AI and Energy Transition

Principles of AI and use in energy applications

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Energy Transition comes with critical challenges

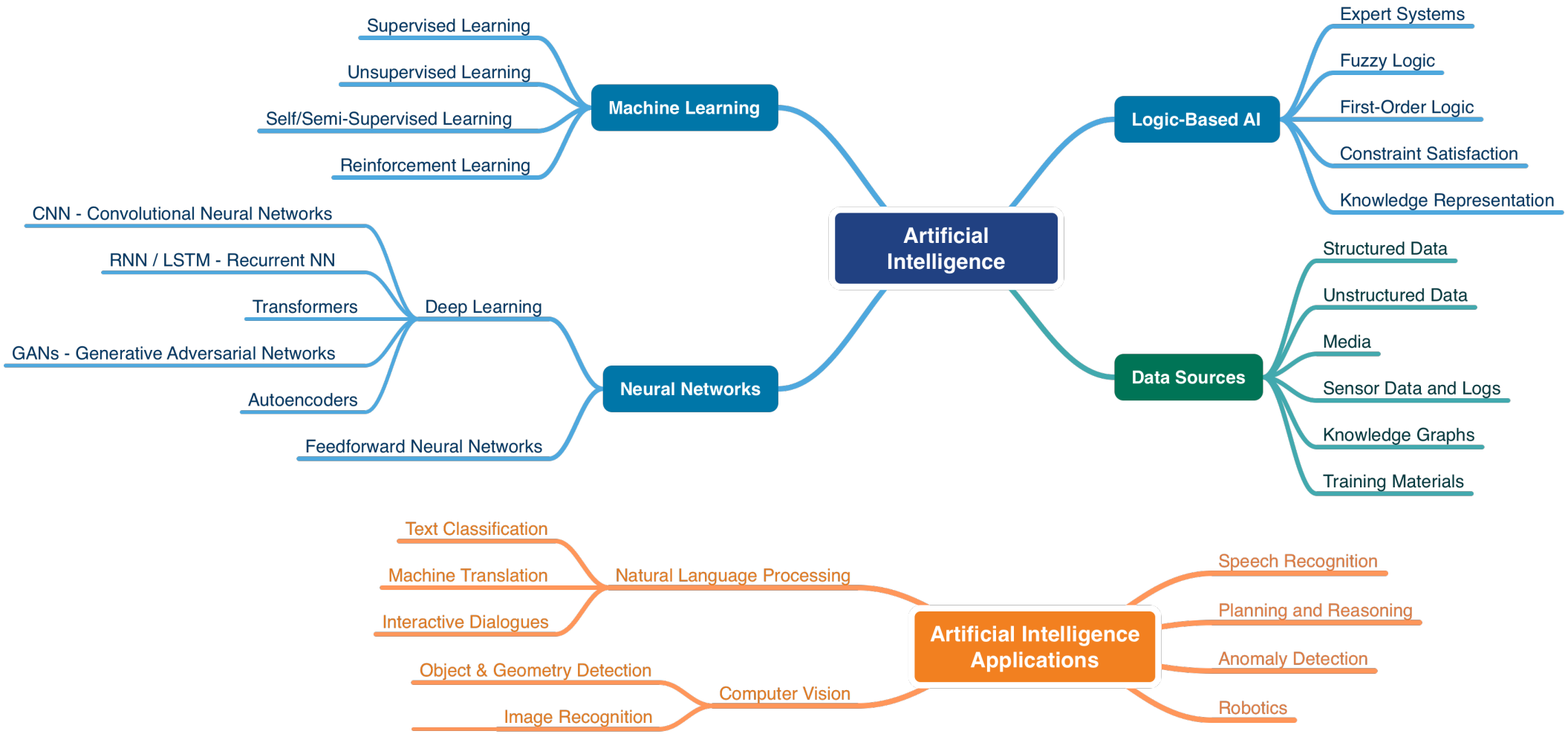
Efficiency calls for resolving all kinds of conflicts:
technical , environmental, social, economical, political

The innovation alphabet

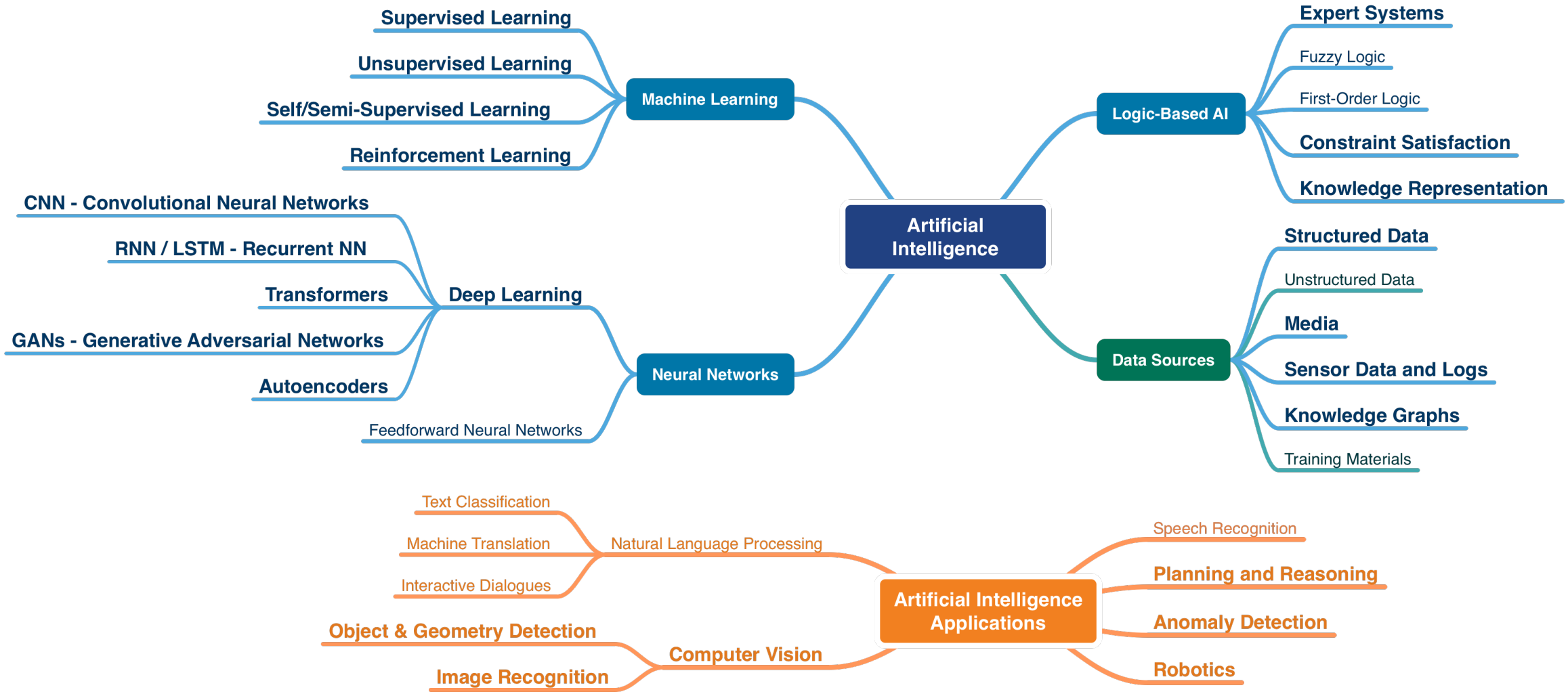
• **AI and related technologies**	➢	**Optimization, forecasting, classification, …**
• **B**lockchain applications	➢	Distributed intelligence + trust, tokenization
• **C**loud-based services	➢	Infrastructures, IoT
• **D**ata science	➢	Data semantics, timeseries management

Keywords: integration, inter-disciplinarity, personalization, hype

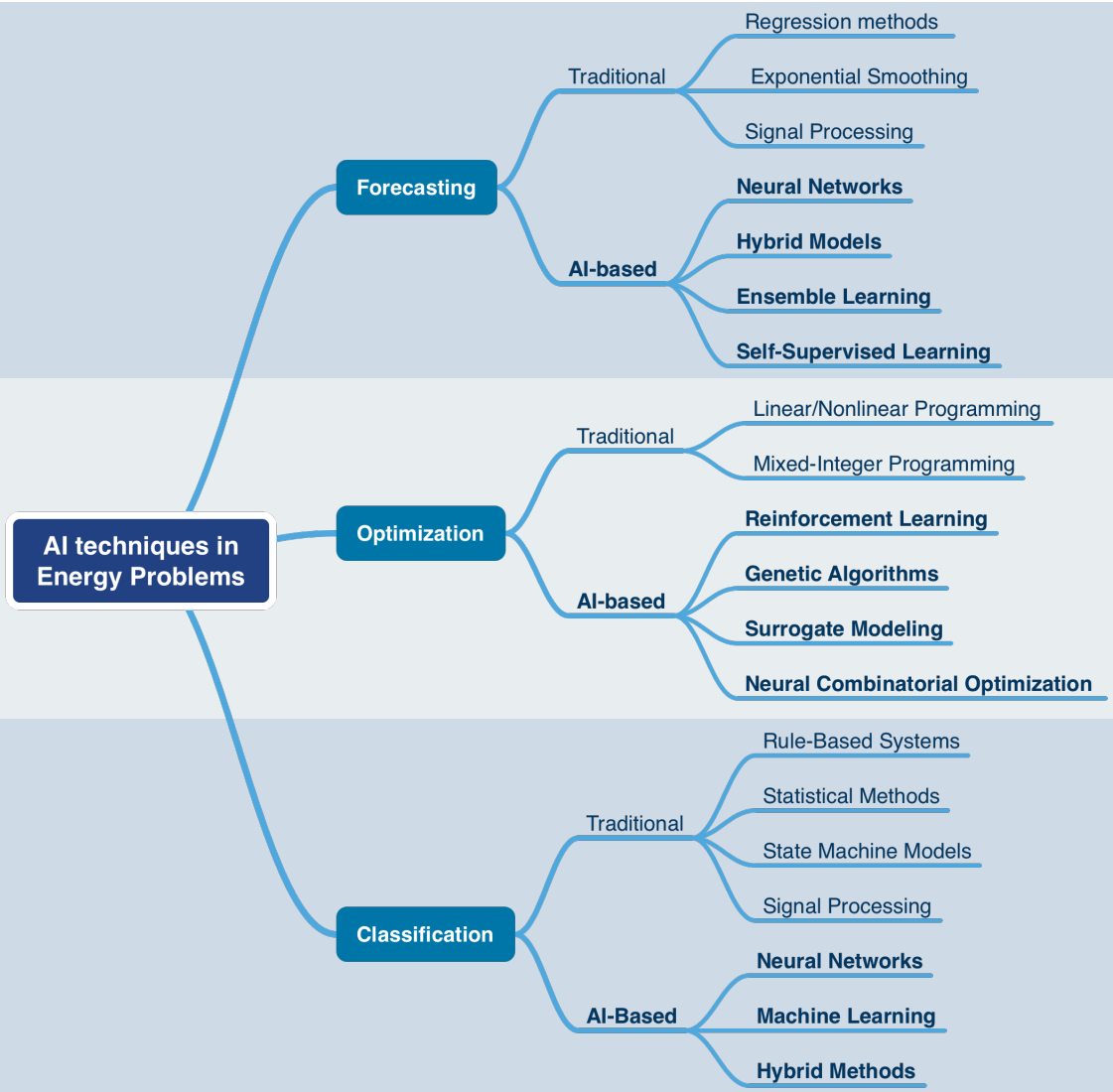
A (very) rough map of AI-related technologies



AI-related technologies: focus on Energy



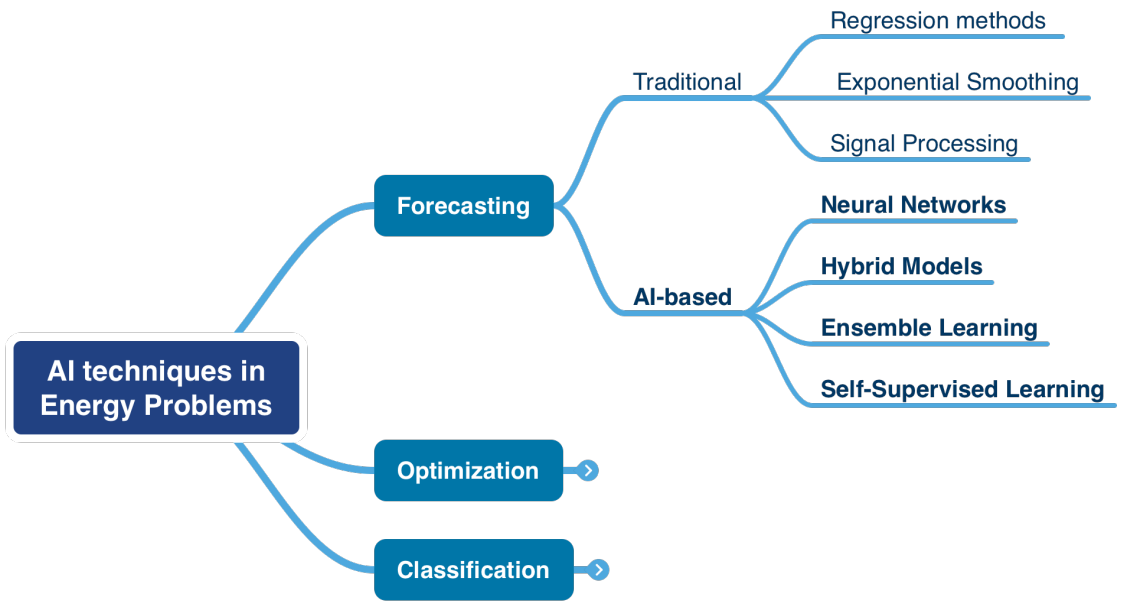
AI Technologies and Energy-Related Applications



Applications

Load (demand)	Domestic consumption
RES generation	EV charging load
Weather	Flexibility & production mix
Price	Vehicle charging
Energy management	Flexibility & production mix
Trading risk management	Vehicle charging
Bidding stategies	Environmental impacts
Storage management	Disaster recovery, Resilience
Energy communities	
Consumer Segmentation	Fault Detection and Classification
Appliance Load	Energy Theft Detection
Power Quality Event Classification	Building Consumption Profiling Classification

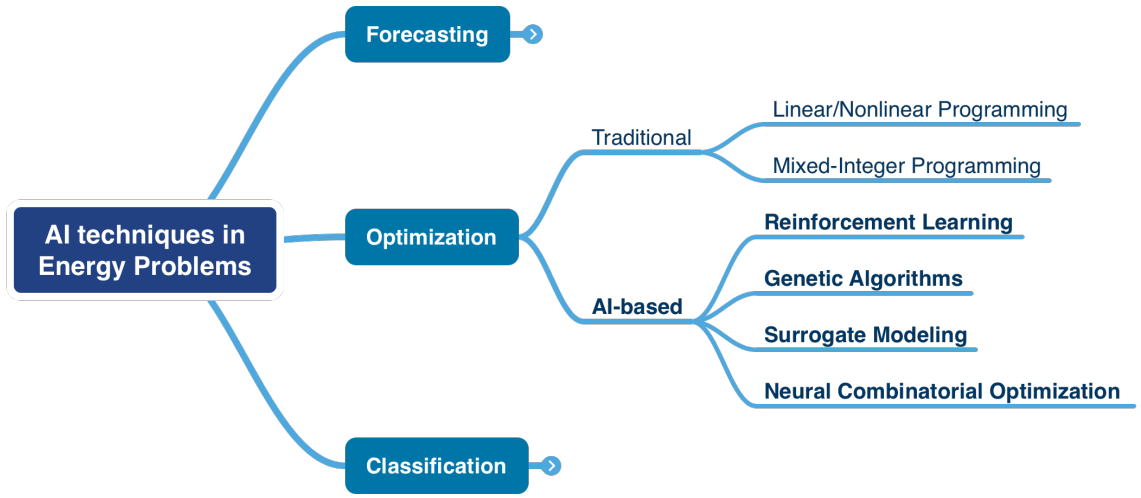
AI Technologies and Energy-Related Applications



Applications – forecasting

- Load (demand)
- RES generation
- Weather
- Price
- Domestic consumption
- EV charging load
- Flexibility & production mix
- Vehicle charging

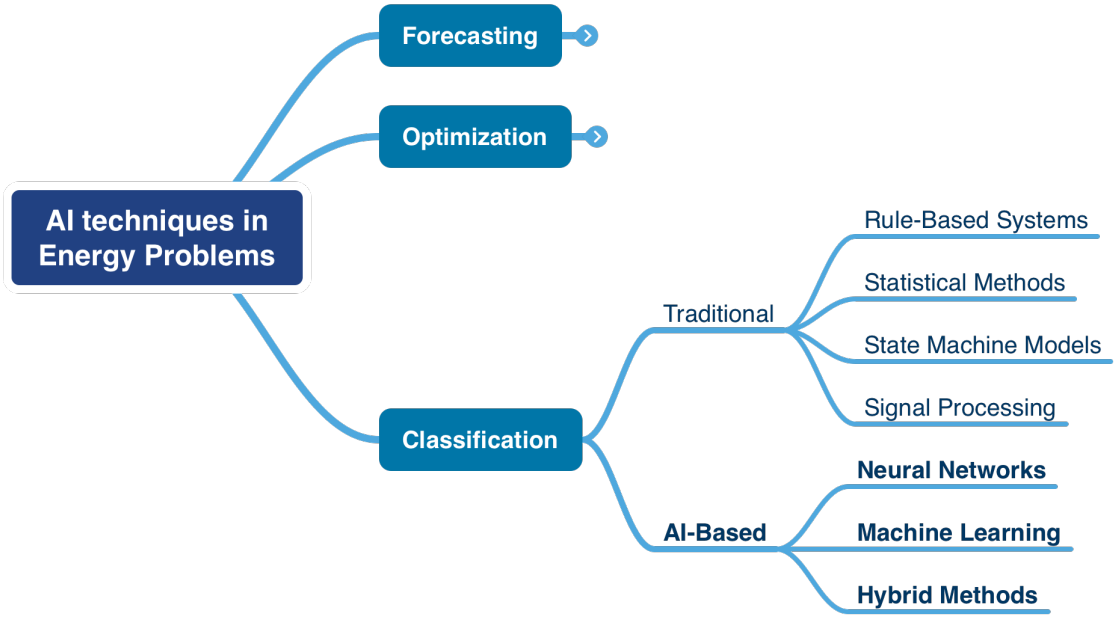
AI Technologies and Energy-Related Applications



Applications – optimization

- Energy management
- Trading risk management
- Bidding strategies
- Storage management
- Energy communities
- Flexibility & production mix
- Vehicle charging
- Automatic control
- Environmental impacts
- Disaster recovery, Resilience

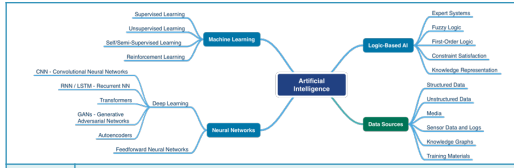
AI Technologies and Energy-Related Applications



Applications – classification

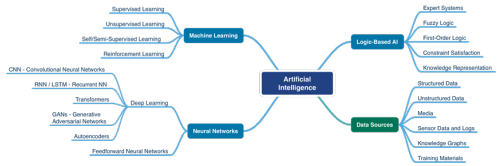
- Consumer Segmentation
- Appliance Load
- Power Quality Event Classification
- Fault Detection and Classification
- Energy Theft Detection
- Building Consumption Profiling

Technologies / Applications (arbitrary, sort of)



		AI					Traditional					
		Neural Networks *	Machine Learning *	Genetic Algorithms	Surrogate Modeling	Neural Combinatorial Optimization	Signal Processing	Linear / Nonlinear / Integer Programming	Rule-Based	Statistical Methods	State Machines
Forecasting	Load (demand)	●	●		●		●	●		●	
	RES generation	●	●		●		●	●		●	
	Weather	●	●							●	
	Price	●	●	●	○		○			○	
	Domestic consumption	●	●		○		●			●	
	EV charging load	●	●				●	●		○	●
	Flexibility & production mix	●	●		●	●		●		○	
	Vehicle charging	●	●		●	●	●	●		○	●
Optimization	Energy management	●	●	●	●	●	●	●	●		●
	Trading risk management		●	●				●	●	●	
	Bidding strategies		●	●		●		●	●		
	Storage management	●	●	●	●	●		●			●
	Energy communities		●	●				●	●	○	○
	Flexibility & production mix	●	●	●	●	●		●			
	Vehicle charging	●	●		●	●		●			●
	Environmental impacts	●	●	●	●					●	
	Disaster recovery, Resilience	●	●		●		●	●	●		●
Classification	Consumer Segmentation	●	●						○	●	
	Appliance Load	●	●				●			●	●
	Power Quality Event	●	●				●		●	●	●
	Fault Detection	●	●		●		●	●	●	●	●
	Energy Theft Detection	●	●				●		●	●	●
	Buildings' Consumption Profiling	●	●				●			●	

Technologies / Applications (arbitrary, sort of)



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	RES generation	●	●		●		●	●		●	
	Weather	●	●							●	
	Price	●	●	●	○		○			○	
	Domestic consumption	●	●		○		●			●	
	EV charging load	●	●				●	●		○	●
	Flexibility & production mix	●	●		●	●		●		○	
	Vehicle charging	●	●		●	●	●	●		○	●

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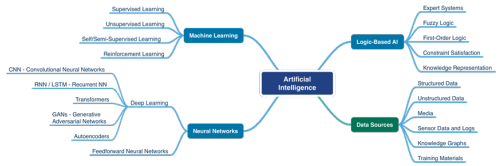

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Optimization	Energy management	●	●	●	●	●	●	●	●		●
	Trading risk management		●	●				●	●	●	
	Bidding strategies		●	●		●		●	●		
	Storage management	●	●	●	●	●		●			●
	Energy communities		●	●				●	●	○	○
	Flexibility & production mix	●	●	●	●	●		●			
	Vehicle charging	●	●		●	●		●			●
	Environmental impacts	●	●	●	●					●	
	Disaster recovery, Resilience	●	●		●		●	●	●		●

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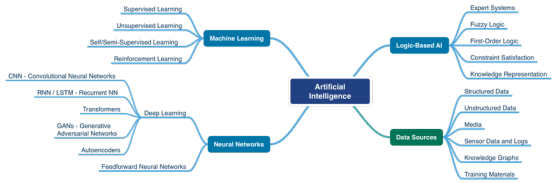

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	Appliance Load	●	●				●			●	●
	Power Quality Event	●	●				●		●	●	●
	Fault Detection	●	●		●		●	●	●	●	●
	Energy Theft Detection	●	●				●		●	●	●
	Buildings' Consumption Profiling	●	●				●			●	

Case: hybrid storage management

RES curtailments are here to stay

- Consider hybrid (BESS, H2) storage

Optimization targets

- Maximize revenue, minimize RES rejections
- RES & BESS CAPEX amortization

Business value

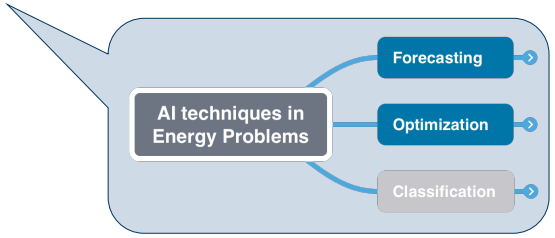
- Long-term planning, new incentives
- Policy and regulatory aspects
- Efficient planning and operation of RES
- New H2 business

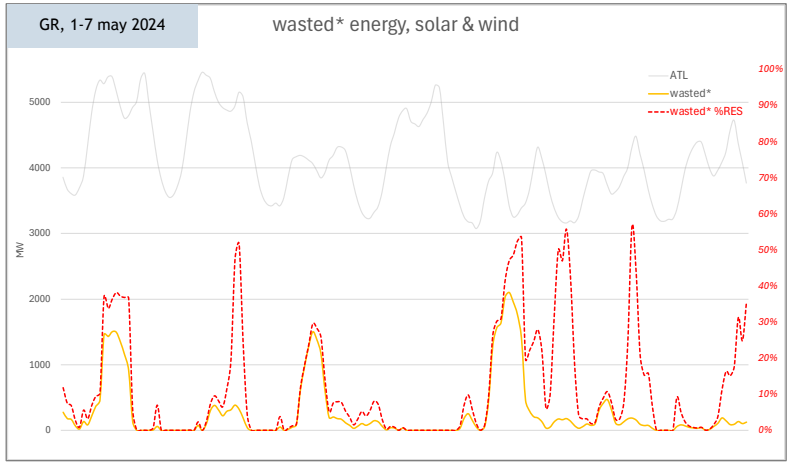
Input: Data, Constraints, Assumptions…

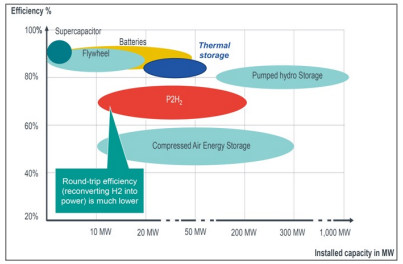
- Production & Price scenarios
- CAPEX & OPEX
- Dimensions and analysis time windows
- Constraints (market, technical, custom)

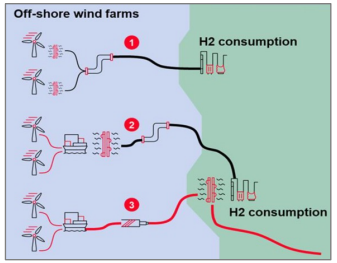
Output: Energy management to…

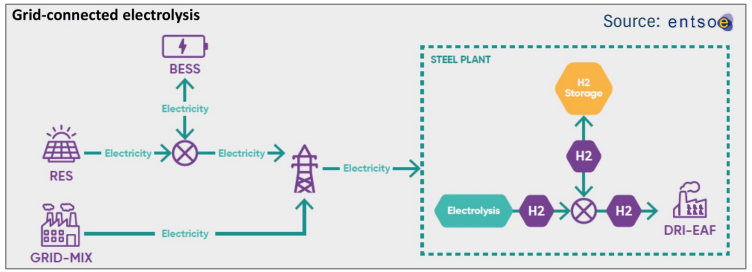
- Minimize curtailed RES
- Maximize H2 production
- Maximize revenue
- CAPEX amortization

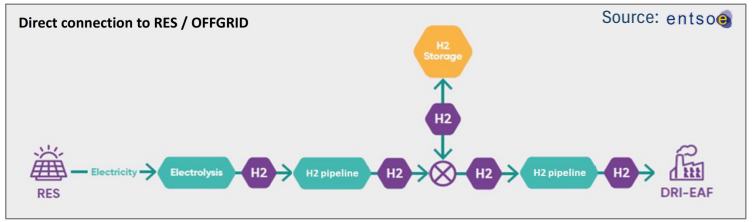


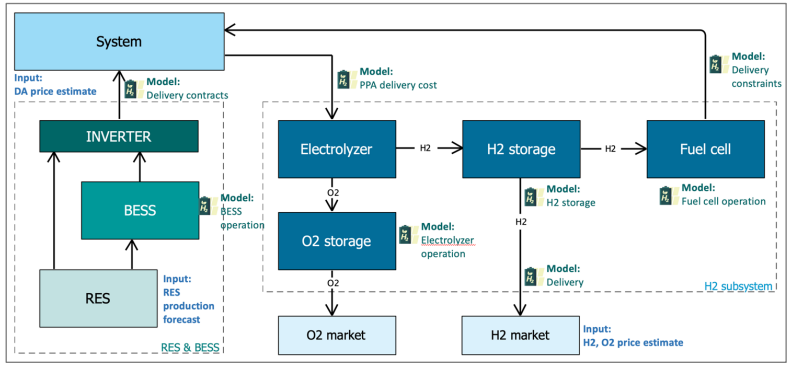


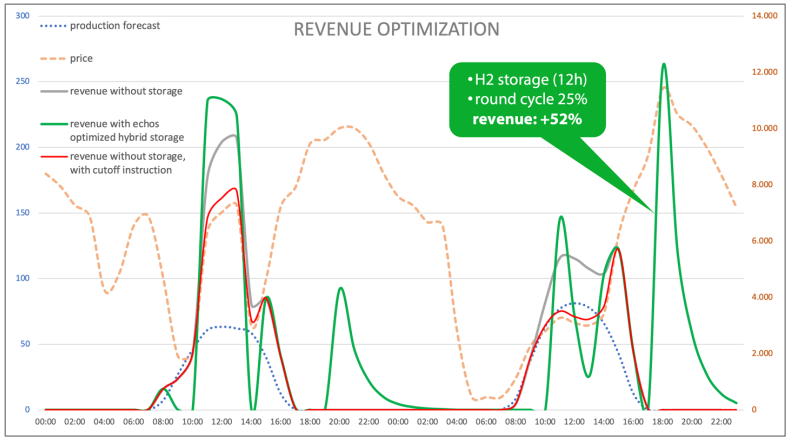




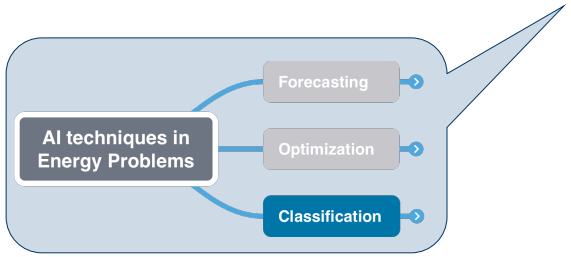


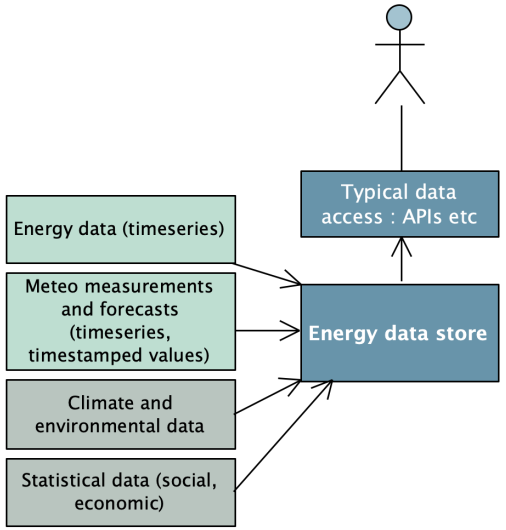




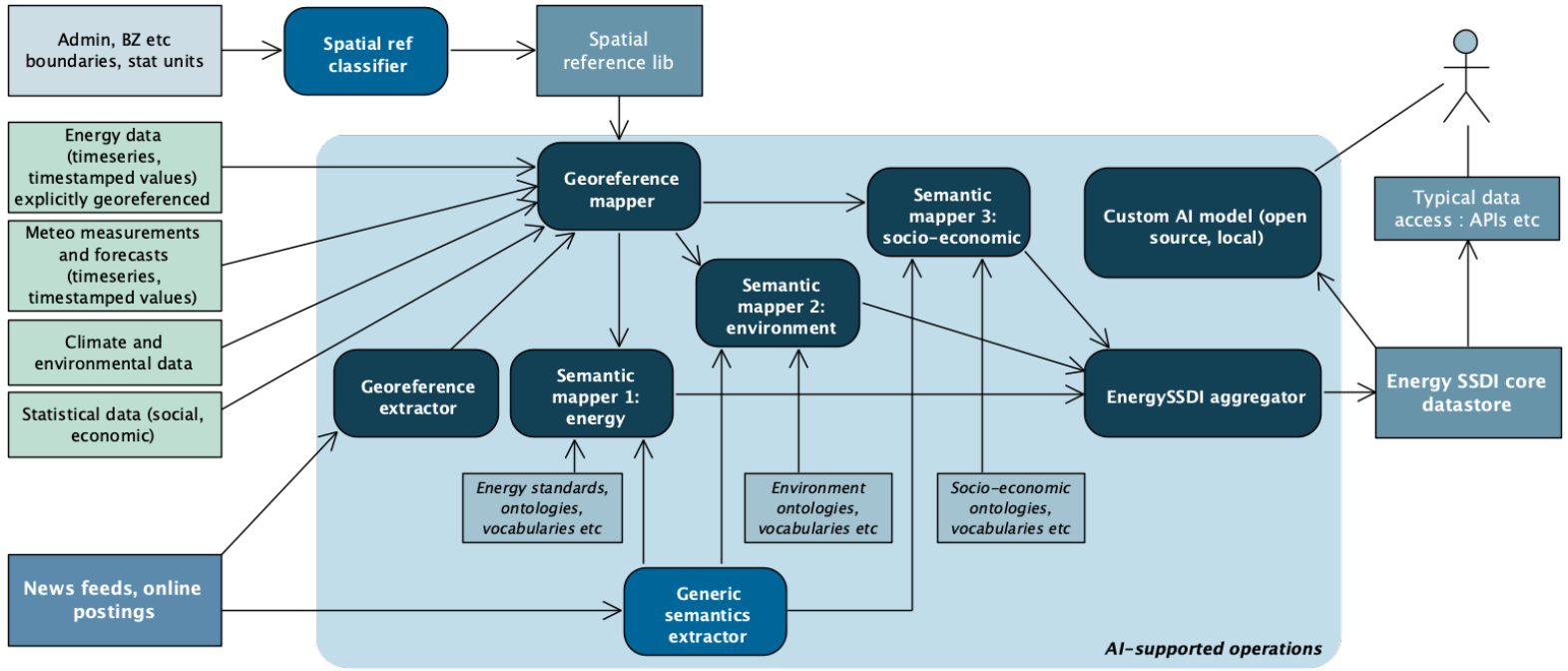


Case: Semantic Spatial Data Infrastructures for Energy



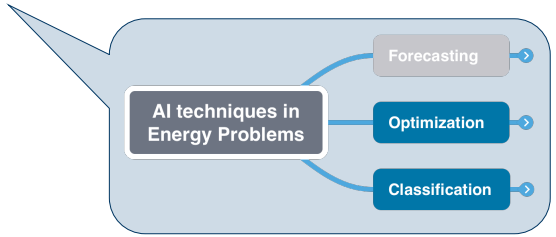


Legacy energy data infrastructures



Modern energy data infrastructures

Case: Semantics of energy timeseries

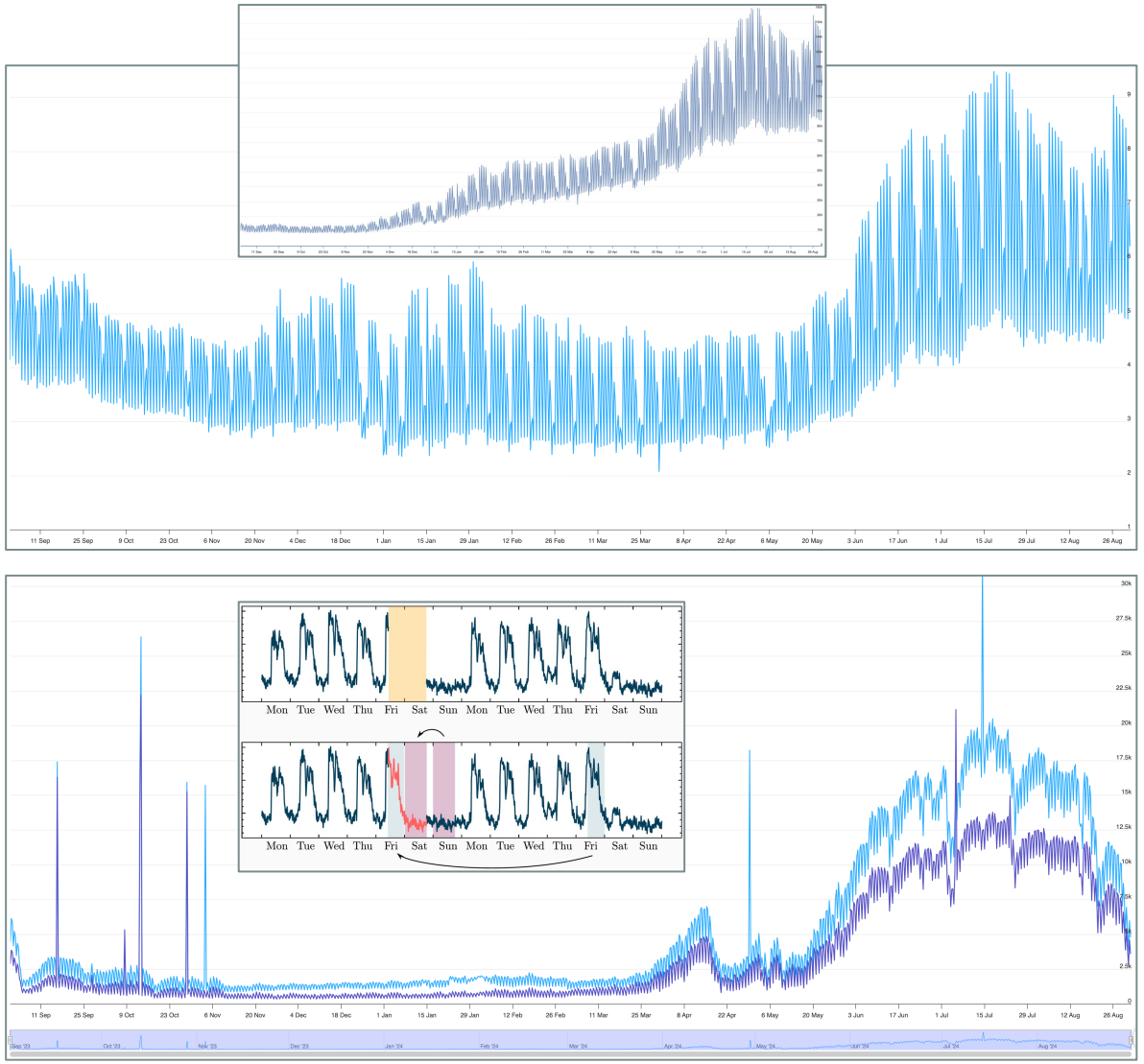


Tools

- AI: NNs, ML
- Traditional signal processing methods

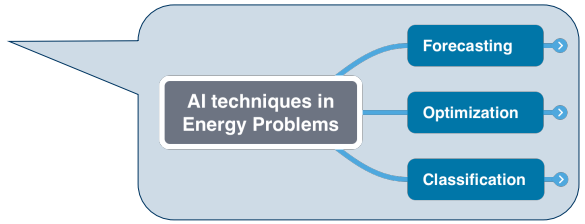
Cases

- Consumer profiling & classification
- Timeseries Business Intelligence
- Regulatory decision support
- Context-aware sanitization
- Semantics-based timeseries imputation



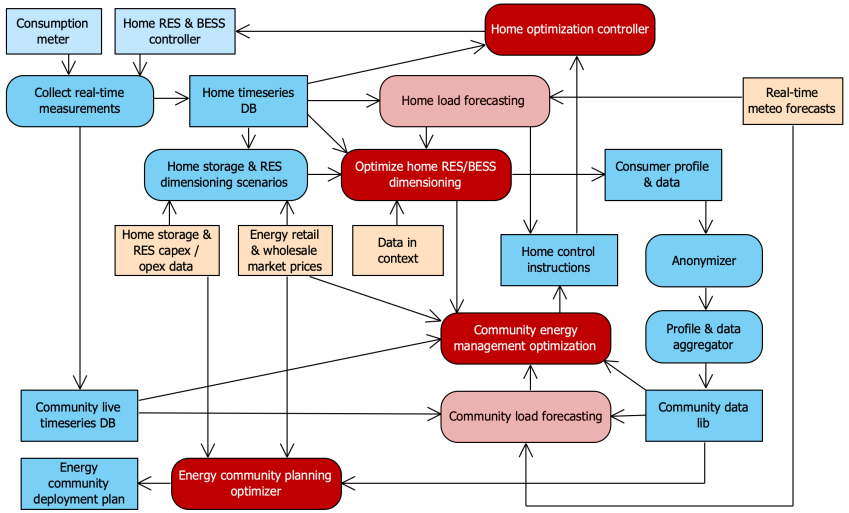
Credits: HEDNO regulatory affairs directorate,

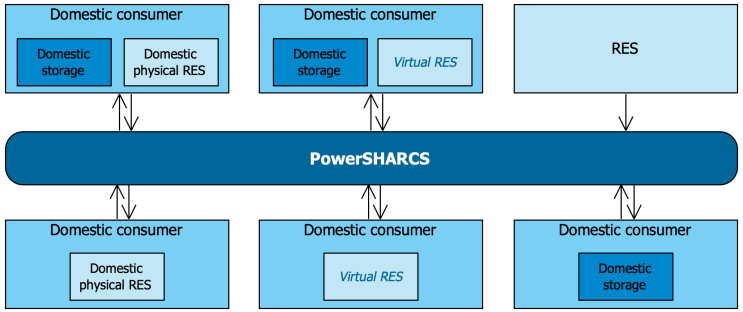
Case: intelligent energy communities

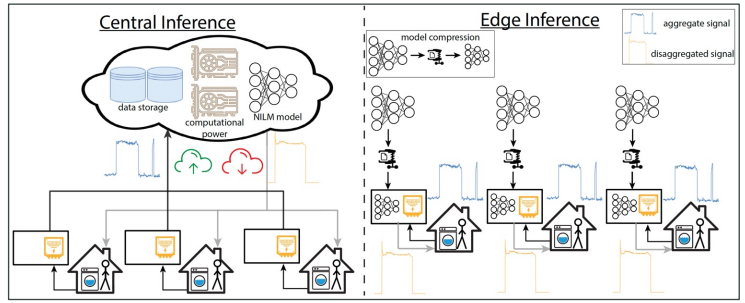


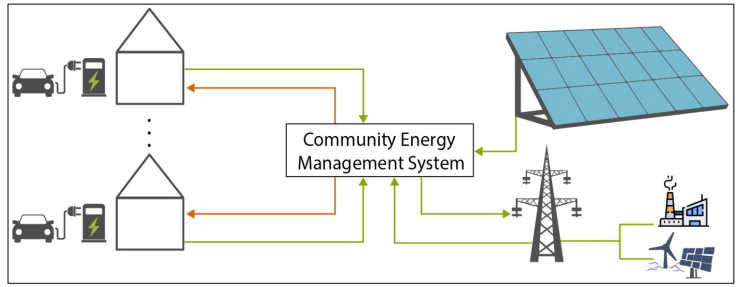
Concept

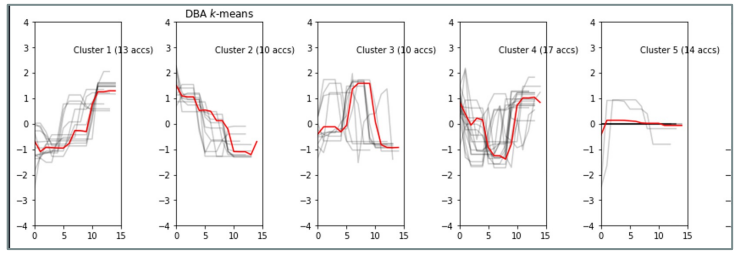
- Autonomous energy (DAO) communities by domestic participants
- Micro-forecasting and optimization
- Continuous profiling at consumer- and community-level
- Sharing of storage & physical home RES
- Virtual RES production from curtailments & PPAs
- Extensive data management











Credits: PowerSHARCS proposal (NTUA, QUBITEQ), Avocado AI

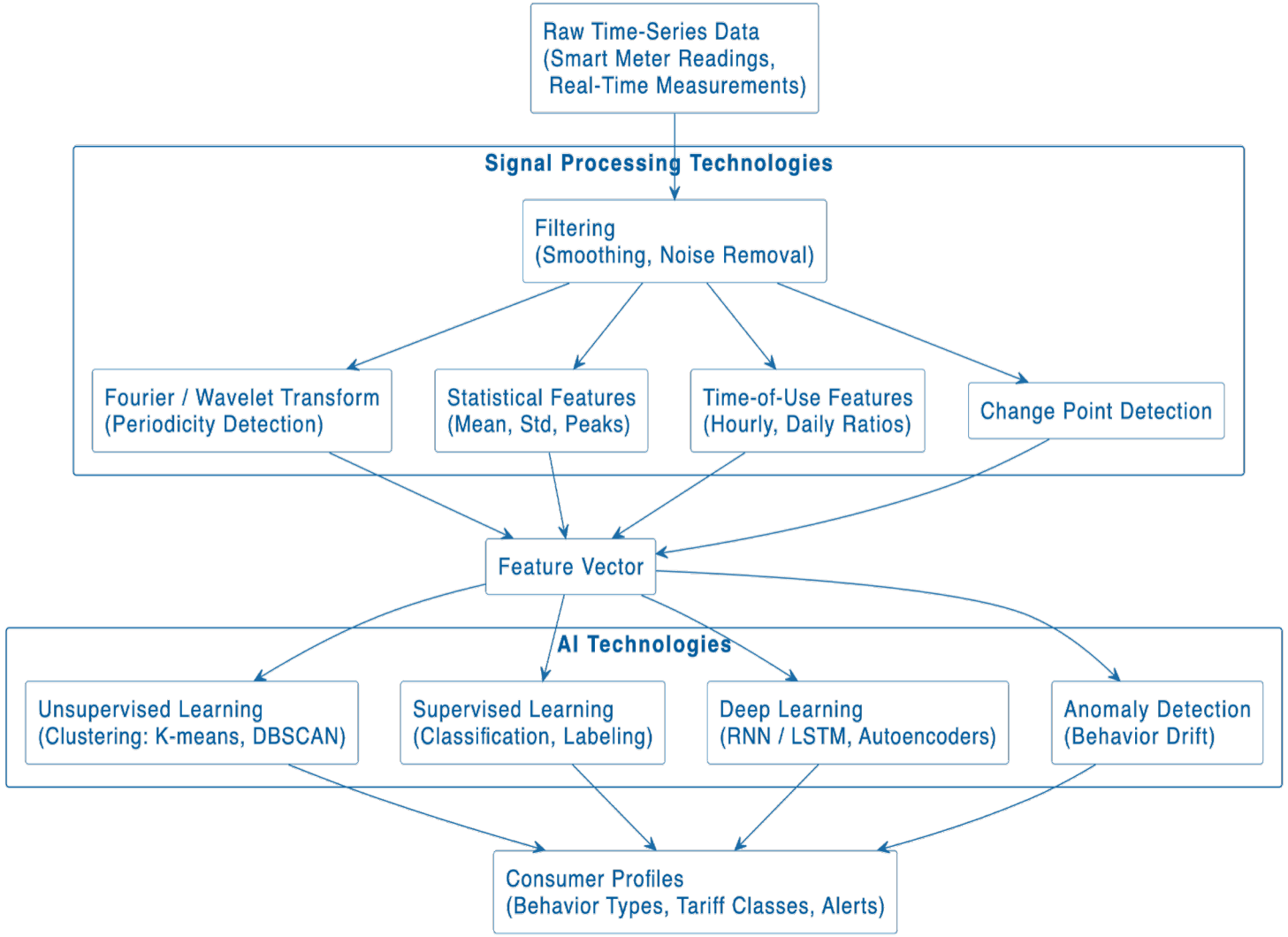
AI + Signal Processing for Energy Profiling

Signal processing for...

- Timeseries management
- Noise removal
- Imputation
- Feature extraction

AI for...

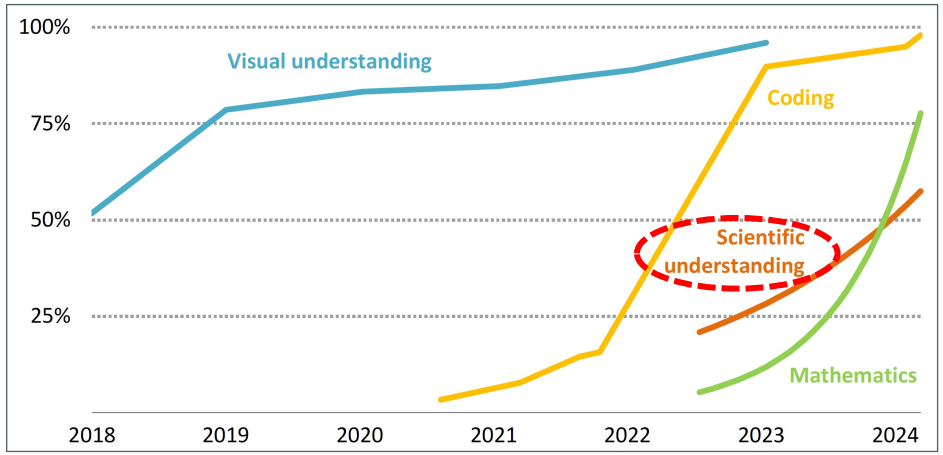
- Forecasting
- Classification
- Optimization



Notable points

AI is very relevant, but it is not a panacea

- AI tariff models are still to be discovered
- QA, liability and ethics of AI
- Need for domain-based assessment of AI tools
- Marketing + politics = hype



Source: IEA 2025

Traditional methods are not dead

- Current technologies (signal processing, optimization methods, etc) still are, and will always be relevant
- Existing & working solutions should still be used, possibly together with AI

Quality of data is a key issue in both AI and traditional methods

AI and Energy Transition

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