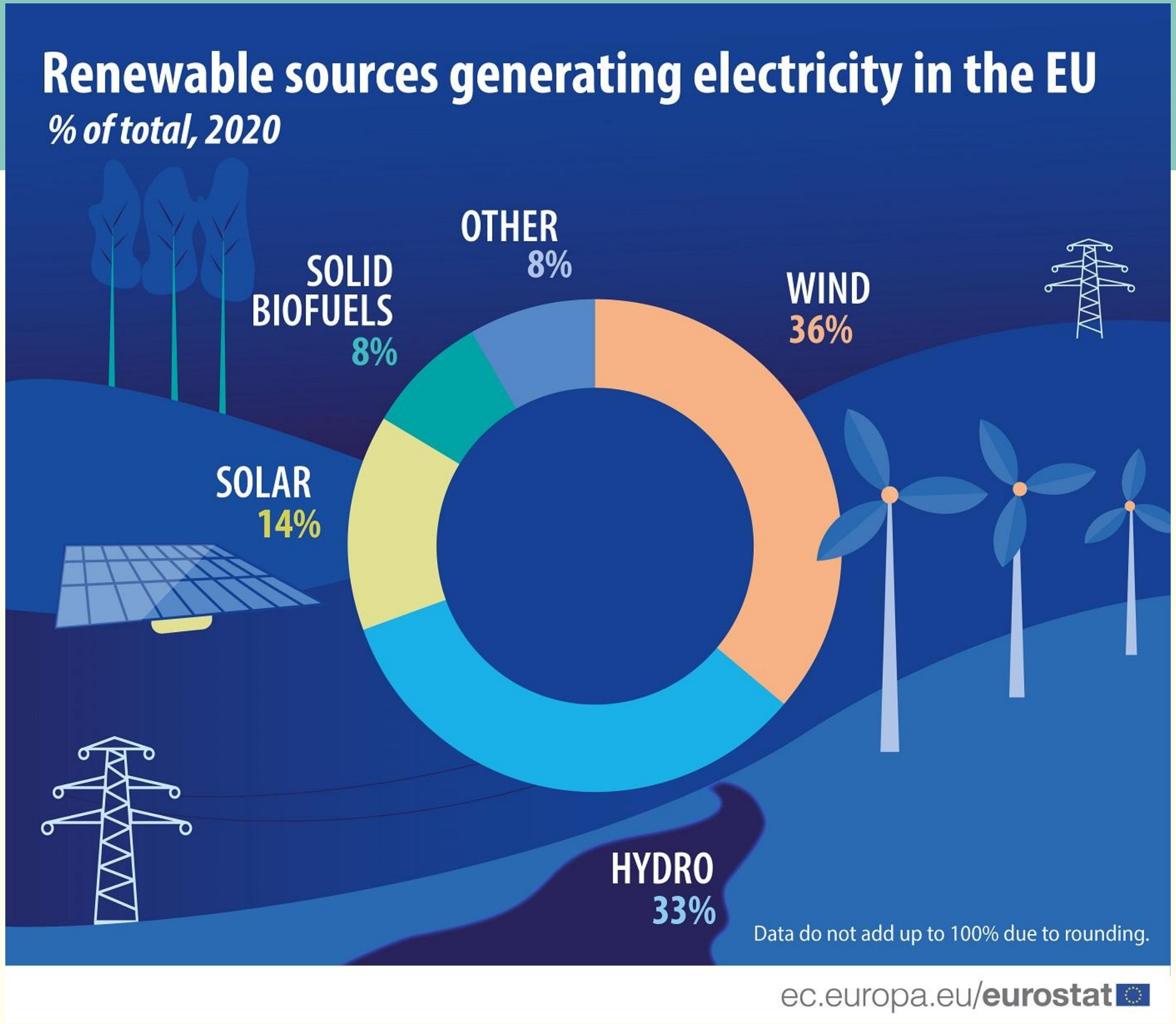
- Increased **carbon footprint** (operational emissions).
- Greater **resource consumption** (energy, water).
- **Urban heat island effect** (buildings contribute to city overheating).

Consequences:

- Financial burden: High energy bills especially affect low-income households (**energy poverty**).
- Higher **lifetime emissions** and greater **environmental impact**.

Transition Toward Renewable Energy in Buildings

Share of renewable electricity generation



Solar PV and Wind Integration

Solar Photovoltaics (PV):

- Converts sunlight directly into electricity.
- Easy to install on rooftops of residential and commercial buildings.
- Costs of solar PV have fallen by over **80%** since 2010 (IEA, *Renewables 2023*).
- Enables **self-consumption** and **net metering** (selling excess electricity to the grid).

Source: Solarenergie.de, *Auslegung einer PV-Anlage*, 2024.

Wind Energy:

- Mostly used for **larger buildings**, campuses, or community microgrids.
- Small-scale wind turbines can be installed where local conditions permit (though less common than solar for single buildings).

Source: BuildingGreen, *The Folly of Building-Integrated Wind*, 2021.

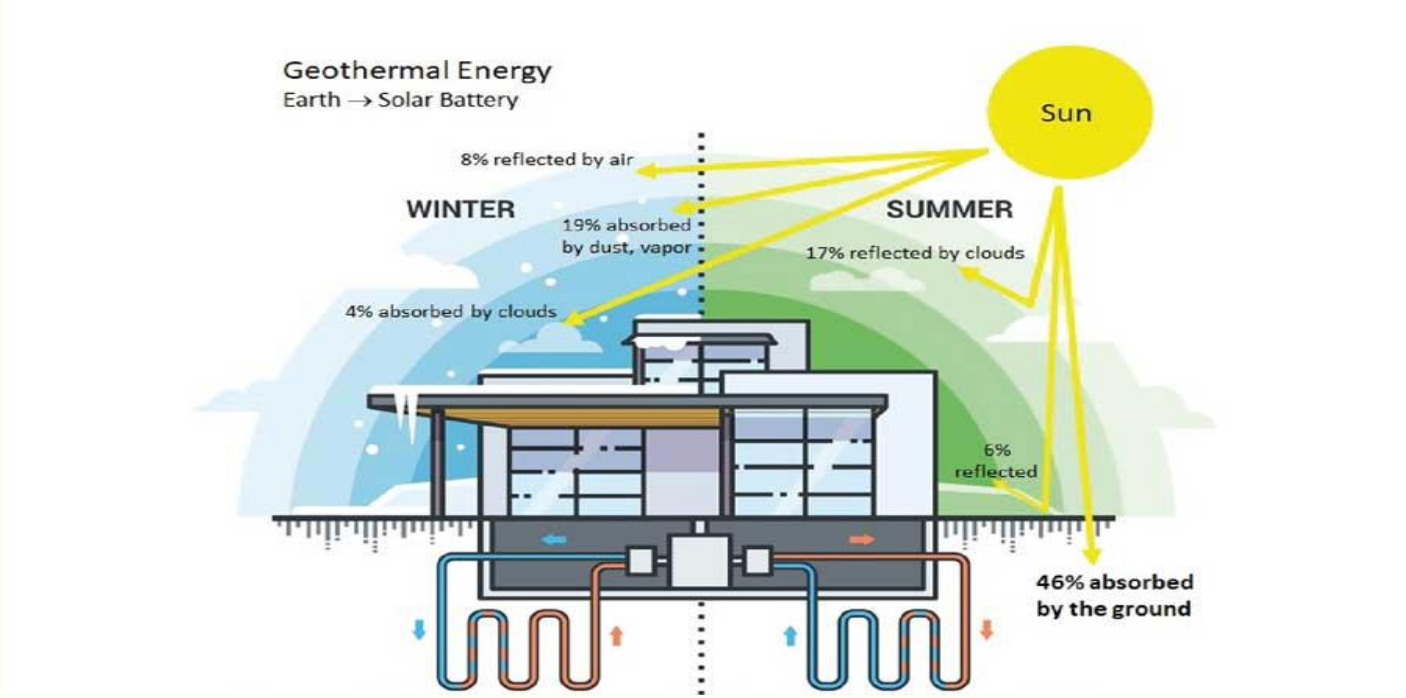
Geothermal and Biomass Integration

Geothermal Systems:

- **Ground-source heat pumps** extract heat from below the Earth's surface.
- Highly efficient for **both heating and cooling**.
- Best suited for **buildings with available land** for ground loops.

Biomass:

- Organic material (wood pellets, agricultural waste) used for **heating** or **combined heat and power (CHP)**.



Source: ACHR News, *Are Geothermal Heat Pumps the Key to a Cleaner Planet?*, 2020.

Environmental and Economic Benefits

Environmental Benefits:

- Massive reduction in **carbon emissions** compared to fossil fuels.
- Helps mitigate **urban heat island effects** (e.g., green roofs with PV panels).
- Reduces **air pollution** (no particulate matter, NO_x emissions compared to combustion systems).

Economic Benefits:

- **Lower operating costs** after initial investment (free sunlight, wind, geothermal energy).
- **Energy independence** reduces exposure to **fuel price volatility**.
- **Increased property value**: Buildings with renewable systems have higher market attractiveness.
- Potential for **new revenue streams** (selling excess solar electricity back to the grid).

Policy Support

EU Green Deal (2020):

- Aims for Europe to become the **first climate-neutral continent by 2050**.
- Strong emphasis on **decarbonizing the building sector**.
- Promotes **massive renovation waves** and integration of **renewables** in all new and existing buildings.
- **Financial instruments** (e.g., Renovation Loan Funds, Horizon Europe) support retrofitting.

Energy Performance of Buildings Directive (Recast 2023):

- **All new buildings must be zero-emission** by 2030.
- **Public sector buildings** must lead by example, becoming zero-emission by 2027.
- Mandatory **renovation of worst-performing buildings** (energy labels F and G).

Emergence of Smart Buildings

Smart Buildings

Source: Veridify, *The Importance of Protecting Smart Building Technology from Cyber Threats*, 2023.

Buildings and Digitalization

- **The Smart Foundation**: Leveraging IoT sensors, smart meters, and AI to manage the complexity of millions of interacting assets.

- **Seamless Interoperability**: ensuring that every smart device, from a car to a heater, can 'talk' to the grid in the same language.

- **Real-Time Coordination**: coupled systems that can optimize energy flows in real-time.

- **Data-Driven Forecasting:** Using digital modelling to support optimizations, and pinpoint system bottlenecks and plan upgrades cost-effectively.

IoT-Driven Smart Energy Management

- **Sensors and devices** embedded in building systems (lighting, HVAC, security, appliances).
- Collect **real-time data** on temperature, humidity, occupancy, energy use, air quality, etc.
- Devices are **connected via networks** (Wi-Fi, Bluetooth, ZigBee).

Automation in Buildings

- **Automatic control** of lighting, heating, cooling, and shading based on real-time conditions and user preferences.

- **Smart thermostats**, **motion-activated lights**, and **automated ventilation** adjust building conditions without manual input.
- Systems use **AI algorithms** to learn patterns and optimize settings.

Intelligent Energy Management

- Monitoring and adjusting energy usage continuously based on **actual demand**.
- Load shifting: Running high-energy devices during **off-peak hours** to save costs.
- **Integration with smart grids** for dynamic electricity pricing and demand-response programs.

Benefits & Advantages

Energy Optimization:

- Systems reduce **unnecessary energy use** (e.g., turning off lights and HVAC when spaces are empty).
- Smart scheduling optimizes **peak load management**, lowering utility bills.
- Some smart buildings achieve **20–40% energy savings** compared to traditional buildings (IEA, *3DEN Report*, 2020).

Predictive Maintenance:

- Sensors track the **health of building equipment** (e.g., HVAC, elevators, lighting systems).
- Systems can **predict failures** before they happen (e.g., alert if a motor shows signs of wear).
- Reduces **unexpected downtime** and **expensive emergency repairs**.
- Extends **equipment life span**.

Benefits & Advantages

User Comfort:

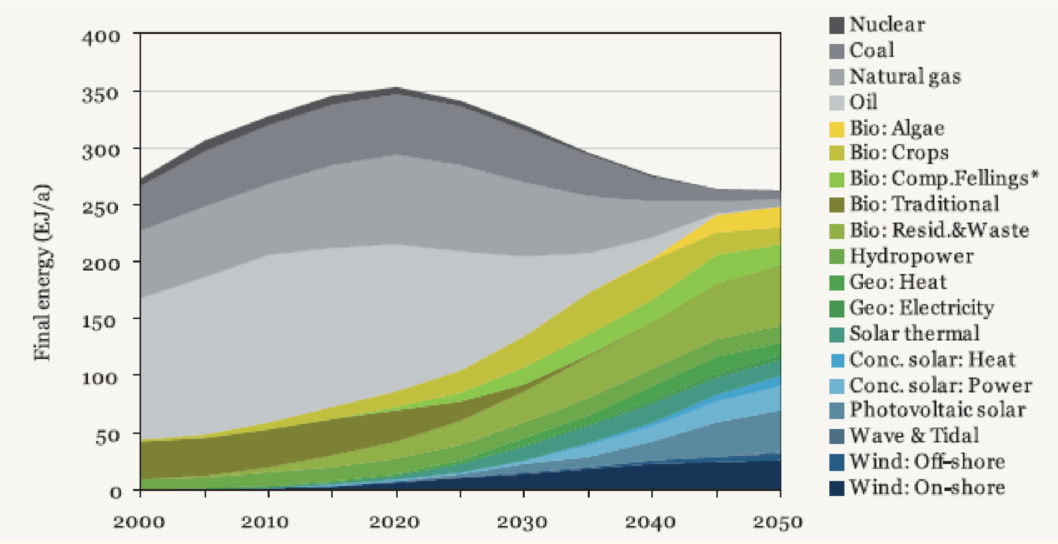
- Dynamic control ensures **consistent indoor temperatures**, **better air quality**, and **natural lighting adjustment**
- Personalization: Systems adapt to **individual preferences** (e.g., preferred room temperature settings).
- Improves **occupant satisfaction**, **health**, and **productivity**.

Source: SemiEngineering, *Buildings Get Smarter Through Tech*, 2023

Energy Sources for Buildings

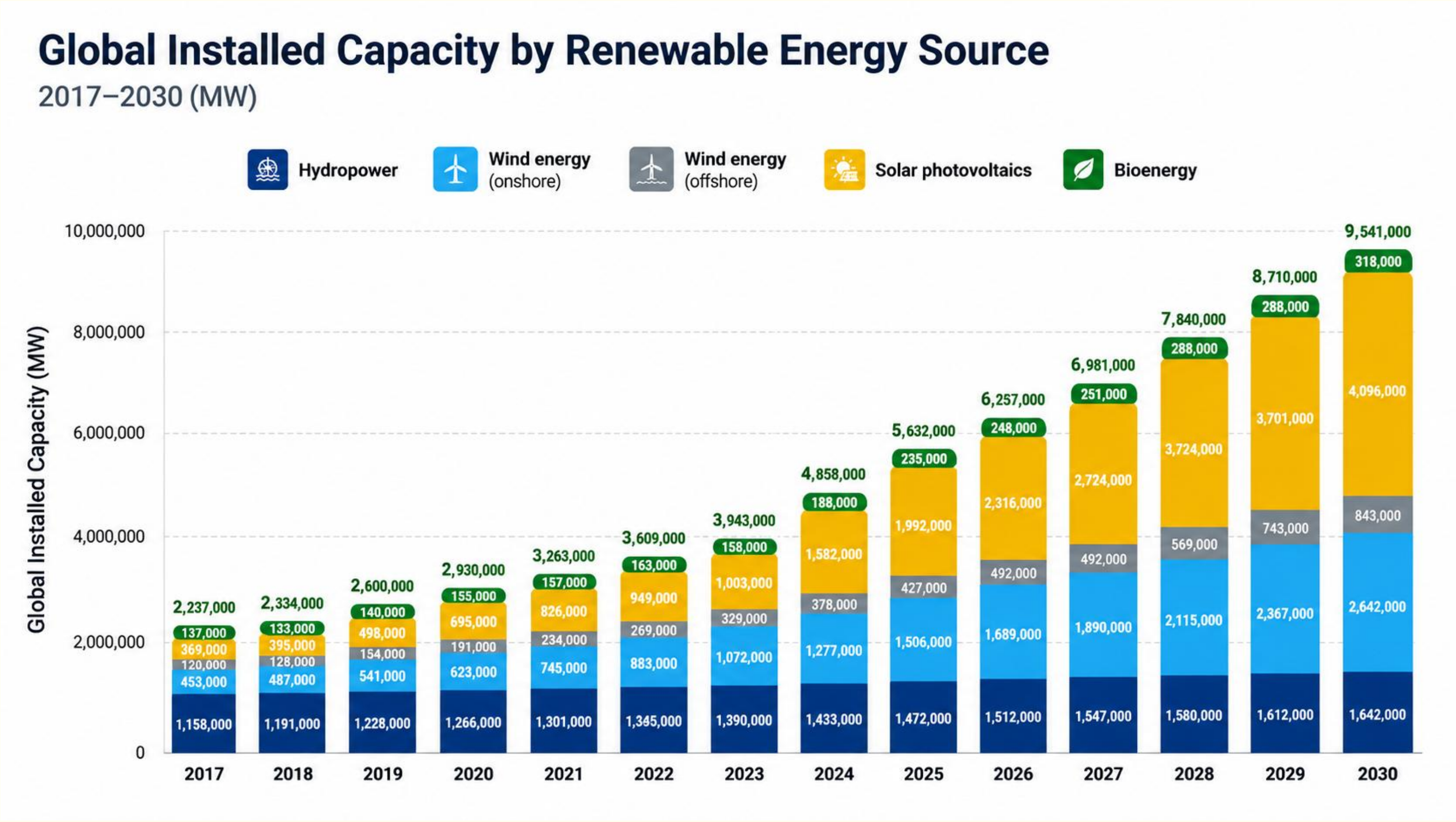
Introduction

- Renewable energy is rapidly transforming the global electricity landscape.
- **Solar PV and Wind** are leading the growth among renewable technologies.
- From 2000 to 2030, variable renewables show a steep upward trend in generation share.
- **Hydropower** remains steady, while **Solar PV** is set to surpass it by 2030.
- This shift reflects the urgency to transition to low-carbon, sustainable energy systems.
- **Buildings**, as major energy consumers, are key to integrating these renewables.
- **Leveraging renewables** in buildings enhances energy efficiency and reduces emissions.



Source: https://skepticalscience.com/100-percent-renewable-by-2050.html

Renewable Energy Capacity Growth



Source: IRENA, IEA

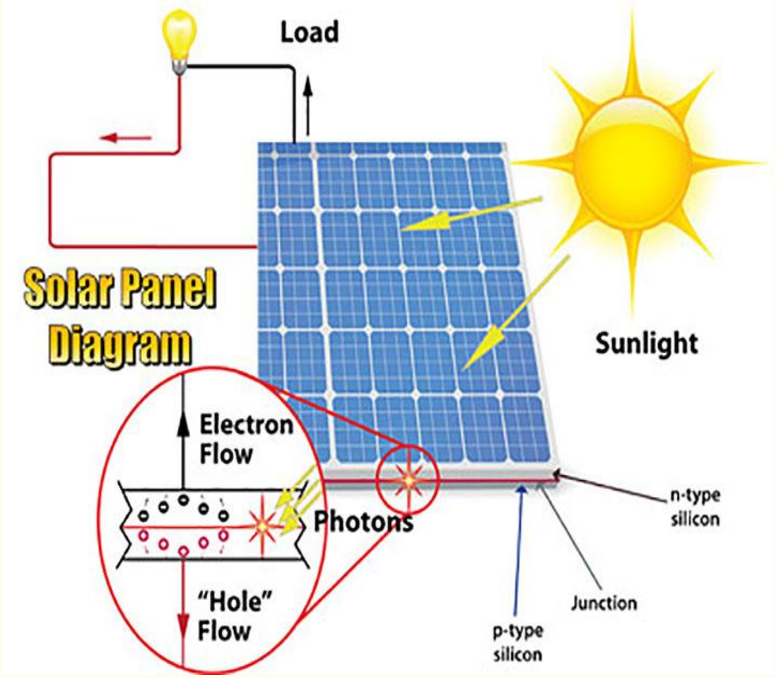
Solar Energy Systems

Introduction

Solar energy systems harness sunlight to generate **electricity or thermal energy**. In buildings, they typically include **photovoltaic (PV) panels**, **inverters**, **mounting structures**, and optionally, **energy storage systems**. These systems reduce grid dependence and carbon emissions.

Key Components:

- **PV Systems**: Convert sunlight directly into electricity using the photovoltaic effect.
- **Solar Thermal Systems**: Capture solar heat for water heating or space conditioning.
- **Inverters**: Convert DC from panels to AC for building use.
- **Energy Storage**: Batteries store surplus energy for later use.
- **Mounting Structures**: Secure panels to roofs, facades, or ground.



Source: ETAP, *Photovoltaic Array Fundamentals*, 2024.

Sources: EESI, *Solar Energy Overview*, 2024. [eesi.org]

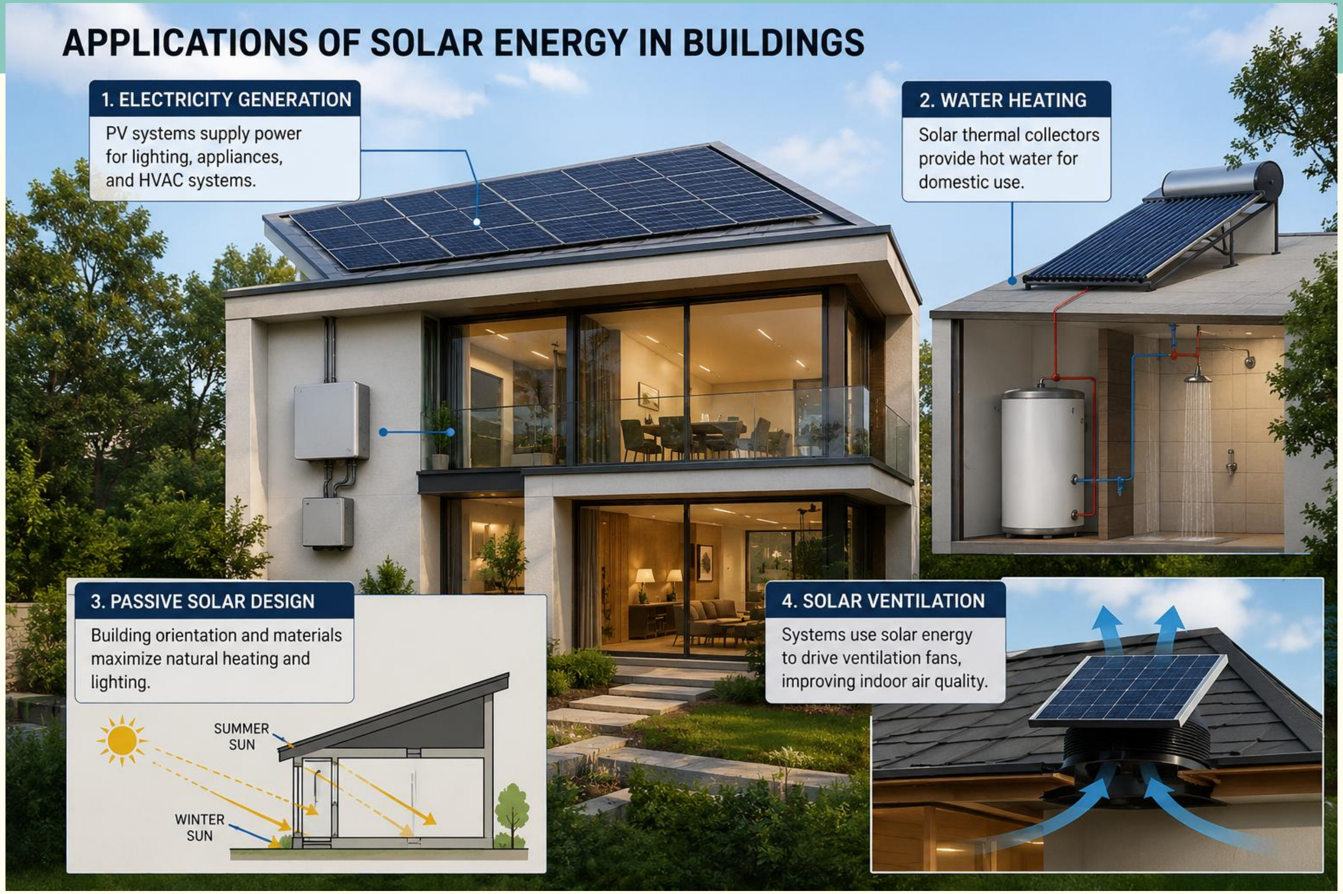
Applications of Solar Energy in Buildings

- **Electricity Generation:** PV systems supply power for lighting, appliances, and HVAC systems.

- **Water Heating:** Solar thermal collectors provide hot water for domestic use.

- **Passive Solar Design:** Building orientation and materials maximize natural heating and lighting.

- **Solar Ventilation:** Systems use solar energy to drive ventilation fans, improving indoor air quality.



Source: U.S. Department of Energy, *Expanding Solar Energy Opportunities through Rooftops and Building Integration*, 2023.

Applications of Solar Energy in Buildings

Principle: Solar panels convert sunlight directly into DC electricity using semiconductor materials (typically silicon).

Installation:
- Roof-mounted systems: Mounted on racks above the roof surface (tilted or flat).
- Building-integrated PV (BIPV): Panels integrated into façades, skylights, or roofing materials.

Efficiency:
- Monocrystalline PV panels (~18–22% efficiency).
- Polycrystalline (~15–18% efficiency).

Role in NZEB: Primary contributor to achieving on-site renewable energy generation.

Source: DSI Solar, *BIPV – PV mit architektonischer Bedeutung*, 2022.

Wind Energy in Buildings

Introduction to Wind Energy in Buildings

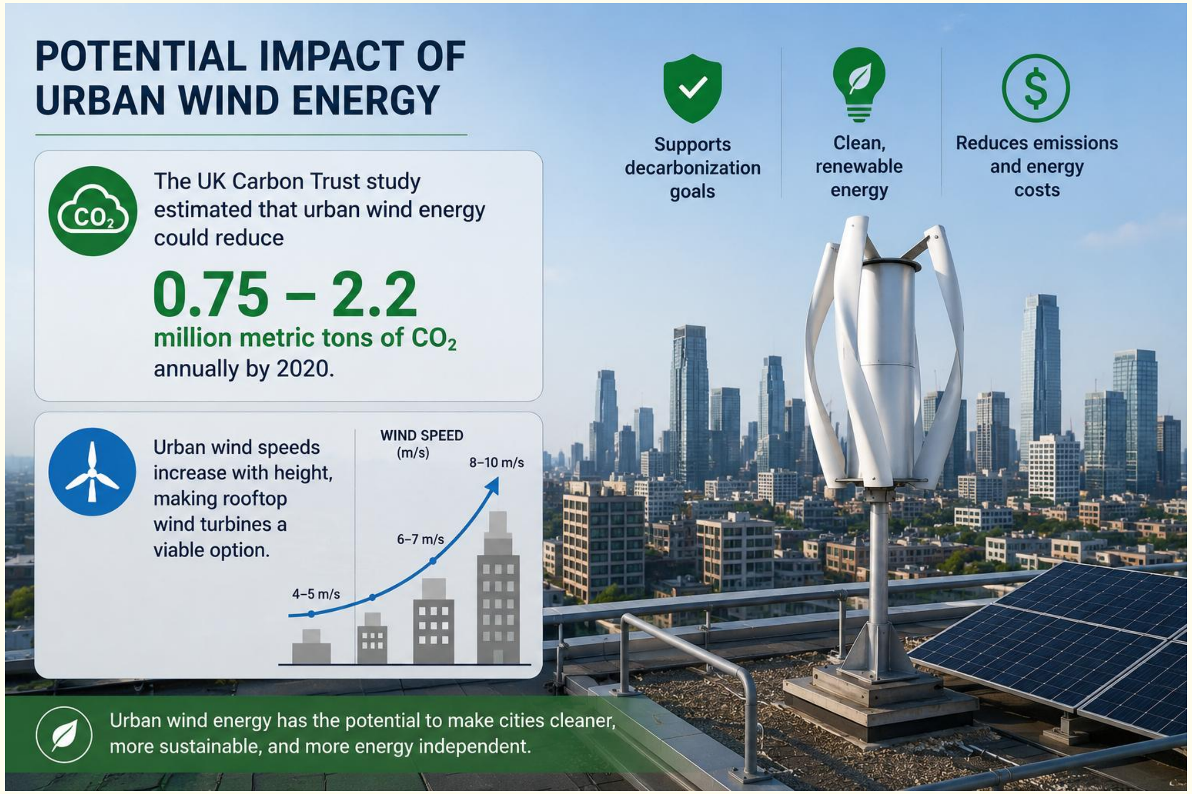
- **Wind power** is one of the **fastest-growing renewable energy** industries, with global expansion driven by energy security & decarbonization efforts.

- **Urban Wind Energy**: While traditional wind farms are located in rural or offshore areas, urban wind energy focuses on **small wind turbines** (SWTs) and Building-Integrated Wind Turbines (BIWTs) to generate local power in cities.

Introduction to Wind Energy in Buildings

Potential Impact:

- The UK Carbon Trust study estimated that urban wind energy could reduce 0.75 - 2.2 million metric tons of CO_2 annually by 2020.
- Urban wind speeds increase with height, making rooftop wind turbines a viable option.



Geothermal Heat Pumps

Introduction

- **Geothermal Heat Pumps** utilize the earth's stable subsurface temperature for **efficient year-round heating and cooling**.
- Just a few feet below the surface, ground temperature remains relatively constant—**warmer than air in winter** and **cooler in summer**.
- GHPs transfer heat to/from the ground using a **ground heat exchanger**, making them act as a **heat source in winter** and a **heat sink in summer**.
- This natural **thermal energy storage** increases efficiency and reduces energy consumption.

Source: German Energy Solutions, *Heat Pumps and Near-Surface Geothermal Energy*, 2024.

District Heating and Cooling (DHC) Systems

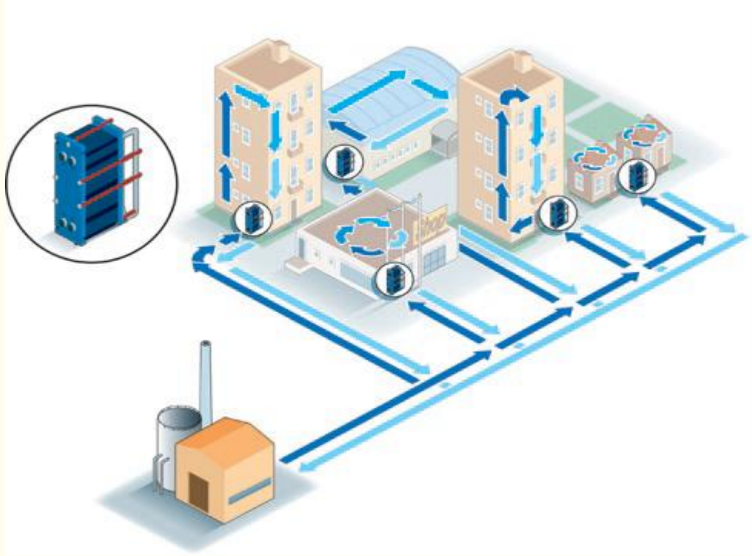
Introduction

District Heating and Cooling (DHC) systems are **centralized thermal energy networks** that supply **hot water, steam, or chilled water** from a **central plant** to multiple buildings via **insulated underground pipelines**. They are used for **space heating**, **cooling**, and **domestic hot water** in urban areas.

- Serve **residential, commercial, and industrial buildings** efficiently.
- Reduce the need for **individual boilers, air conditioners, or water heaters**.

Common **energy sources** include:

- **Waste heat** recovery from power plants or industry
- **Renewables** like **solar thermal**, **geothermal**, or **biomass**
- **Combined Heat and Power (CHP)** systems that generate electricity and recover heat

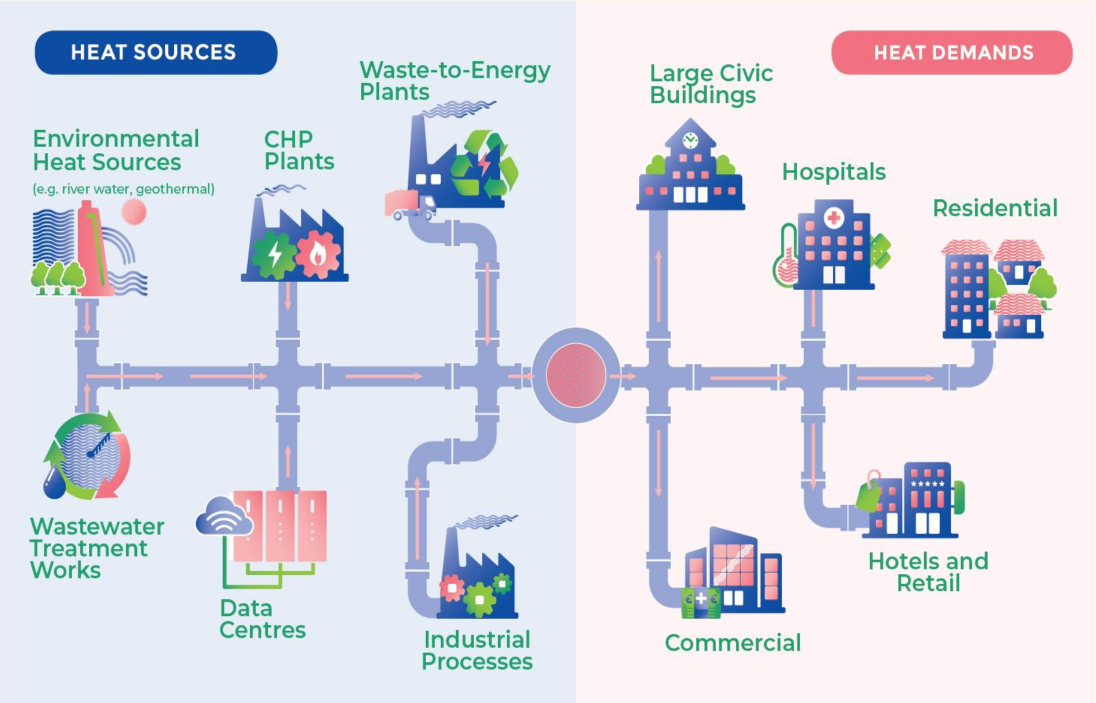


Source: Alfa Laval, *What Is a District Cooling System?*, 2024.

Source: UNEP, *District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy*, 2022.

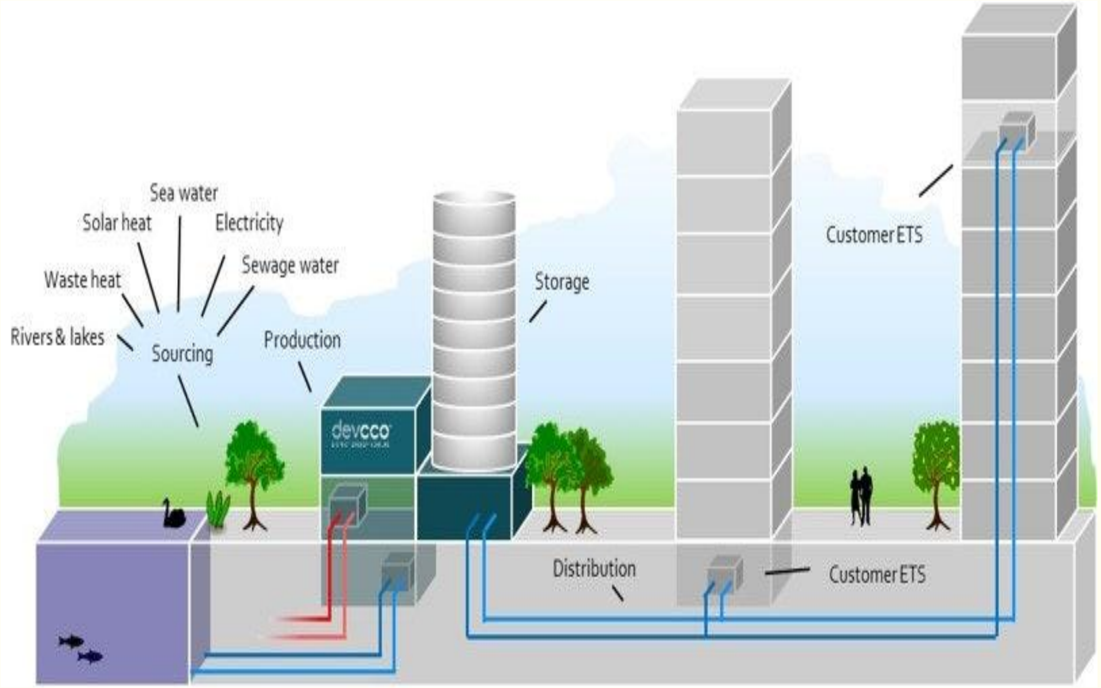
District Heating and Cooling Systems

District Heating



Source: Guide to District Heating, *What Is District Heating?*, 2024.

District Cooling



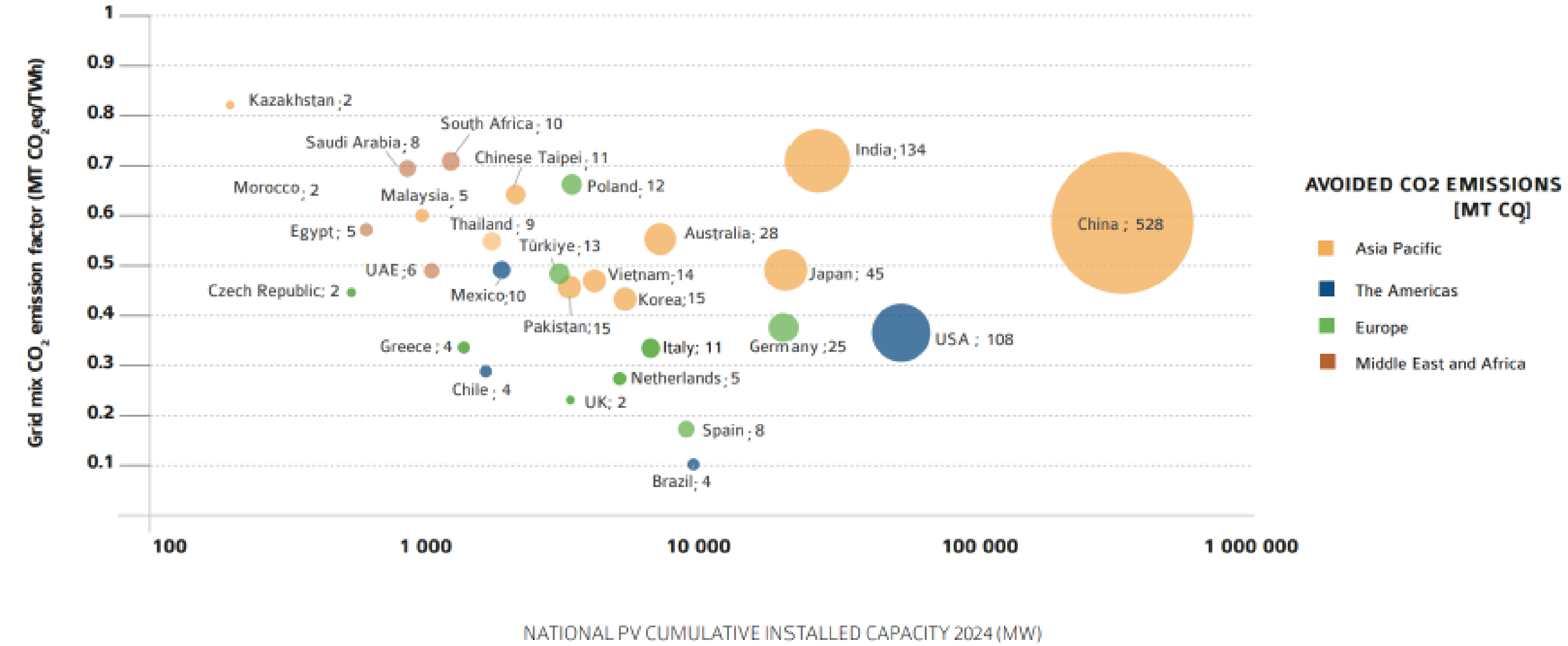
Source: IEA, *The Go-To Guide for Sustainable District Cooling*, 2023.

Building Added/Integrated Photovoltaics BAPV/BiPV

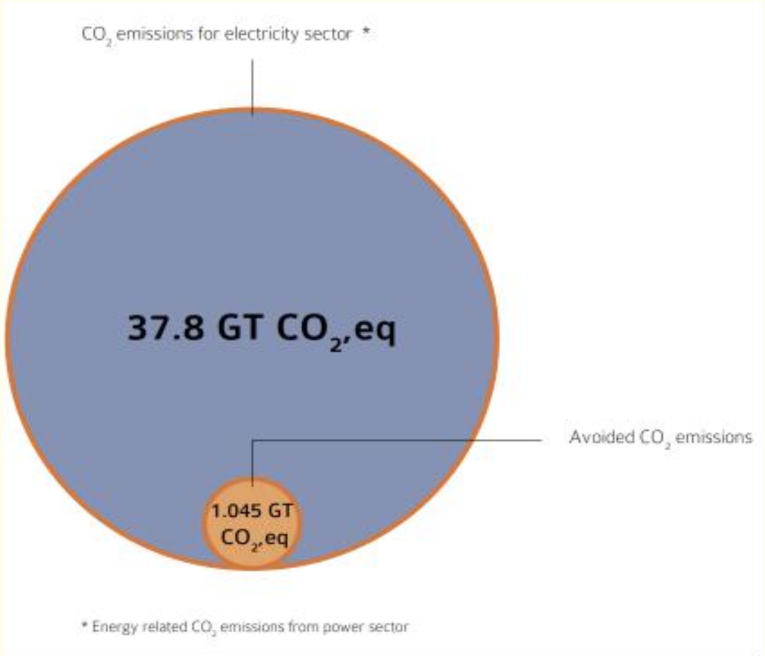
nZEBRA

Solar PV contribution

- **Solar PV** is the **foremost renewable energy technology** for cost-optimised **climate-change mitigation**.
- Meeting the ambitious goals of a **climate-neutral economy** requires **massive PV installations**, ranging from **20 to 75 TWp**, by **2050**, and further expanding from **75 to 170 TWp** by **2100** in progressive **global energy scenarios**.
- The more **CO2** the power mix in a country emits, the more **positively PV installations** will contribute to **avoiding emissions.**

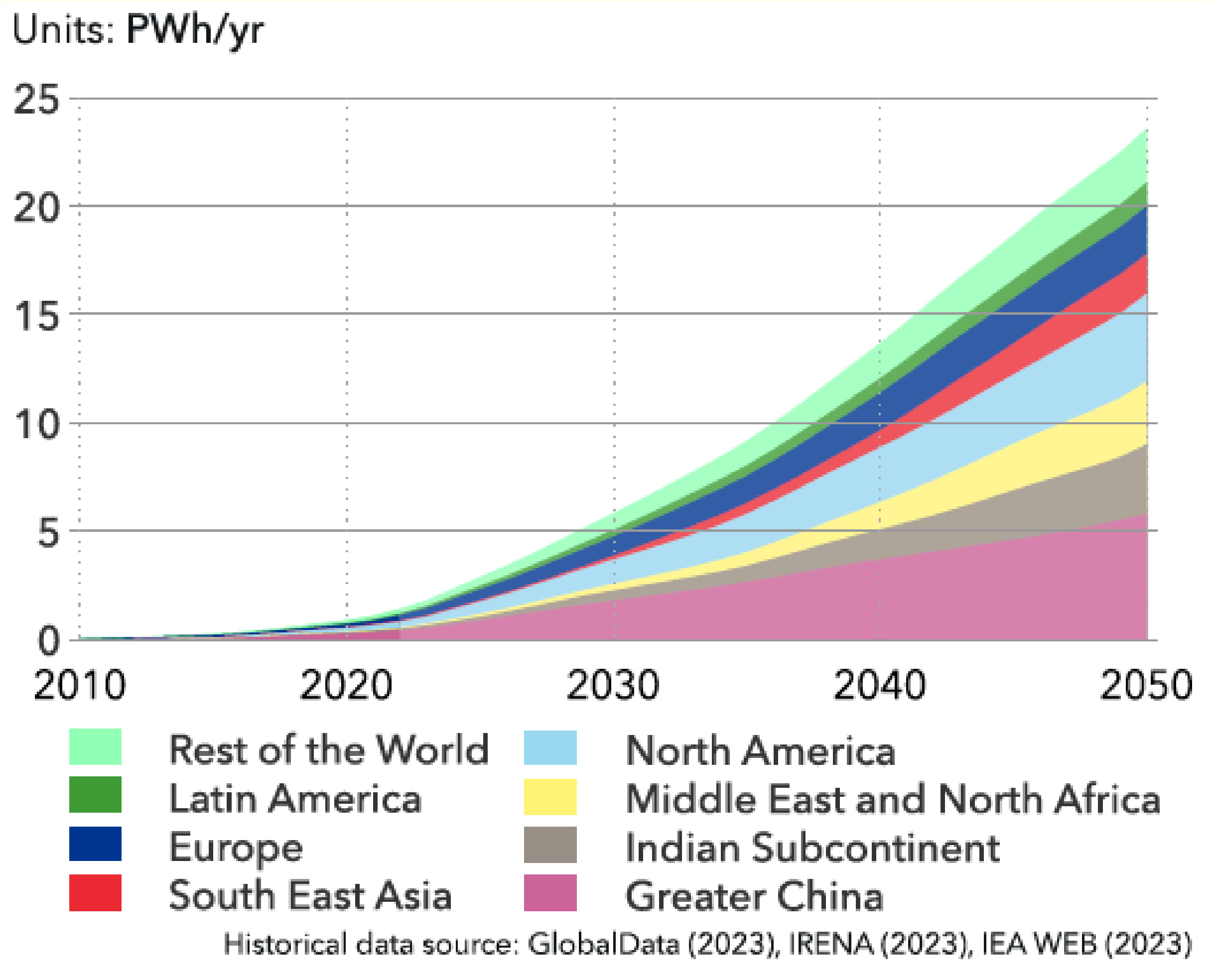


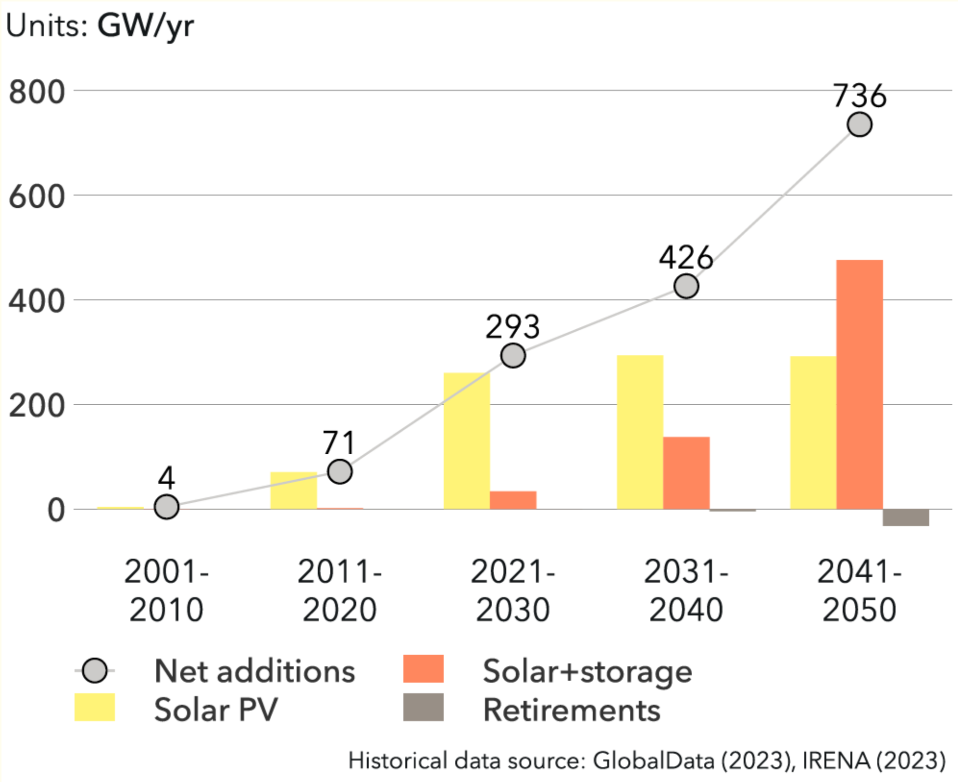
CO2 emissions avoided by PV
Source: IEA PVPS 2025



Avoided CO2 emissions as percentage of energy sector total emissions
Source: IEA PVPS 2025

Solar PV contribution



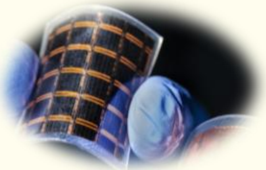
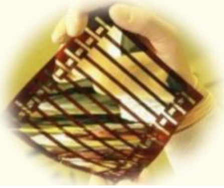
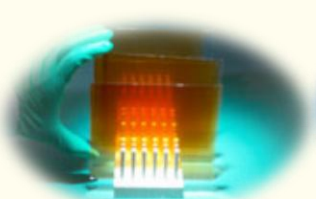


Global Solar Capacity Additions and Retirements
Source: GlobalData 2023, IRENA 2023

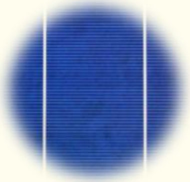
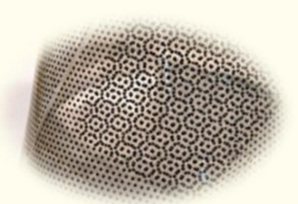
Grid-connected solar PV and Solar+storage electricity generation by region
Source: DNV 2023

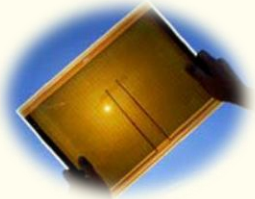
Solar Photovoltaics Technology

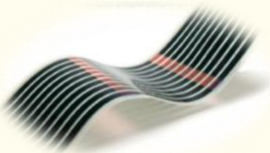
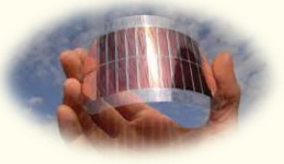
Current and future development

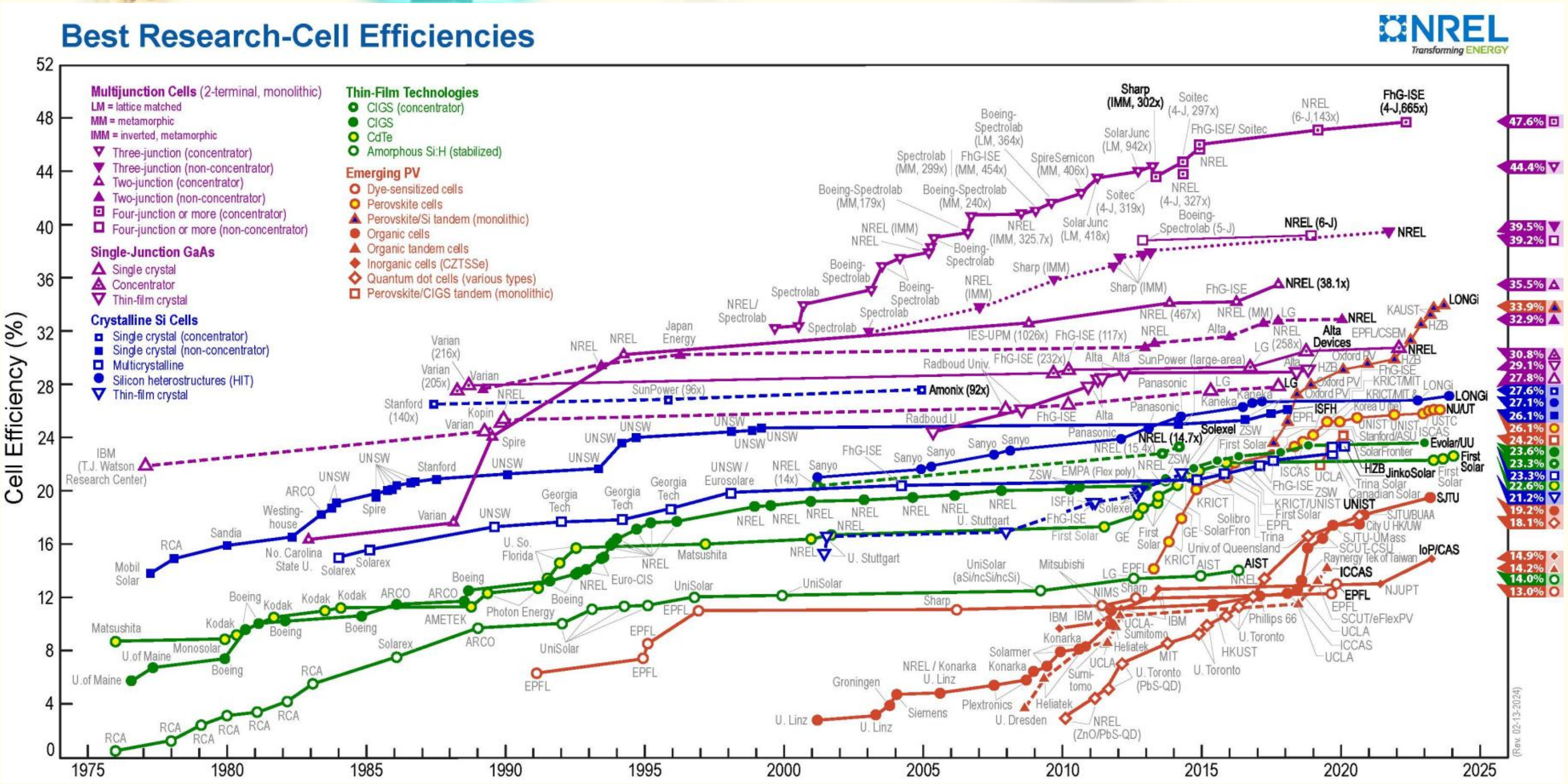








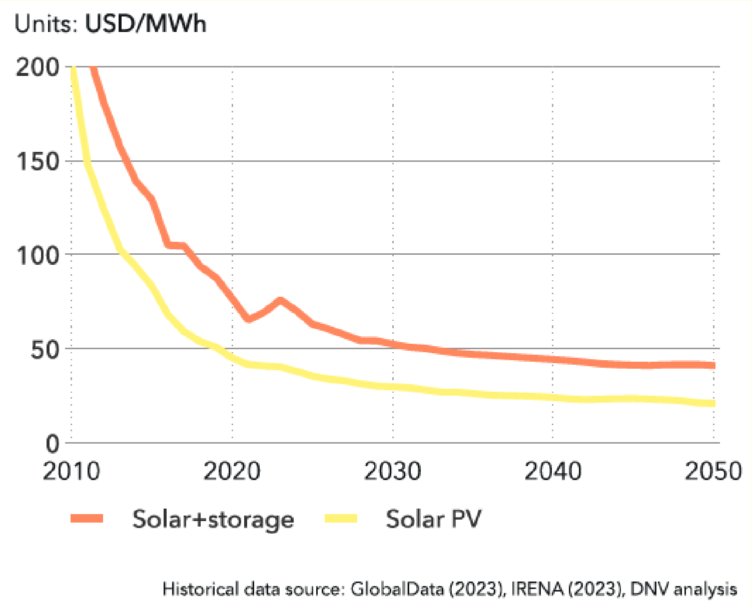
Best Research Cell Efficiency
Source NREL

Solar Photovoltaics Technology

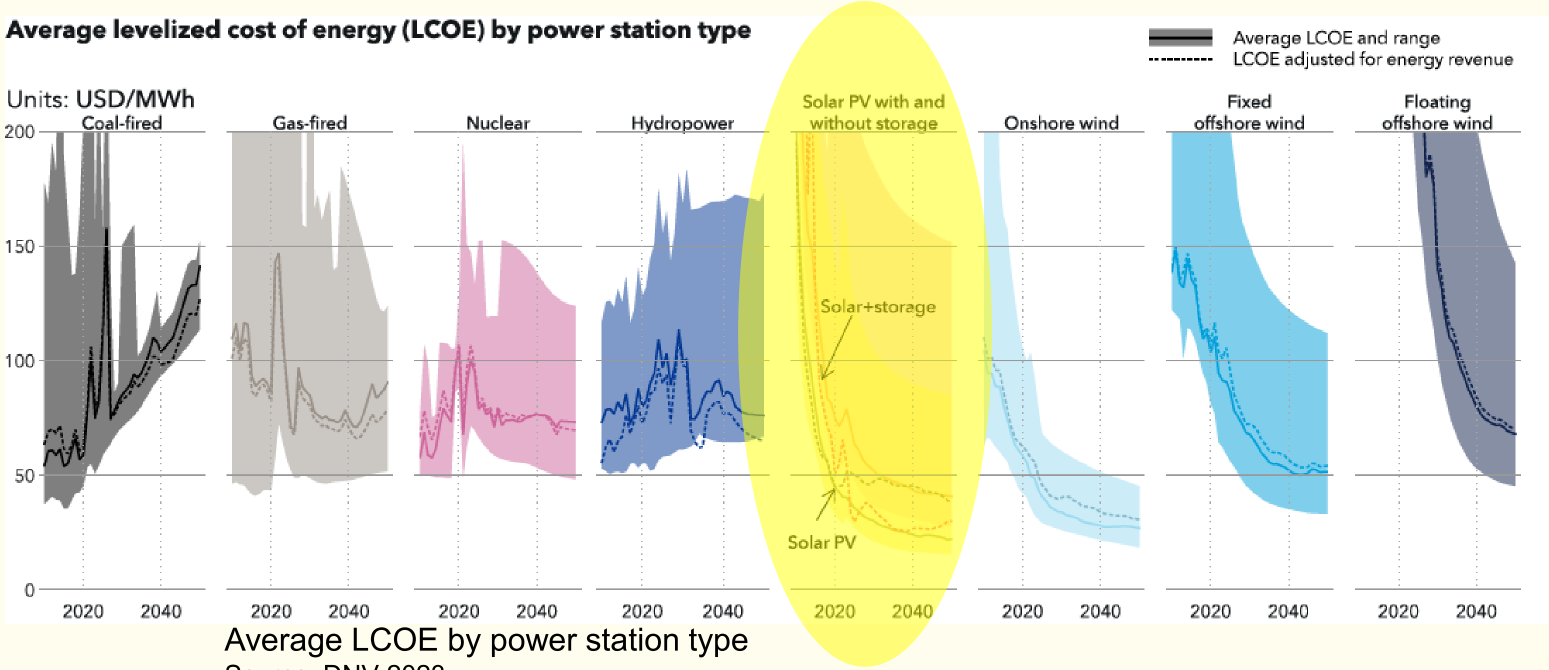
The levelized cost of energy (LCOE)

- As of now, the **global average LCOE** for **solar PV** hovers around **USD 41/MWh** and **USD 69/MWh** for **solar paired with storage**.
  - From **2020 to 2050**, technological learning rates, that driven by **technological advancements**, **economies of scale**, and **improved manufacturing** and **deployment practices**, are projected at **12% LCOE drop** for solar PV.

- Solar PV is set to break the **USD 30/MWh** mark by **2030** at **the global average**, with **on-site storage.**
- From **2030 to 2050**, the global weighted average of **solar PV LCOE** will reduce by **1.5% per year**, reaching **USD 22/MWh**.



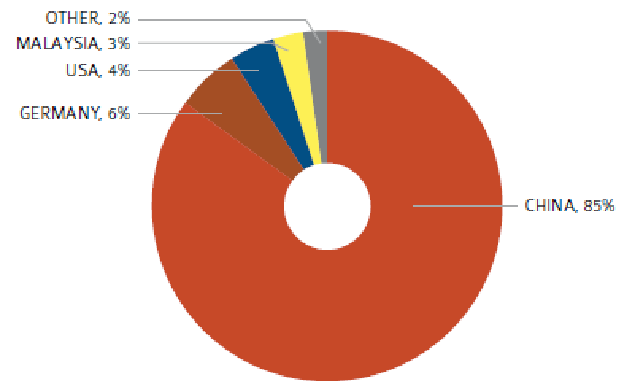
World average levelized cost of solar energy
Source: IRENA 2023, DNV 20203



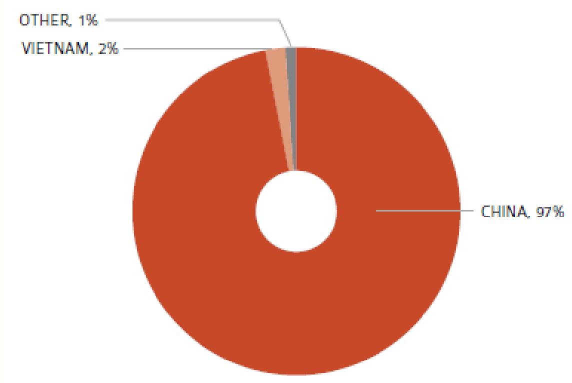
Average LCOE by power station type
Source: DNV 2023

Trends in Solar Photovoltaics Industry

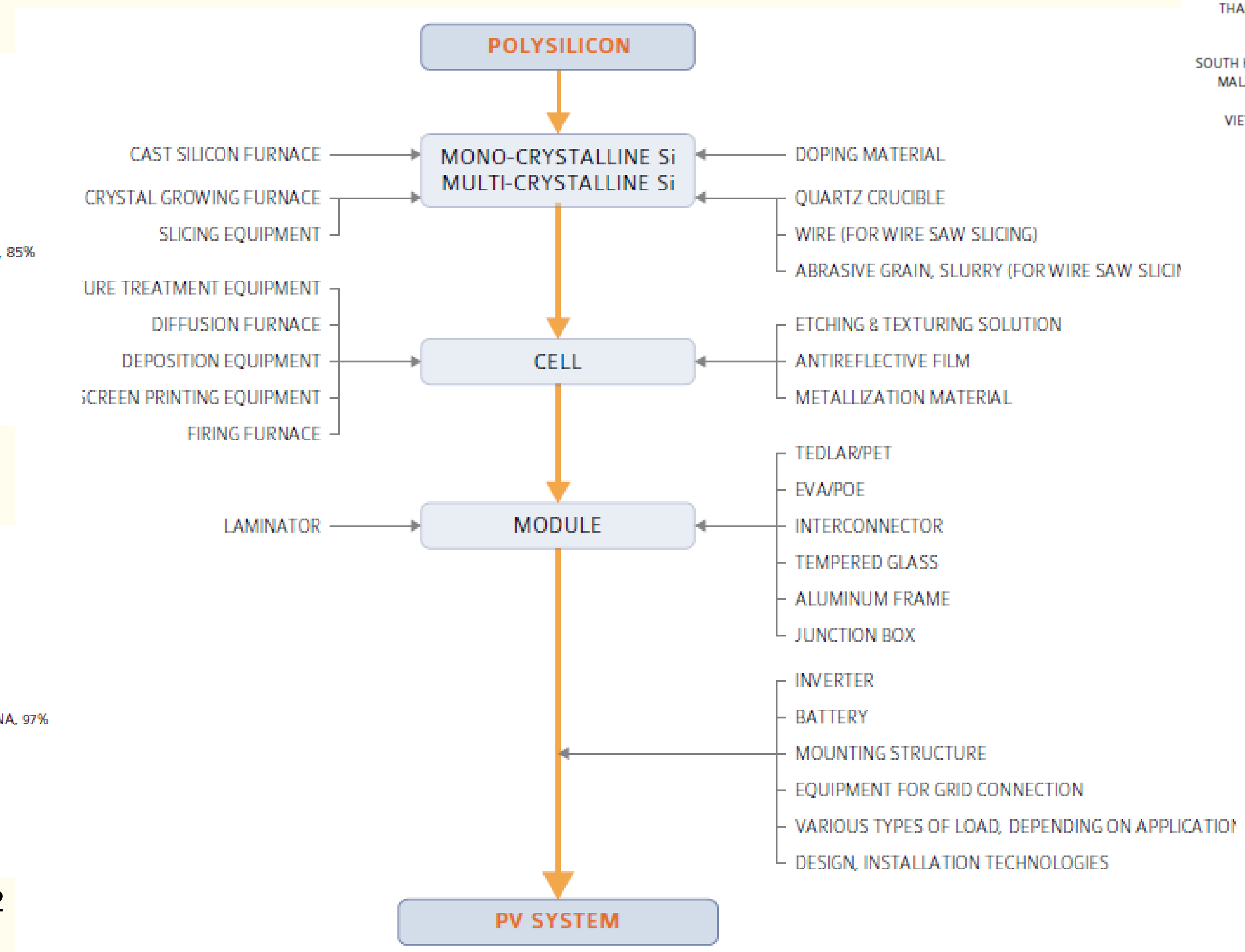
The upstream PV sector



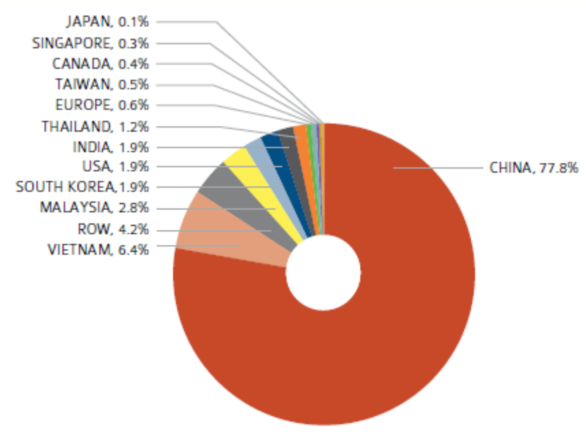
Share of Polysilicon Production in 2022
Source: IEA PVPS



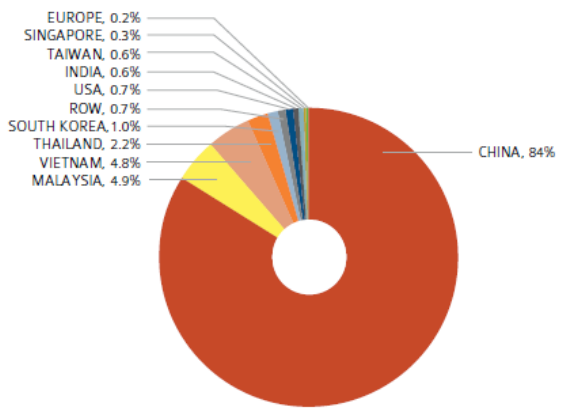
Share of PV Wafer Production in 2022
Source: IEA PVPS



PV System Value Chain (example of crystalline silicon PV technology)
Source: IEA PVPS



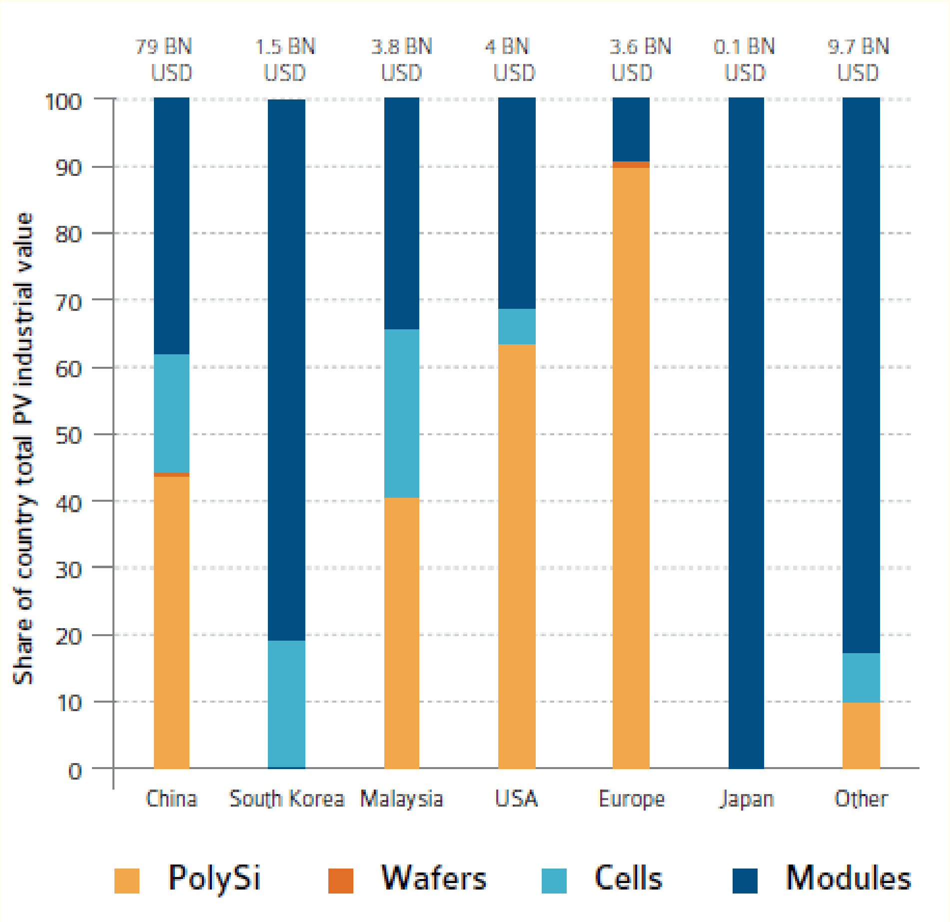
Share of PV Module Production in 2022
Source: IEA PVPS



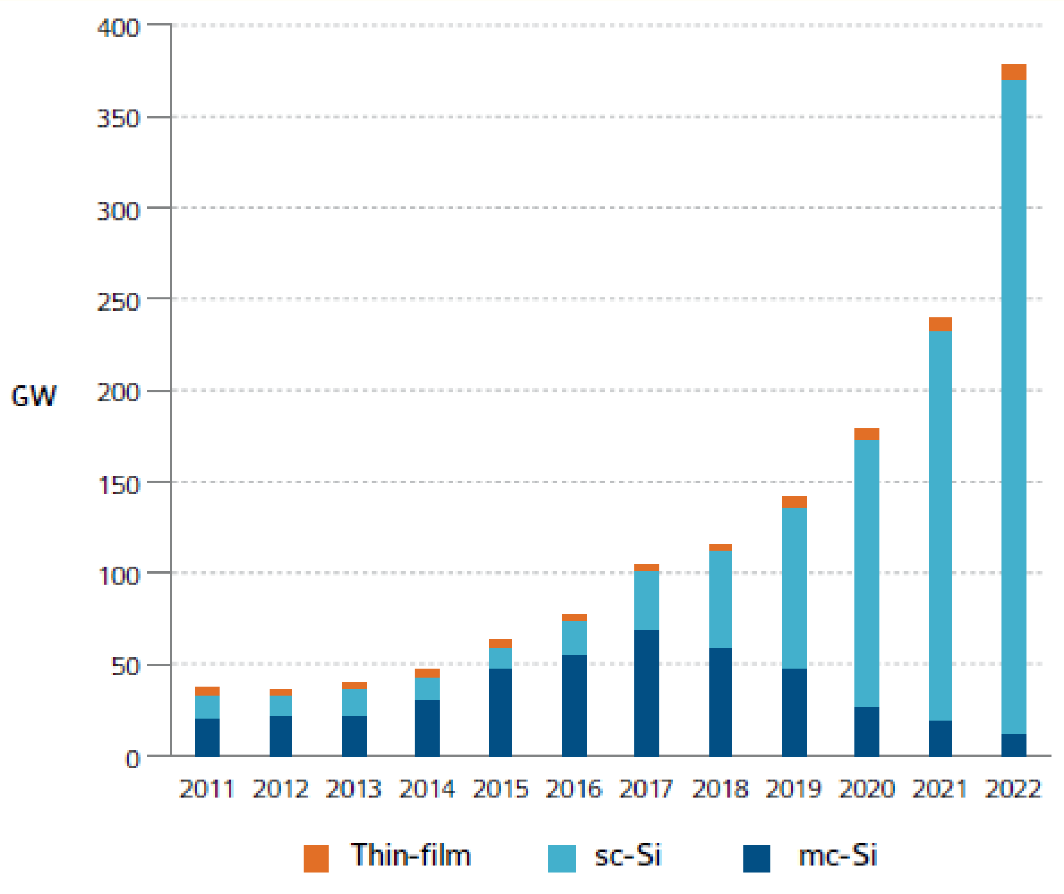
Share of PV Cell Production in 2022
Source: IEA PVPS

Trends in Solar PV Industry

The upstream PV sector



Source: IEA PVPS



Source: IEA PVPS

Trends in Solar Photovoltaic Applications

Prospects and technological advancement

Source: M. H.Shubbak, Advances in solar photovoltaics: Technology review and patent trends, Ren. & Sust. Energy Reviews, 2019.

Trends in Solar Photovoltaics Applications

Prospects and technological advancement

- **PV electricity** production
- **PV integration** and sector coupling
- The **electrification** of transport
- The **energy storage** market
- The electrification of **heating and cooling**
- **Green hydrogen** and hydrogen derivatives

Source: IEA PVPS

Building-integrated Photovoltaics (BiPV)

- A BIPV module is both a photovoltaic (PV) module and a construction product, designed to serve as part of the building structure.
- It is the smallest unit in a BIPV system that cannot be divided further electrically or mechanically.
- It retains essential **building-related functionality** (e.g., roofing, cladding, etc.).
- If removed, it must be replaced by a **suitable construction product** to maintain building function.
- A system where all PV modules fulfill the criteria of a BIPV product.
- It includes necessary **electrical components** to connect to AC or DC systems.
- It also comprises **mechanical mounting systems** that integrate the BIPV products into the building structure.

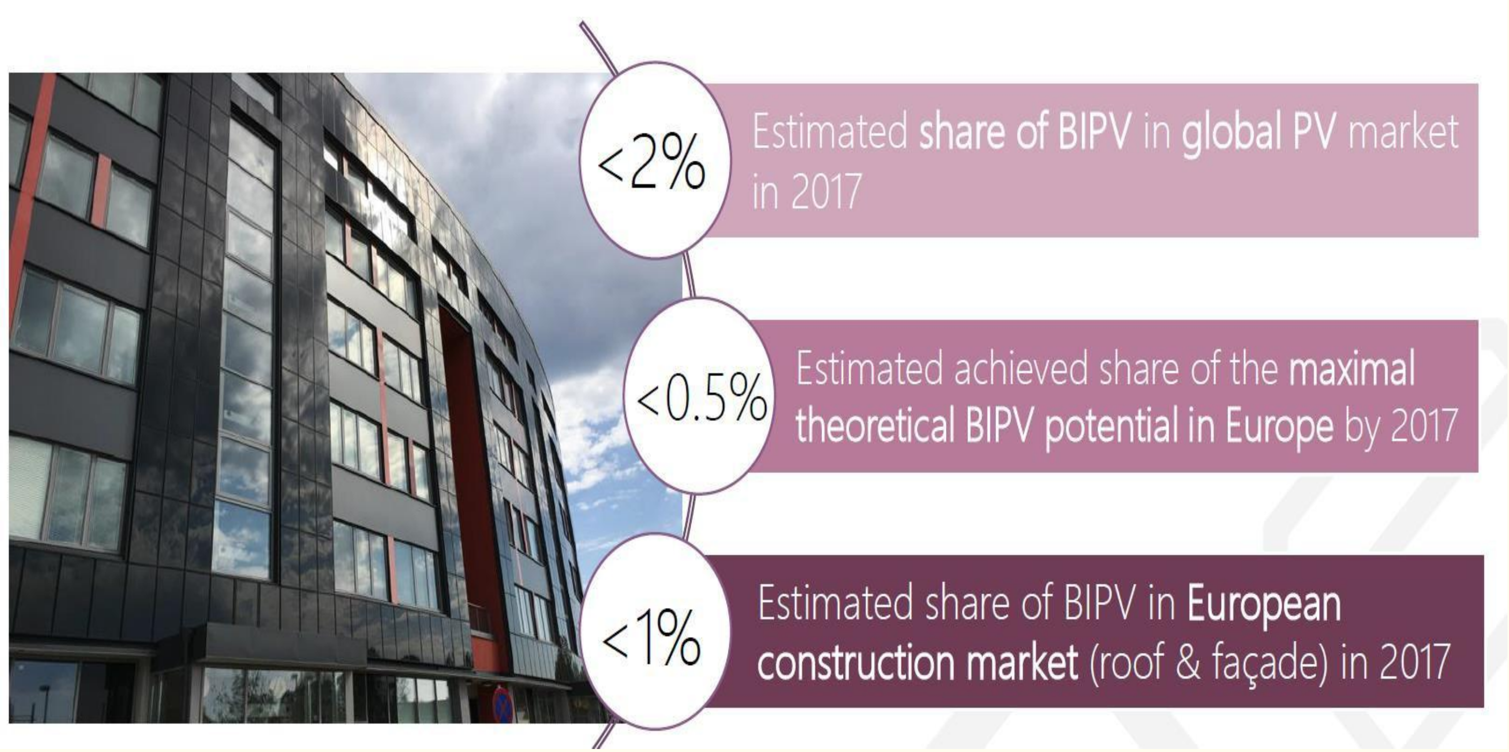
Source: Reinders et al., *Photovoltaic Solar Energy: From Fundamentals to Applications*, 2017. [Wiley & Sons]

BAPV (Building-applied Photovoltaics):

- BAPV systems are mounted on existing building surfaces without replacing building materials. They are added to the building after construction.
- Examples: Rooftop solar panels mounted on brackets.
- Advantages: Easier to install and retrofit, but less integrated into the building design.

Source: iSolarParts, *The Difference Between BIPV and BAPV*, 2023.

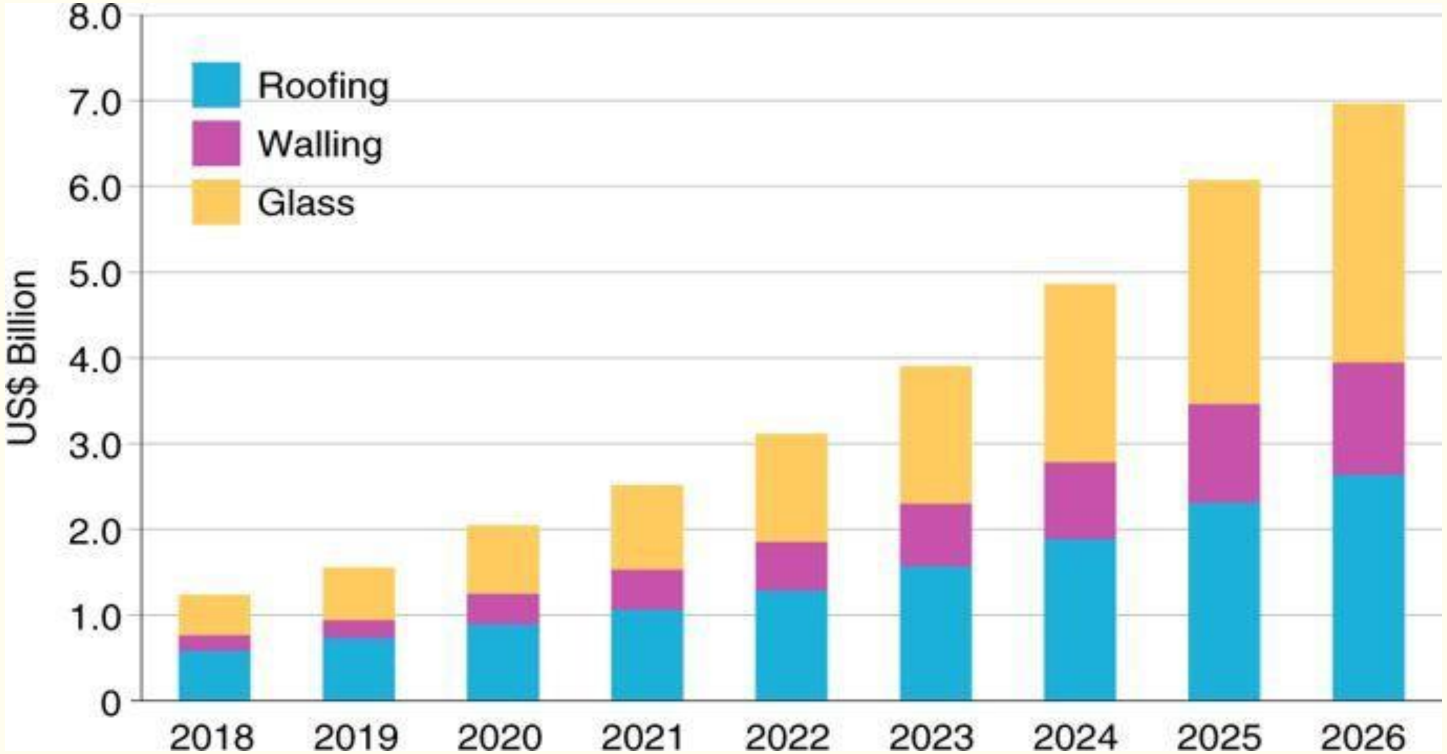
BIPV Market Share



BIPV Moves from the Niche to the Mass Market!

Source: Reinders et al., *Photovoltaic Solar Energy: From Fundamentals to Applications*, 2017.

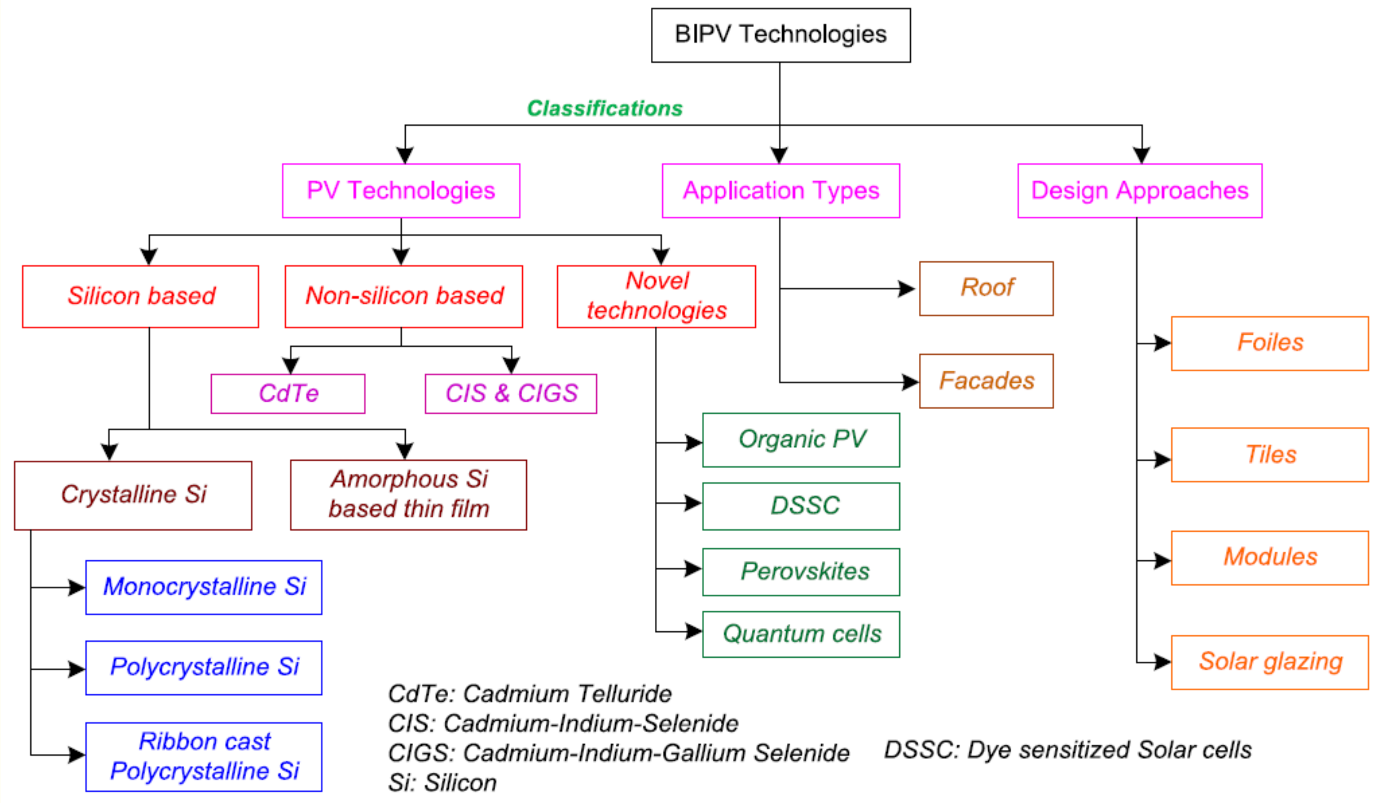
Global BIPV Market Grow



Source: Balliff et al, Nature Energy 2018, (based on n-tech research, 2017)

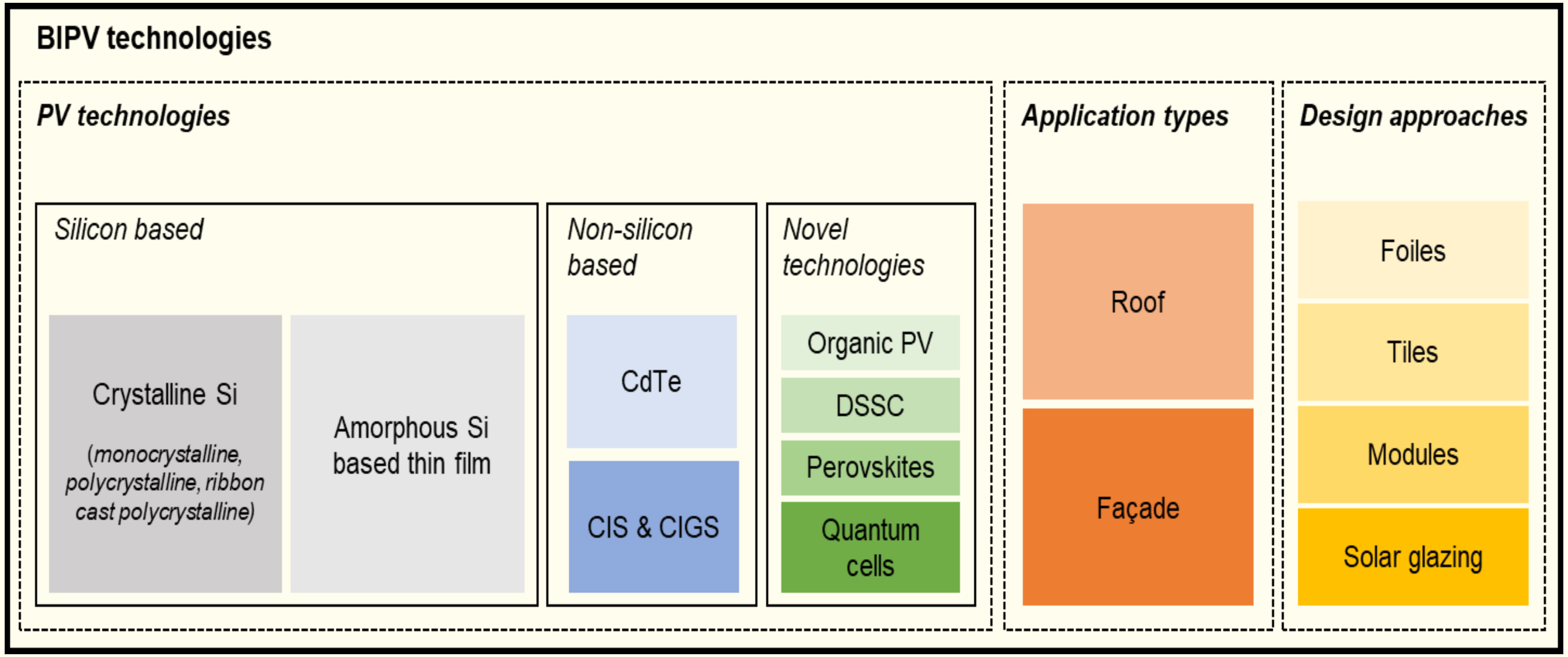
BiPV Technologies

BiPV Technologies



Source: Pillai et al., *Review on Building Integrated Photovoltaic Systems*, 2022.

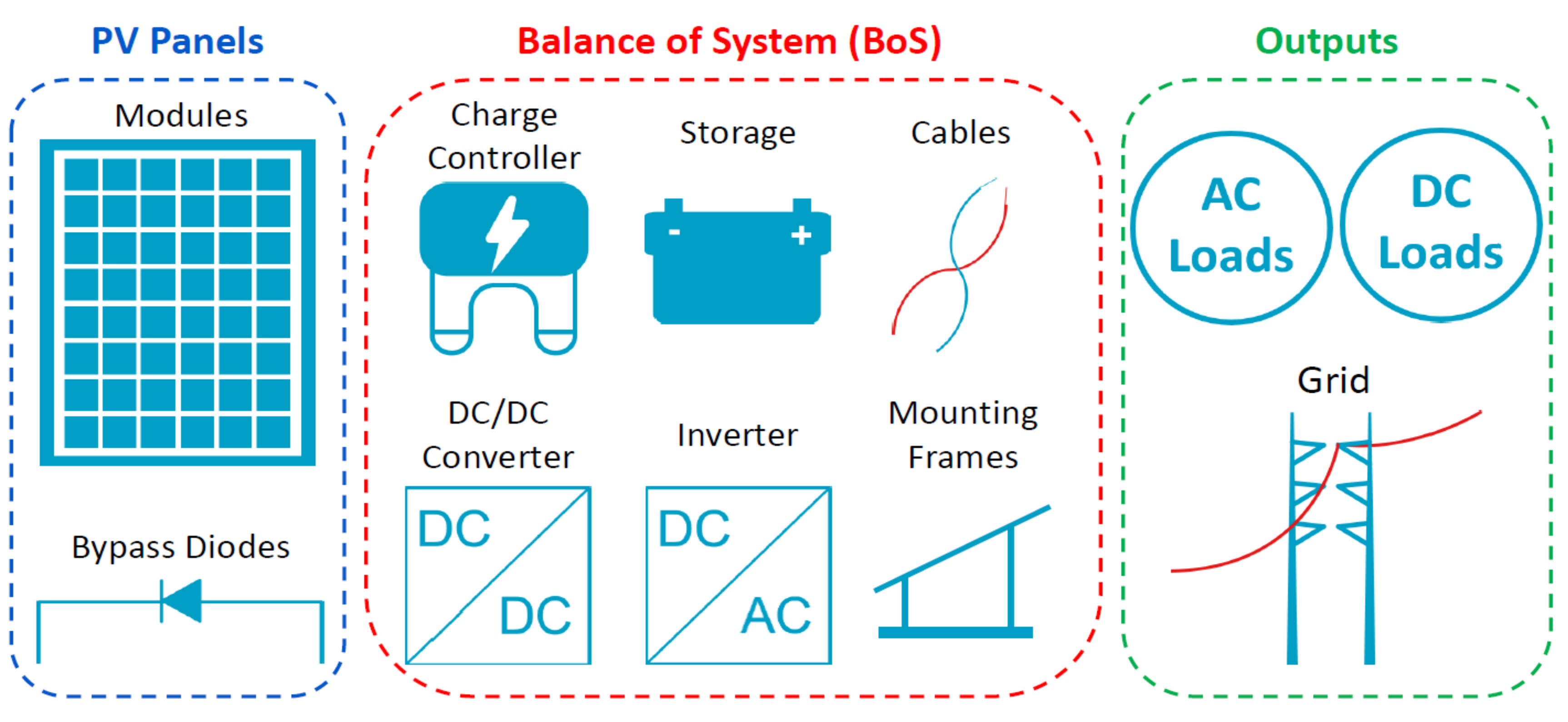
BiPV Technologies



Source: Pillai et al., *Review on Building Integrated Photovoltaic Systems*, 2022.

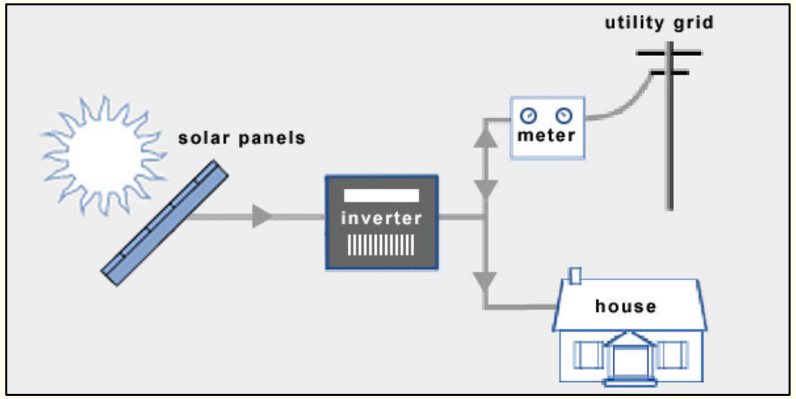
System Components

Components of Photovoltaic System

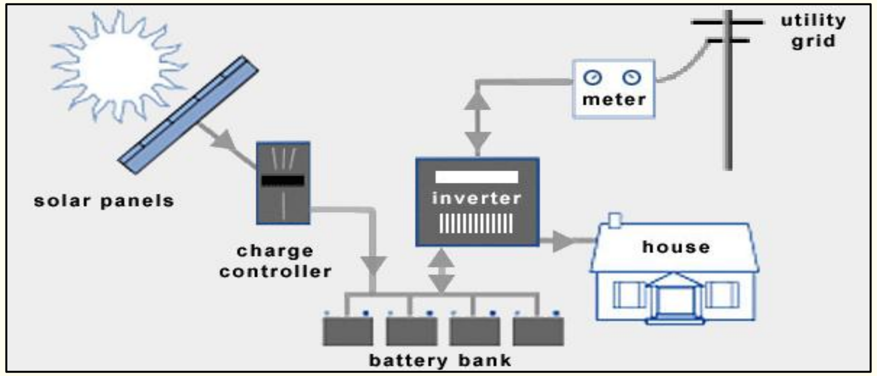


Source -O. Isabella, PVSSS 2018, TU Delft '' Advanced modelling of U/AIPV systems from location to load''.

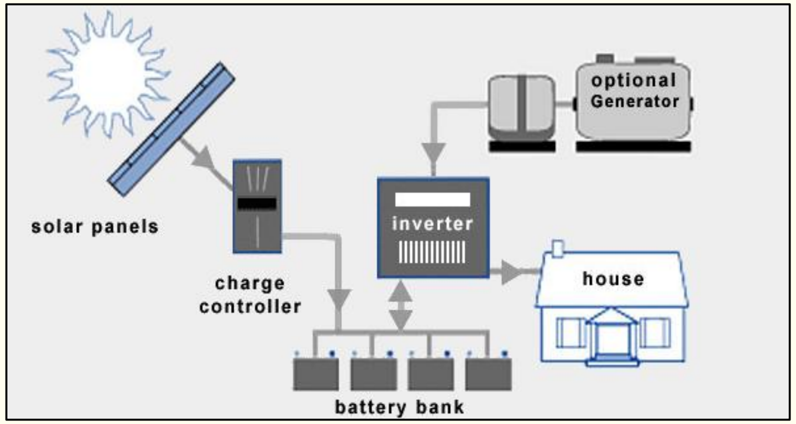
Types of Solar Photovoltaic systems



Grid-tied system



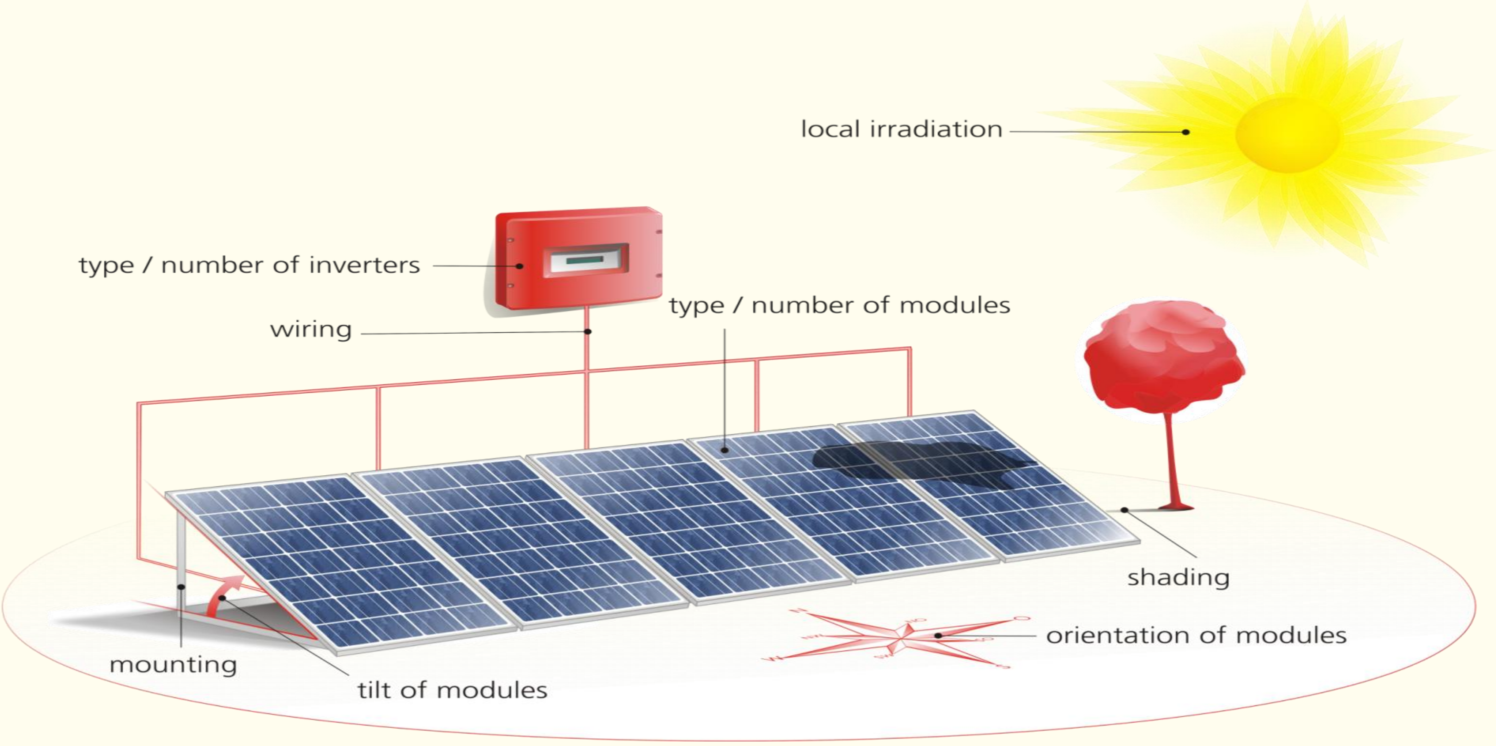
Hybrid solar system



Stand-alone system

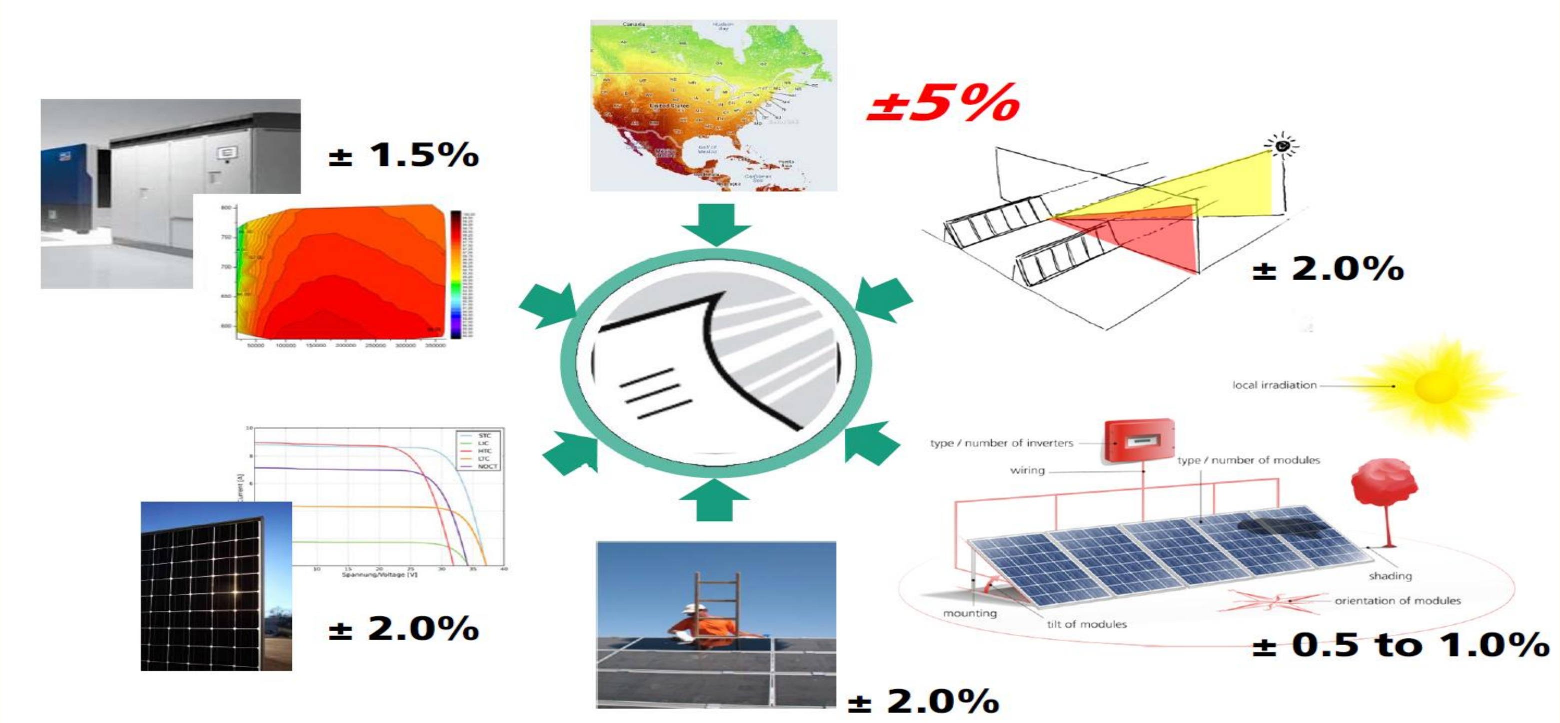
Source: www.energyinformative.org

Photovoltaic system monitoring



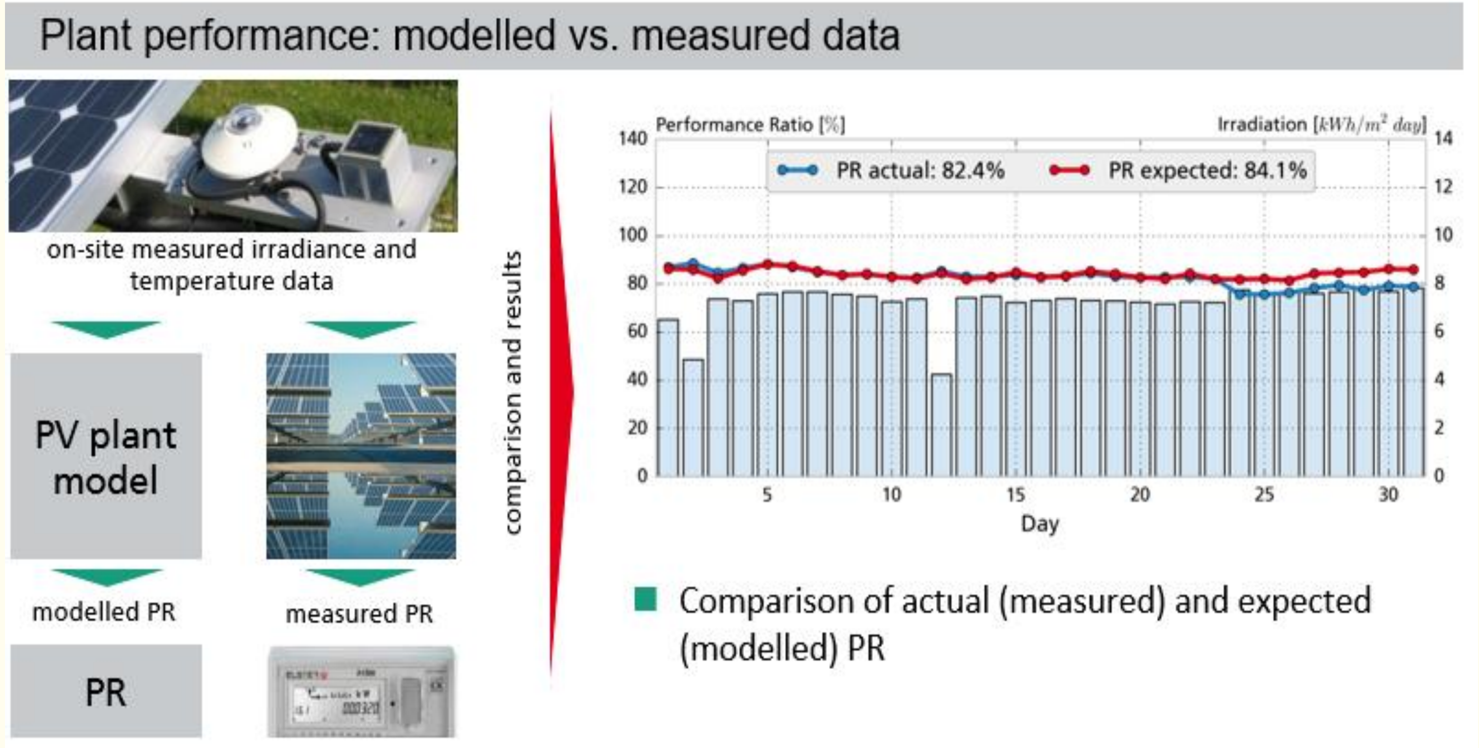
Source: Schill & Rüther, *Fraunhofer ISE – Photovoltaics Division*, n.d. [Fraunhofer ISE / UFSC]

Energy losses in Solar Photovoltaic systems



Source: Komoto et al., *Energy from the Desert: Very Large Scale PV Power Plants*, 2015. [IEA]
Schill, *Fraunhofer ISE – Photovoltaics Division*, n.d. [Fraunhofer ISE]

Performance assessment



Source: Fraunhofer ISE, Photovoltaics Division

The performance ratio is the ratio of the actual and theoretically possible energy outputs

Demand Side Management

Introduction

- **Demand Side Management (DSM)** refers to the strategies used to **influence and optimize energy consumption** on the consumer side rather than the supply side.

- DSM includes actions like **shifting**, **reducing**, or **modifying** energy use patterns without affecting user comfort or productivity.

- It is implemented using **energy-efficient technologies**, **behavioral programs**, **automated control systems**, and **incentive mechanisms**.

Why DSM should be used in NZEBs?

- Net Zero Energy Buildings (NZEBs) aim to **balance their annual energy demand with on-site renewable energy production**.

- Renewable sources (e.g., solar, wind) are **intermittent** and cannot always match real-time demand.

- DSM helps **align building energy demand** with **renewable generation availability**, making energy use smarter and more sustainable.

- Reduces reliance on external non-renewable grids, making NZEBs **truly self-sufficient** and resilient.

Battery Energy Storage Systems (BESS) in Buildings

nZEBRA

Introduction to Battery Energy Storage Systems (BESS) in Buildings

Introduction

- **Battery Energy Storage Systems (BESS)** are critical for enhancing energy efficiency and reliability in modern buildings.
- BESS have emerged as one of the most important enabling technologies for the decarbonization of the built environment.
- They store excess energy often from **renewable sources** like solar allowing for **flexible usage** during peak hours or outages.
- ESS help in **load balancing**, **reducing energy costs**, and supporting **grid independence**.
- By enabling **demand-side energy management**, storage systems make buildings smarter, more resilient, and environmentally sustainable.
- Integration of storage is key to achieving **net-zero energy goals** and improving the overall performance of **Building Energy Management Systems (BEMS)**.

Source: Byrne et al., *Energy storage for buildings*, 2020

Why Buildings Need Battery Storage?

The main drivers for **battery deployment** in buildings include:

- Maximization of **self-consumption** of PV electricity
- **Peak demand** reduction and **demand charge management**
- **Backup power** during grid outages
- **Demand response** participation
- Improved **energy resilience**
- Enhanced **grid flexibility**
- Reduction of **carbon emissions**
- Integration of **electric vehicles** and **heat pumps**
- Participation in **local energy communities**

Source: Byrne et al., *Energy storage for buildings*, 2020

Battery Energy Storage Systems (BESS) in Buildings

Methodologies for BESS in Buildings

The design of a building-scale BESS typically follows several stages:

Step 1: Load Assessment
The building's energy consumption profile is analyzed using:

- Historical electricity demand data
- Hourly load profiles
- Seasonal variations
- Peak demand characteristics
- Key parameters include:
- Annual electricity consumption (kWh/year)
- Peak demand (kW)
- Load factor
- Daily load patterns

Step 2: Renewable Energy Assessment
The available renewable energy generation is evaluated:

- Rooftop PV systems
- Building-integrated photovoltaics (BIPV)
- Small wind turbines
- Local renewable resources

Methodologies for BESS in Buildings

Step 3: Battery Sizing
Battery capacity depends on:

- Energy demand
- Desired autonomy
- Peak shaving objectives
- Backup requirements
- Economic considerations

Step 4: Economic Assessment
Several indicators are used:

- Net Present Value (NPV)
- Internal Rate of Return (IRR)
- Payback Period
- Levelized Cost of Storage (LCOS)

Building Type	Battery Capacity
Residential	5–30 kWh
Commercial	50–500 kWh
Large Commercial	500 kWh–5 MWh
Campus/Microgrid	>5 MWh

Types of Battery Energy Storage Systems

Lithium-Ion Batteries
- Most widely used in modern BESS due to **high energy density**, **long lifespan**, and **fast charging**.
- Suitable for **residential**, **commercial**, and **grid-scale** applications.
- Common chemistries: NMC, LFP.

Lead-Acid Batteries
- Mature and **low-cost** technology, used in off-grid and backup systems.
- Shorter lifespan and lower efficiency compared to lithium-ion.
- Best for **low-cycle**, **cost-sensitive** use cases.

Flow Batteries
- Store energy in **liquid electrolytes** in external tanks.
- Offer **scalability**, **long cycle life**, and are ideal for **long-duration storage**.
- Suitable for **large-scale, stationary applications**.

Applications of Battery Energy Storage Systems (BESS)

Applications of BESS

Peak Shaving
Battery systems discharge during periods of high demand to reduce peak loads.
Benefits:
- Reduced demand charges
- Lower grid stress

Load Shifting
Energy is stored during low-price periods and used during high-price periods.
Benefits:
- Reduced electricity bills
- Increased flexibility

Self-Consumption Enhancement
PV-generated electricity is stored locally and used later.
Benefits:
- Reduced grid imports
- Increased renewable utilization

Backup Power
BESS can provide uninterrupted power for:
- Hospitals
- Data centers
- Emergency facilities
- Smart homes

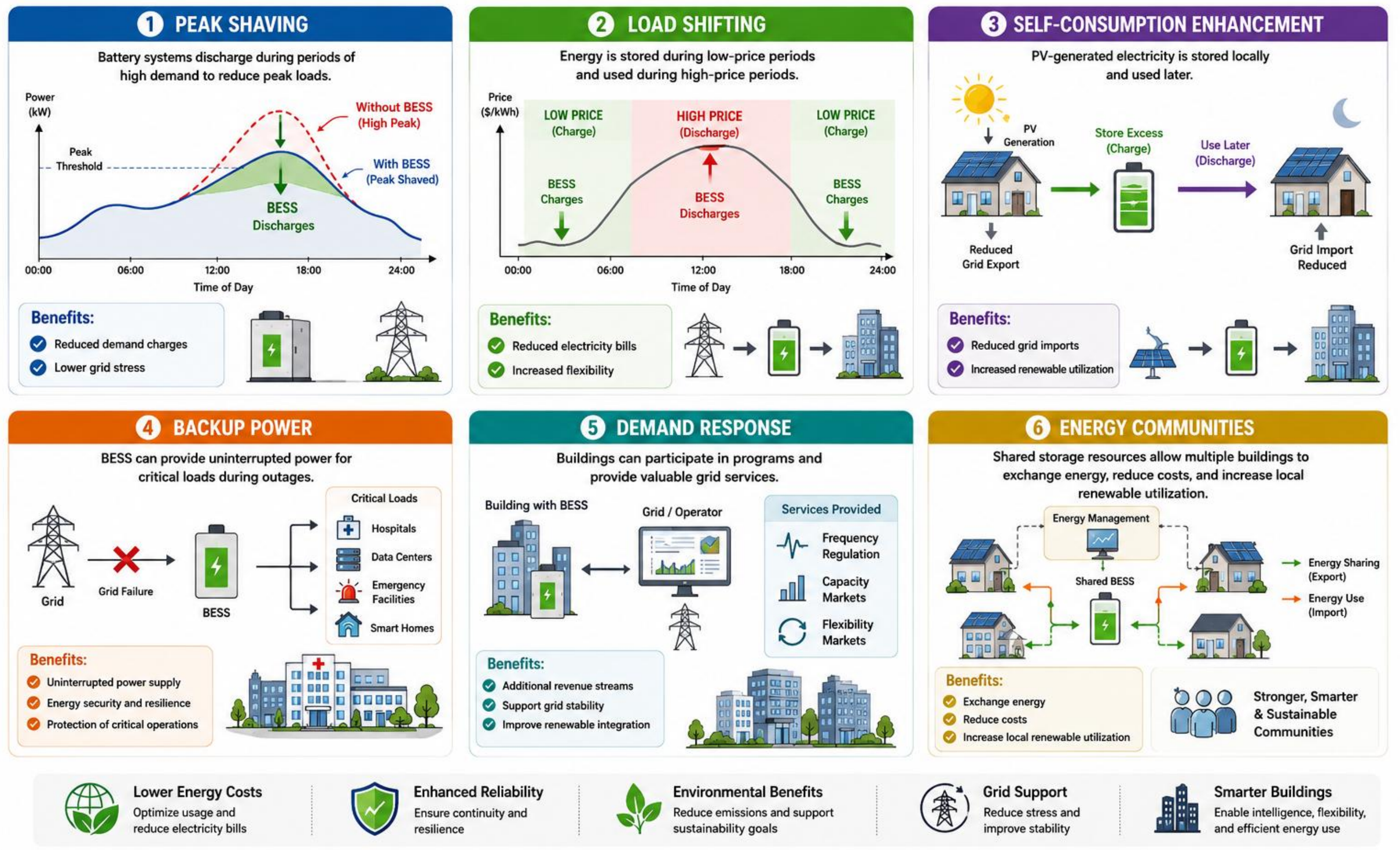
Applications of BESS

Demand Response

- Buildings can participate in:
- Frequency regulation
- Capacity markets
- Flexibility markets

Energy Communities

- Shared storage resources allow multiple buildings to:
- Exchange energy
- Reduce costs
- Increase local renewable utilization



Future Outlook for BESS

Future Outlook

1. Solid-State Batteries

- Higher energy density
- Improved safety
- Longer lifetime
- Commercial deployment is anticipated during the next decade.

2. AI-Driven Autonomous Buildings

Future buildings will integrate:

- Battery storage
- Renewable energy
- Electric vehicles
- Smart appliances

3. Vehicle-to-Building (V2B)

Electric vehicles will function as mobile storage systems supporting building operations.

4. Vehicle-to-Grid (V2G)

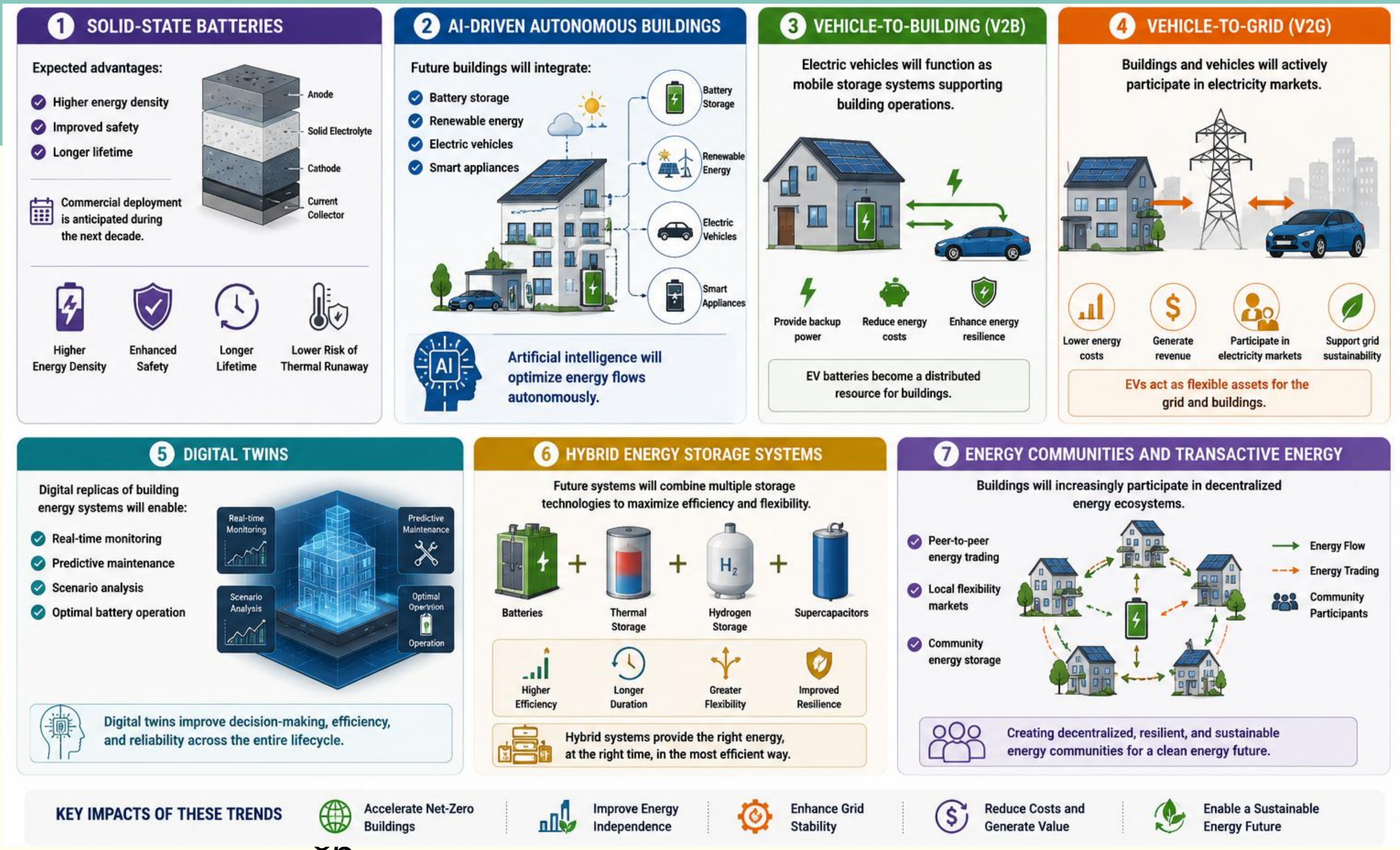
Buildings and vehicles will actively participate in electricity markets.

5. Digital Twins

Digital replicas of building energy systems will enable:

- Real-time monitoring
- Predictive maintenance
- Scenario analysis
- Optimal battery operation

Future Outlook



6. Hybrid Energy Storage Systems

Future systems will combine:

Batteries

- Thermal storage
- Hydrogen storage
- Supercapacitors

7. Energy Communities and Transactive Energy

Buildings will increasingly participate in:

- Peer-to-peer energy trading
- Local flexibility markets
- Community energy storage

Smart Buildings and Near-Zero Energy Buildings (nZEB)

Introduction to NZEB Buildings

Introduction to Sustainable Buildings

- Sustainable buildings are designed to **minimize environmental impact** throughout their lifecycle — from construction to operation and demolition.
- Focuses on **energy efficiency**, **resource conservation**, **healthy indoor environments**, and **minimizing carbon footprint**.

Key Features:

- Use of **eco-friendly materials**
- **Water conservation** systems (e.g., rainwater harvesting)
- **Energy-efficient designs** (passive heating/cooling)
- **Waste reduction** during and after construction

Source: Meng, *Smart Building cube berlin by 3XN*, 2025

Evolution into Smart Buildings

Smart buildings evolved from sustainable concepts by **adding automation, intelligence, and digital control** to further optimize performance.

Source: Veridify, *The Importance of Protecting Smart Building Technology from Cyber Threats*, 2023.

Key Characteristics:

- **Automation and real-time control** of HVAC, lighting, and security
- **IoT integration** for continuous monitoring and adaptive responses
- **Data-driven decision making** to enhance comfort, safety, and energy use
- **Self-learning systems** that evolve with occupant behavior and environment

Impact:

- Enhances **energy savings** beyond traditional efficiency measures
- Improves **occupant satisfaction** and **operational resilience**
- Enables **dynamic interaction** with smart grids and energy market

Near-Zero Energy Buildings (nZEB)

Definition:
- Buildings with **very high energy efficiency**.
- The **small amount of energy they still need** is largely supplied by **renewable sources**, either **on-site** (like rooftop solar) or **nearby**.
- Officially defined under the **European Commission's nZEB Principles (2023)**.

Why They Matter:
- Buildings are major contributors to **energy use and carbon emissions**.
- nZEBs help **drastically reduce the energy footprint** of the built environment.
- They are a **key part** of reaching **climate neutrality by 2050**.

Source: Professional Energy Solutions, *Net Zero Building*, 2024.

How Do nZEBs Achieve High Efficiency?

Main principles:

- **Minimize energy demand** through smart building design.
- **Use natural elements** like sunlight and ventilation (called *passive strategies*).
- **Recover and reuse energy** wherever possible (e.g., heat recovery).
- **Integrate renewable energy sources** like **solar PV** or **geothermal**.

EU Regulations for nZEB

Key policies shaping the future:

- **All new buildings** in the EU must be **zero-emission** by **2030**.
- **Public sector buildings** must reach zero-emission even earlier, by **2027**.
- **Existing worst-performing buildings** must be **renovated** to higher energy standards.
- **Solar PV installations** will become mandatory for new large buildings.
- **Financial support** is available for energy-efficient construction and renovation under EU programs like **Horizon Europe** and **NextGenerationEU**.

Source: European Commission, *nZEB Principles*, 2023

Smart Readiness Indicator

Introduction to Smart Readiness Indicator (SRI)

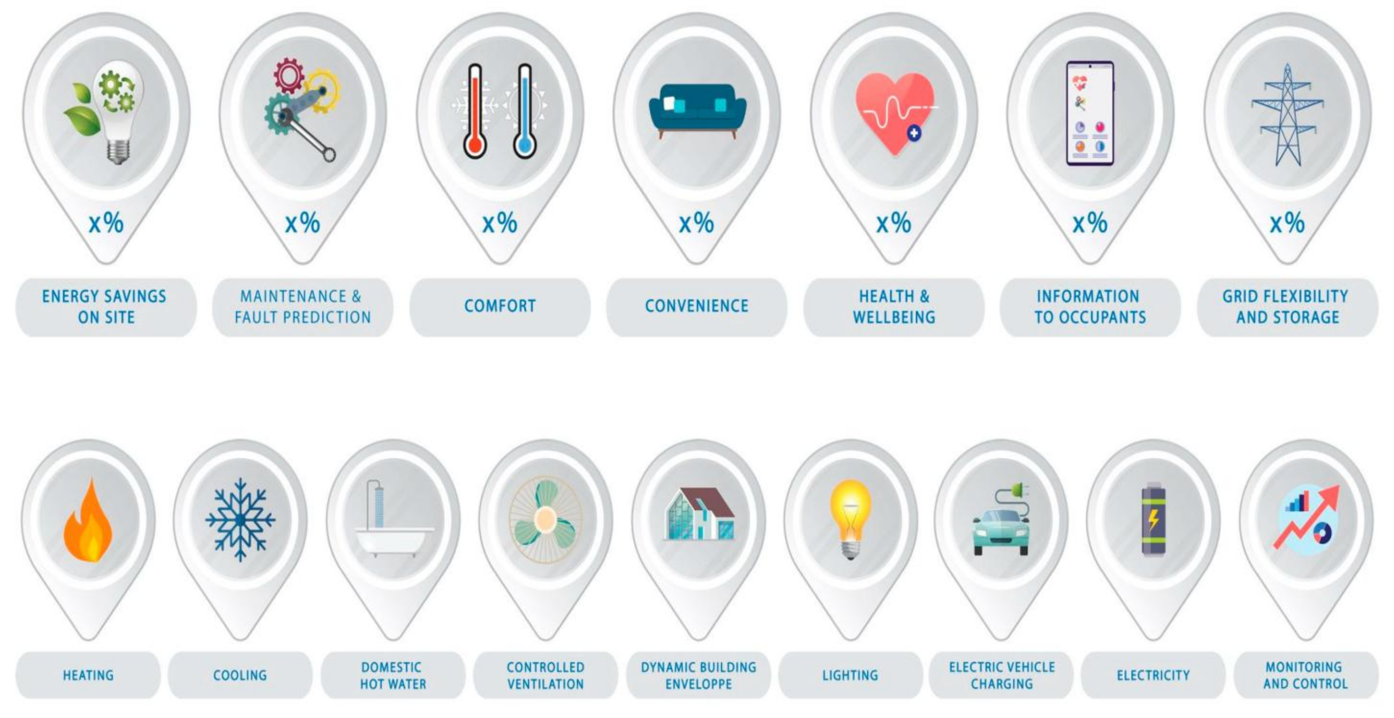
- The **SRI** is an EU-wide metric assessing how well buildings can adapt their operation through smart technologies.
- Defined under Article 8 of the **Energy Performance of Buildings Directive (EPBD)**.
- It promotes **digital and smart building technologies** like automation, control systems, and IoT.
- Enables benchmarking of smart capabilities across different buildings (residential, commercial, etc.).
- Aims to raise awareness among building owners, occupants, and service providers.
- Voluntary for EU Member States, but expected to be widely adopted in national policies.

Source: European Commission, *Smart Readiness Indicator Factsheet*, 2023.

Source: European Commission, *EU Buildings Factsheet*, 2022

Key Objectives of the SRI

- Promote digitalization of the building sector.
- Provide transparency to building users and owners.
- Encourage deployment of smart technologies (e.g., sensors, automation).
- Enhance **energy flexibility** and support **demand-side management**.
- Complement **NZEB** goals by integrating smart control and monitoring features.



Source: Casini, *Smart Buildings and the Smart Grid: Integration and Future Challenges*, 2020.

Source: EC Joint Research Centre, *SRI Implementation Guidelines*, 2023.

Assessment Domains of SRI

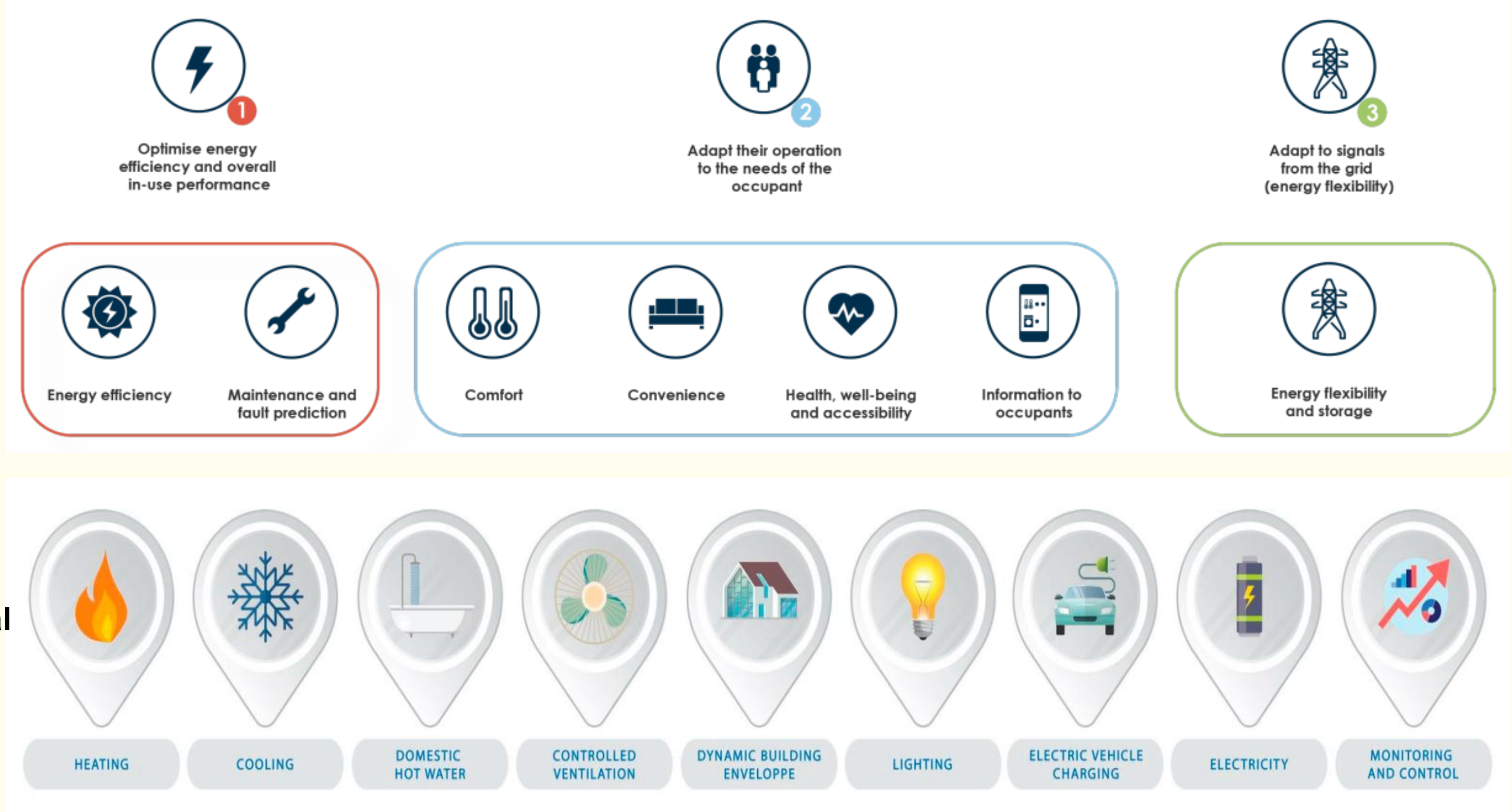
SRI evaluates smartness across 9 technical domains:

- Heating
- Cooling
- Domestic hot water
- Ventilation
- Lighting
- Dynamic building envelope
- Electricity
- EV charging
- Monitoring and control

Each domain is assessed for its contribution to:

- Energy efficiency
- Comfort and convenience
- Energy flexibility

- **3 Key Themes**
- **7 Impact Criteria**
- **9 Technical Domains**



Source: REHVA, *The Smart Readiness Indicator for Buildings: Current Status and Next Steps*, 2023.

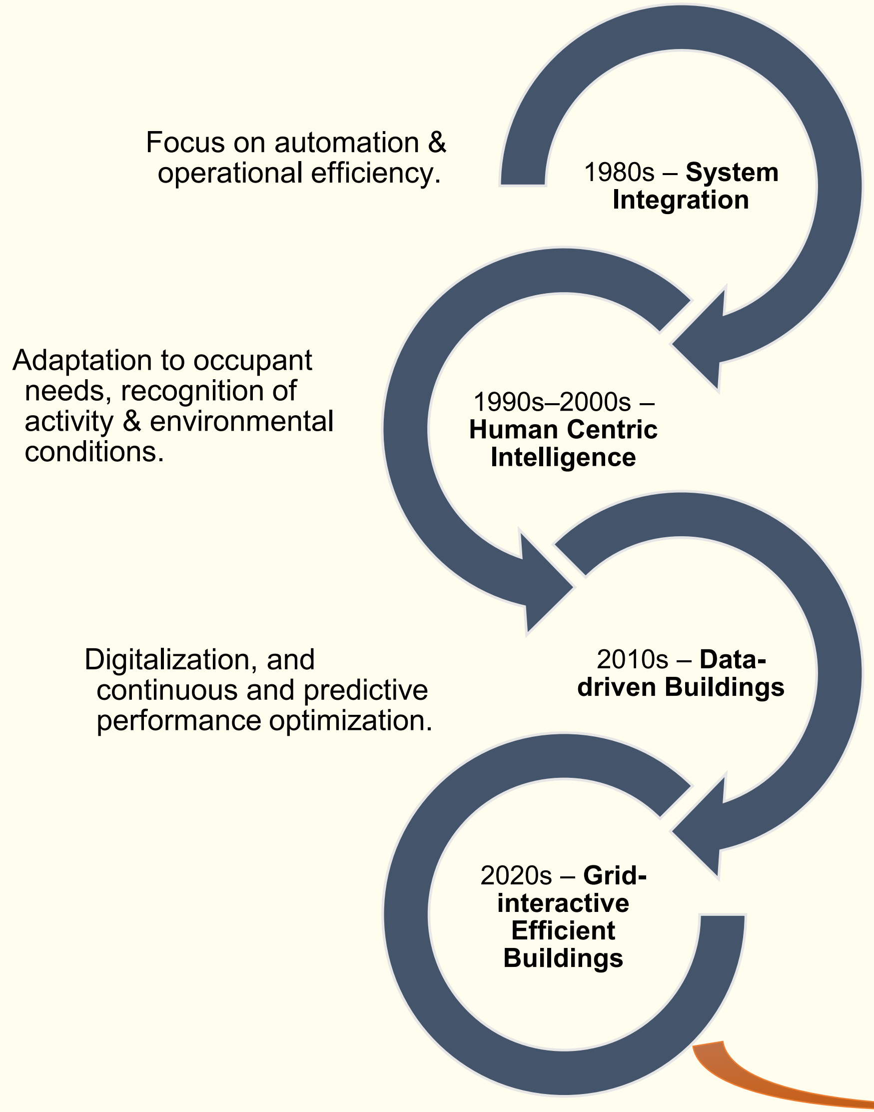
Buildings and Electrification

- **Direct substitution:** fossil fuels, as energy carriers, are replaced with electricity. For example, heat pump instead of gas boiler.

- **Easy transport:** Eases the transfer of energy between sectors can be used directly without the need for an intermediary.

- **Increase flexibility**: Electrifying the demand-side adds flexibility to the overall energy system.

Buildings and Grid Interaction



Grid-interactive efficient buildings (GEBs): Energy-efficient buildings that provide demand flexibility by optimizing grid services, energy costs, and occupants' needs and preferences with the integration of smart devices.

GEBs can manage their demand and generation based on external grid signals such as price, CO_2 emissions, or grid congestion.

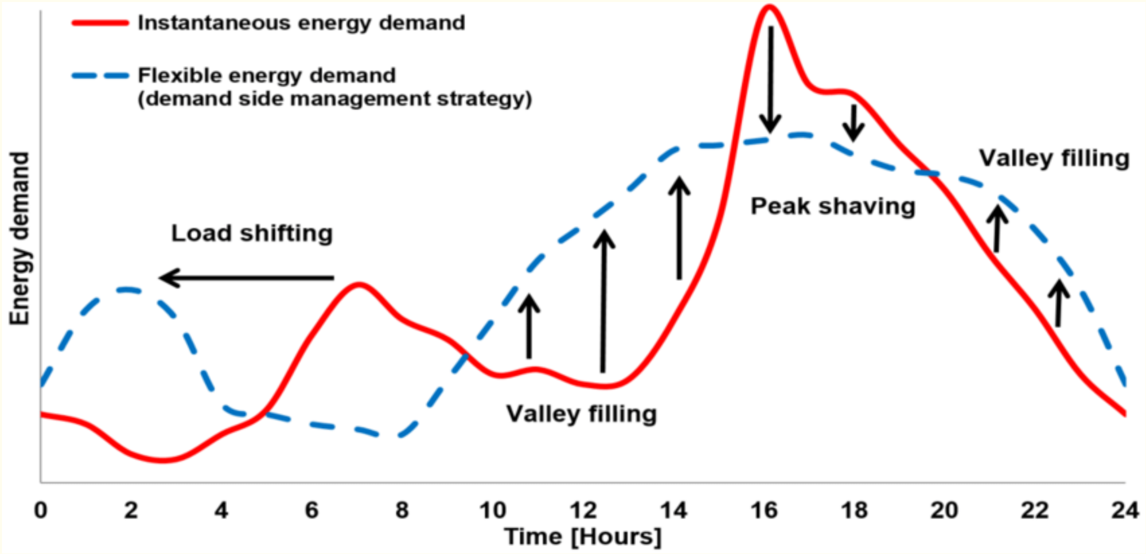
Koltsaklis, N. E., Dagoumas, A. S., & Panapakidis, I. P. (2017). Impact of the penetration of renewables on flexibility needs. Energy Policy, 109, 360–369.

Buildings and Flexibility

The ability to change **when** and **how much energy you use**, or **produce**, and still meet **your needs** (e.g, comfort, productivity, charging done, etc.).

In simple terms, it is the ability to **use energy differently:**

- use less right now (**peak shaving**)
- use more right now (**valley filling**)
- move use to another time (**load shifting**)

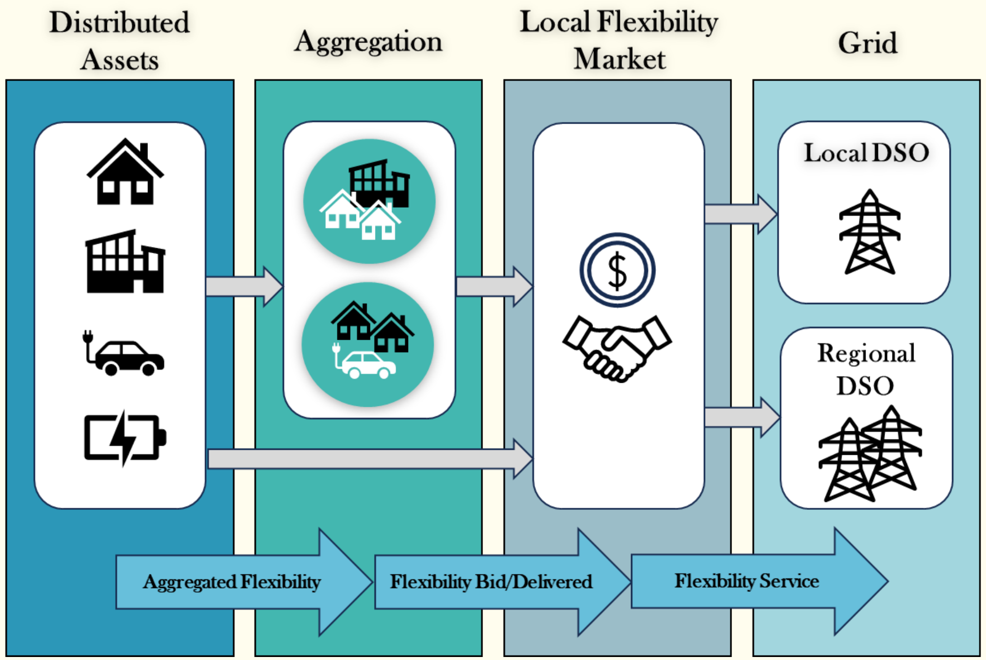


Johra, H., Marszal-Pomianowska, A., Ellingsgaard, J. R., & Liu, M. (2019, November). Building energy flexibility: A sensitivity analysis and key performance indicator comparison. In Journal of Physics: Conference Series (Vol. 1343, No. 1, p. 012064). IOP Publishing.

Flexibility Markets

Boosting distributed generation and demand-side flexibility transactions.

- **The prosumer:** Transitioning users from passive energy consumers to prosumers who are rewarded for helping the grid balance itself.
- **Aggregators as intermediaries**: Specialized companies pool thousands of small devices to offer flexibility services.
- **Increase in grid stability:** Providing operators with a digital toolset to manage variability without resorting to expensive physical grid expansion.
- **Need of market transparency:** creating a level playing field where all resources, whether a small battery or a large generator, can participate and be paid fairly.
- **Need of policy enablers:** Shifting regulatory focus toward inclusive schemes.



Minniti, S., Haque, N., Nguyen, P., & Pemen, G. (2018). Local markets for flexibility trading: Key stages and enablers. Energies, 11(11), 3074.

Thank You

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