Re-imagining Energy System *Integration*

Exploring sustainable energy solutions

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COLUMBIA CLIMATE SCHOOL
Climate, Earth, and Society

Meet the Team

Columbia University x Universty of Western Macedonia

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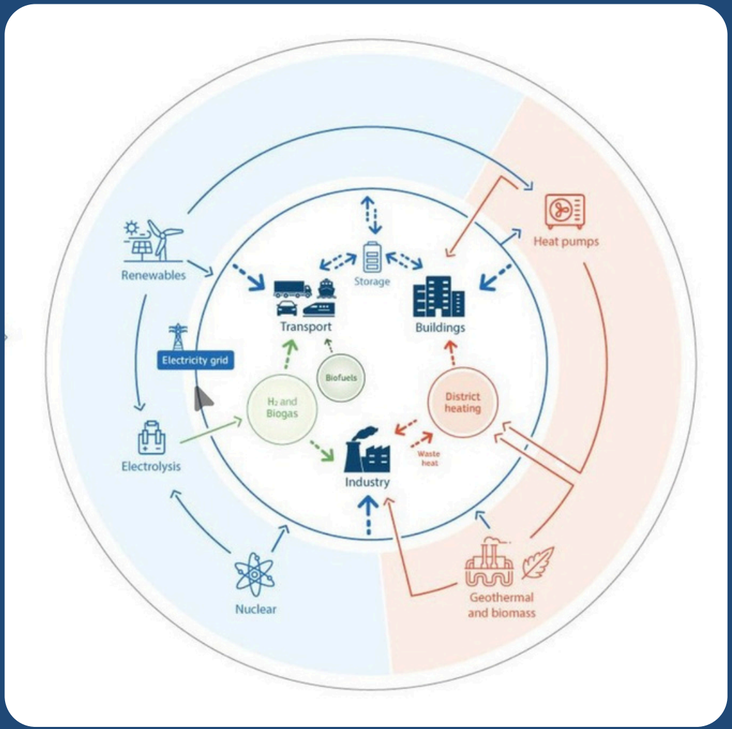
Why does *Energy Systems Integration (ESI)* Matter?

The EU ESI Model



(EU , 2023)

Energy Systems Integration (ESI):

- ESI integrates electricity,heat, fuels, transport, water, and communication systems.
- ESI enhances flexibility, efficiency, and cost-effectiveness while reducing waste.
- Energy trilemma: decarbonisation, affordability, and security

(Ruth & Kroposki, 2014)

How ESI supports the transition

- ESI diversifies energy sources to meet peak demand flexibly;
- Reduces costs through shared infrastructure and improved resource use;
- Enables greater renewable energy systems (RES) integration and reduces greenhouse gas emissions.

(Berjawi etal., 2021)

Nuclear

Solar

Wind

Hydro

Geothermal

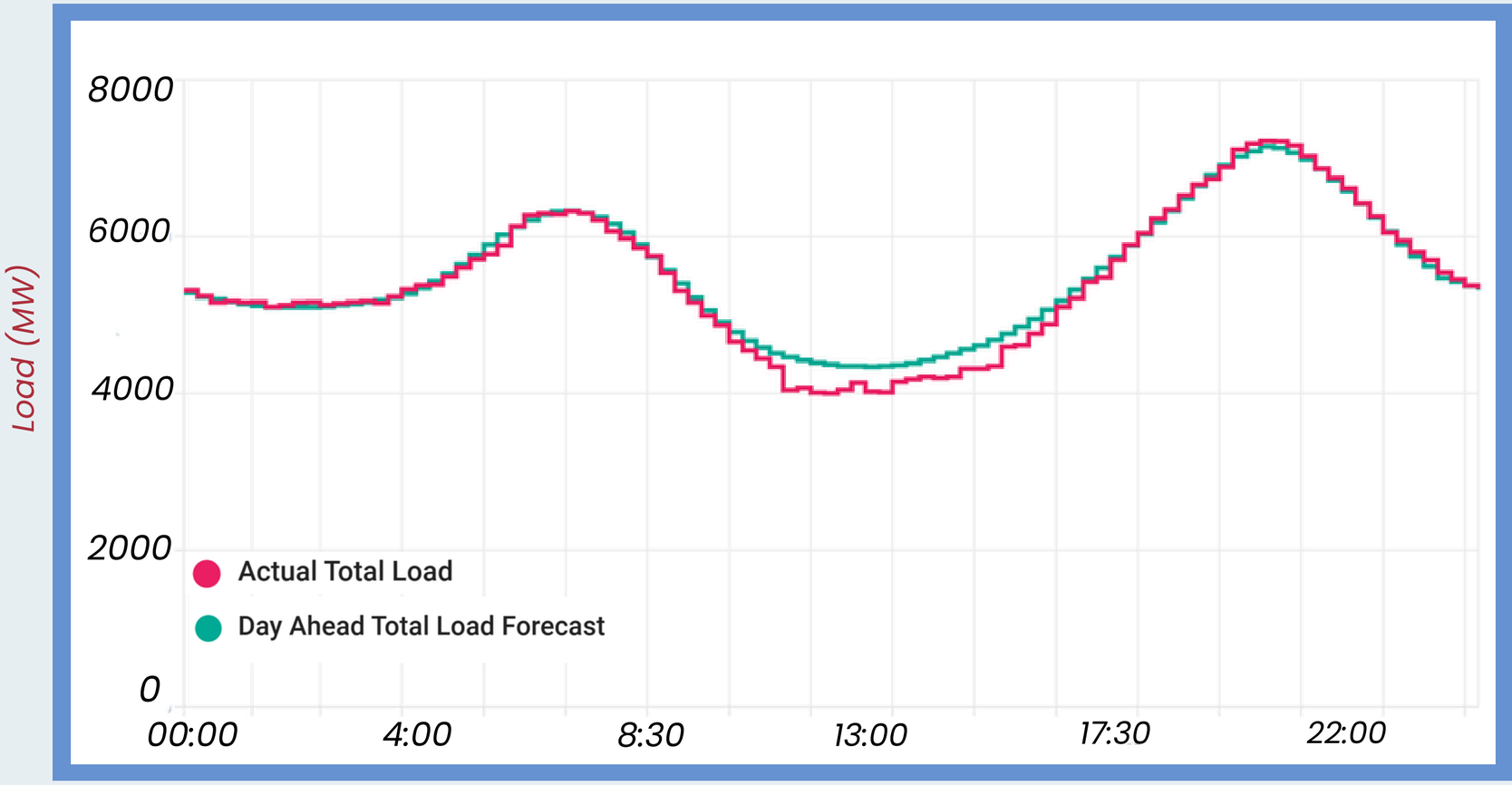
Demand side *management*

Consumption is typically lower during the afternoon.

RES energy production is at its peak during the afternoon.

Energy is wasted due to curtailment of PVs.

Typical Daily Demand Load

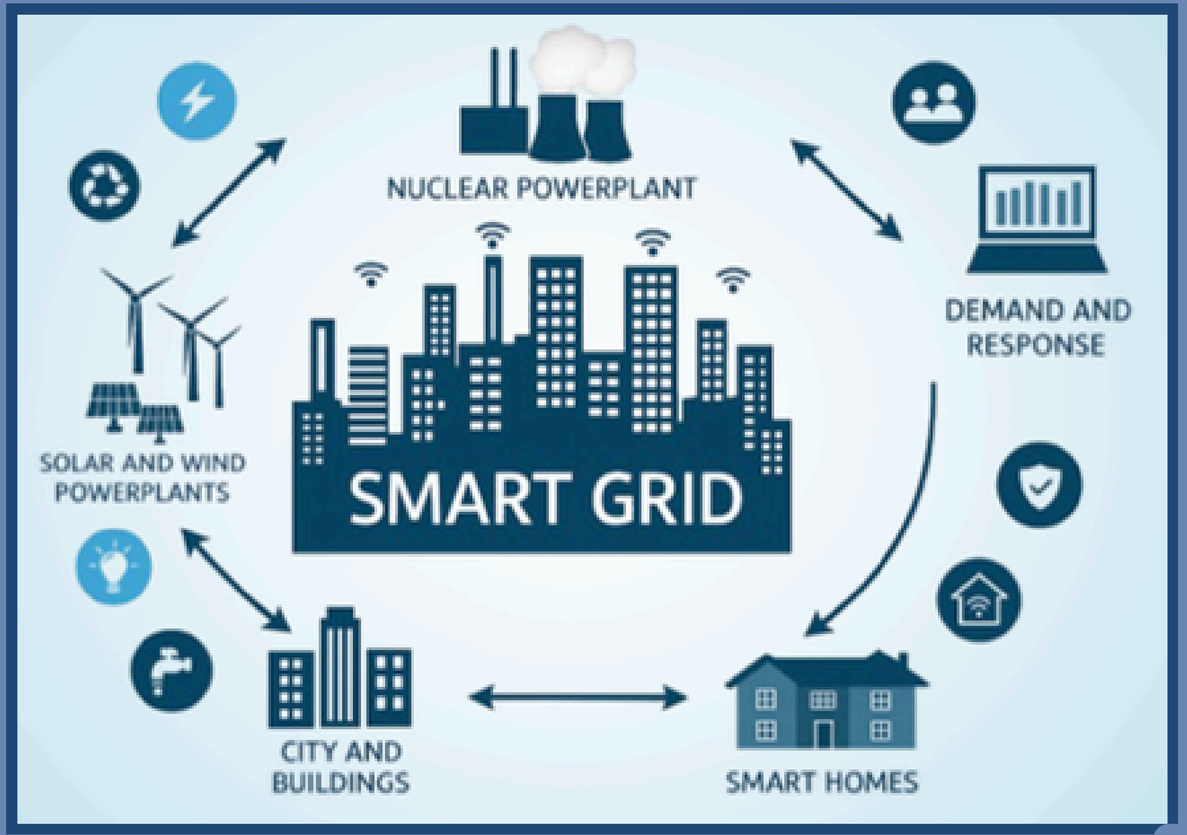


Source: entsoe Transparency platform

Smart grids

An upgraded electrical network that uses digital technology, sensors, and two-way communication to monitor and manage the transport of electricity

- **Two-Way Communication** enables utilities and consumers to share data in real time.
- **Renewable Energy Systems Integration** addresses the intermittent nature of renewable energy technologies.
- **Grid reliability** reduces instability and balances energy consumption efficiently.



Source: Smart Power Grids vs Traditional Grids: A Complete Guide-Fly-wing

Technology for a *Cleaner, Cheaper, Smarter* Grid

1

Internet of Things (IoT)

- Smart Meters

2

Virtual Power Plants (VPP)

- V2G
- Demand Management

3

Smart Energy Storage

- BESS
- Pumped Hydropower
- Green Hydrogen

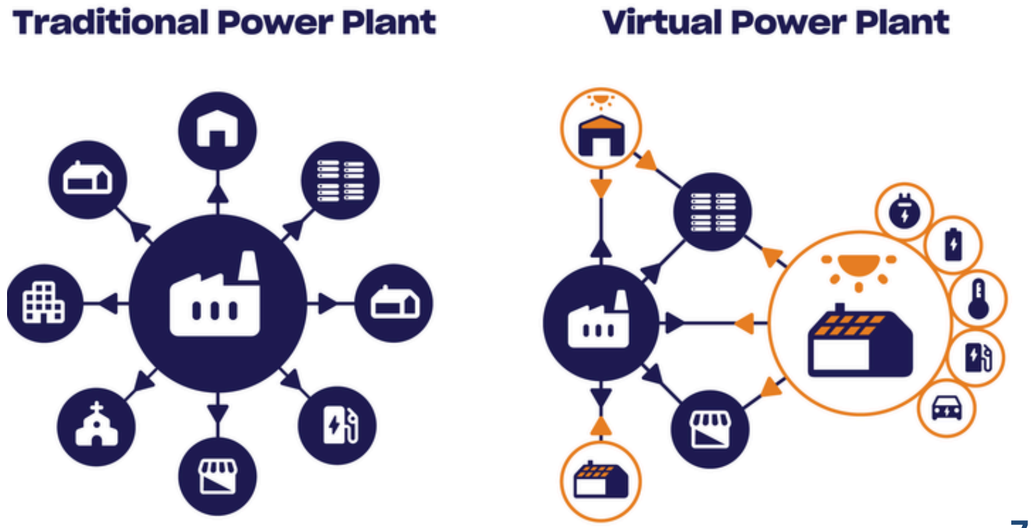
In 2024, the Hellenic Electricity Distribution Network Operator (HEDNO) signed contracts for the deployment of ***2.76 million next-generation smart meters*** *and the development of a new* ***central Meter Data Management (MDM) system***

Designing Virtual Power Plants for resilient infrastructure

- Enable aggregation of distributed energy resources into a coordinated digital system
- Provide fast-acting capacity during peak periods
- Advance integration of dynamic energy storage coordination allowing for adjustment of charge and discharge cycles based on grid conditions

Integration of Electric Vehicles
→ **Vehicle-2-Grid**

- Mobile energy storage units
- Supports stabilization of the grid



Source: Solar United Neighbors

CERTH Hydrogen Hub (H2HUB)

Hydrogen for Energy Storage

278GWh of RES curtailed in first four months of 2025

Construction of first of a kind technology is underway

- Greece will be **uniquely positioned** to create new knowledge for deploying hydrogen storage. technologies coupled with existing PV resources.
- Co-location of hydrogen storage facilities with heavy industries enables industrial efficiency.

Global Integration Initiative

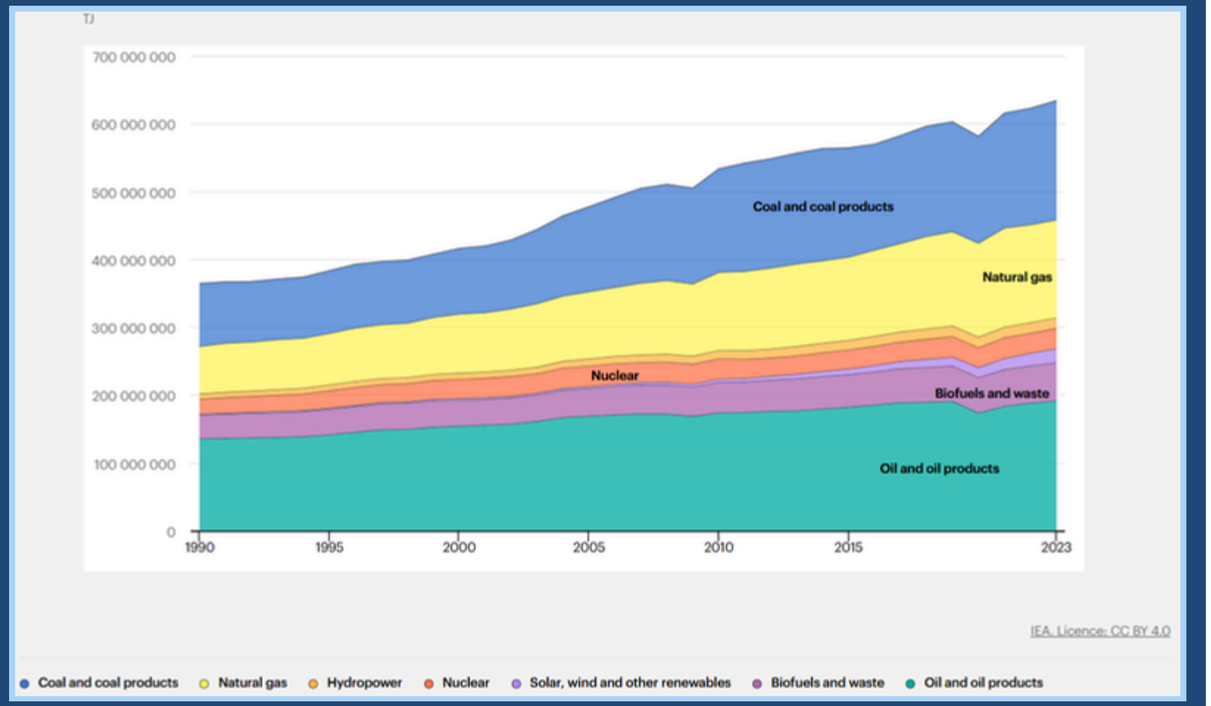
Successful Projects with an important impact

Initiative	Region	Main Goal	Key Success
ISGAN	Global	International smart-grid cooperation	Standardization & collaboration
WISEGRID	EU	Consumer-centered smart grids	Active citizen participation
InteGrid	EU	Renewable flexibility markets	Stable decentralized grids
Denmark wind model	EU	High wind penetration	Renewable balancing success
China UHV grids	Global	Long-distance renewable transfer	Massive renewable integration
US GRIP	USA	Grid resilience	Climate adaptation & modernization
Greece smart islands	Greece	Island decarbonization	Sustainable local integration

IEA and European Comission

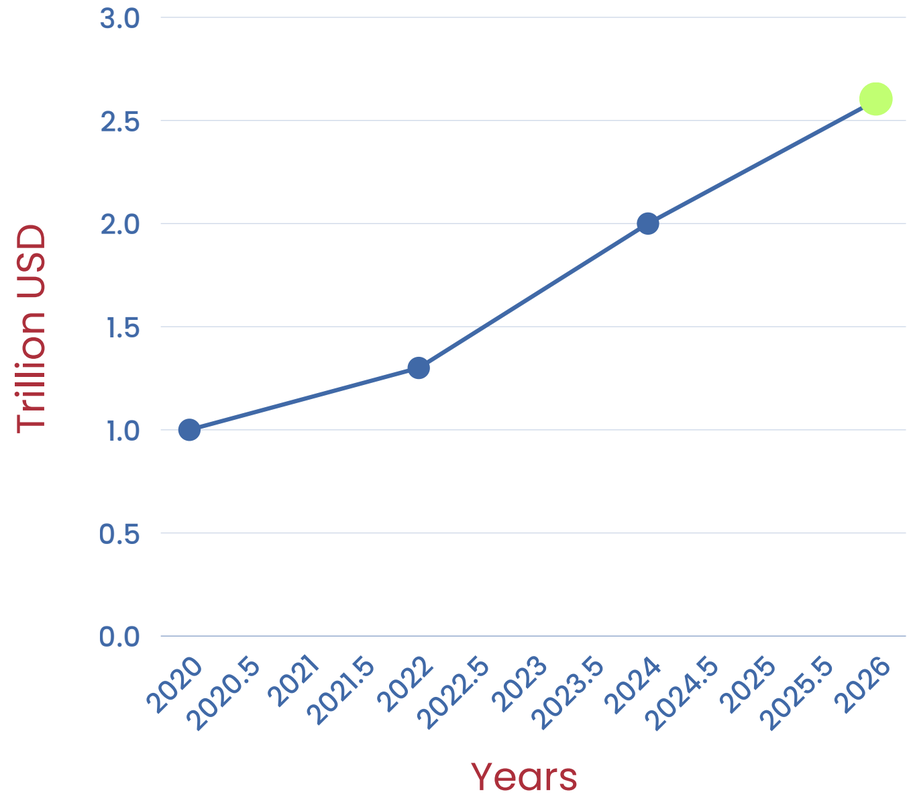
Investments in Global Energy Integration

Energy Usage Statistics Data and Prediction until 2030



IEA

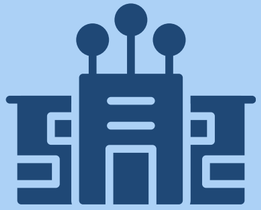
Semi-annual financial investment data



Rising investments in energy in the past six years is indicative of global interest in expanding energy access.

Opportunities & Challenges for RES Integration

Enviromental Considerations



Technological Considerations

Social & Political Considerations

Economic Considerations

Each consideration presents a systematic assessment of both the enabling opportunities and the structural challenges that policymakers, engineers, investors, and communities must navigate to advance energy access and affordability.

Renewable energy potential

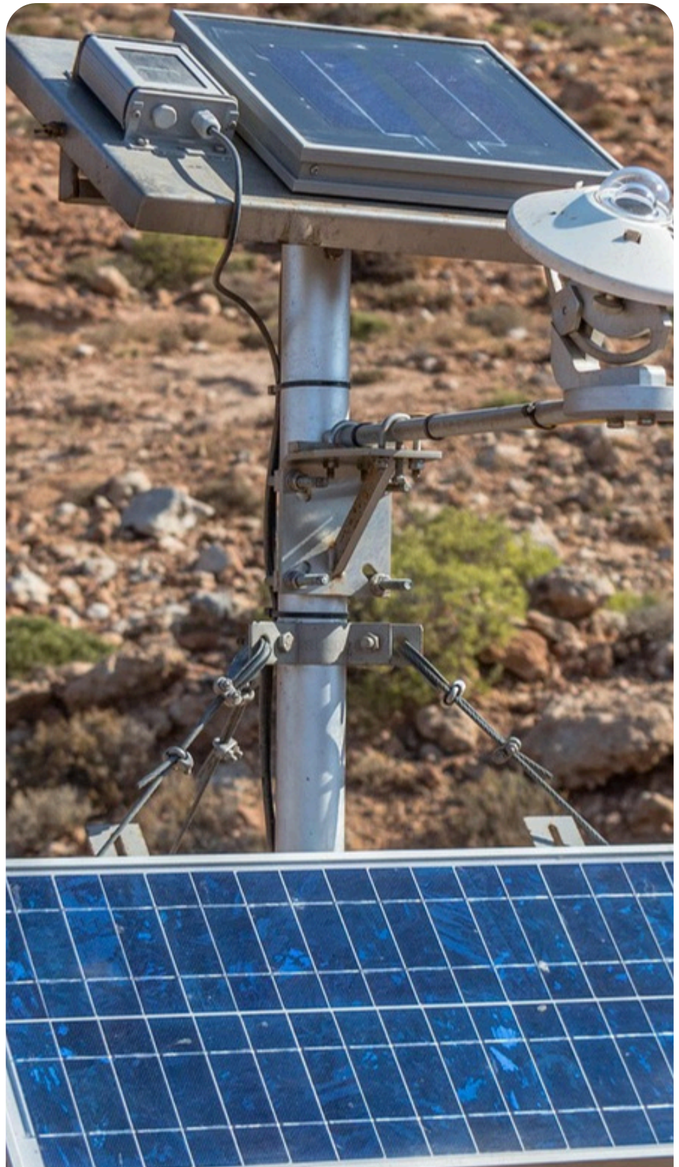
→ Solar, hydro, wind, geothermal.

80% renewable target 2040

→ Goal: 66% energy mix and diversity!

Local innovations and startups

→ Startups in clean energy ~Optimems VPP



Greece's RESI Journey

Tilos Island Case Study

- Combines RES technologies with local small-scale battery storage, smart metering, and demand-side management
- RES supplied over 50% of annual electricity consumption
- Covered ~85% of the island's energy needs
- Potential to achieve 100% renewable energy integration on one small island, and beyond! (Li, 2022)

Thank you for your attention!

Q & A

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