Large scale integration of renewable energy systems into electricity markets

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  - 2020, 2030, 2050
- **Challenges in electricity markets**
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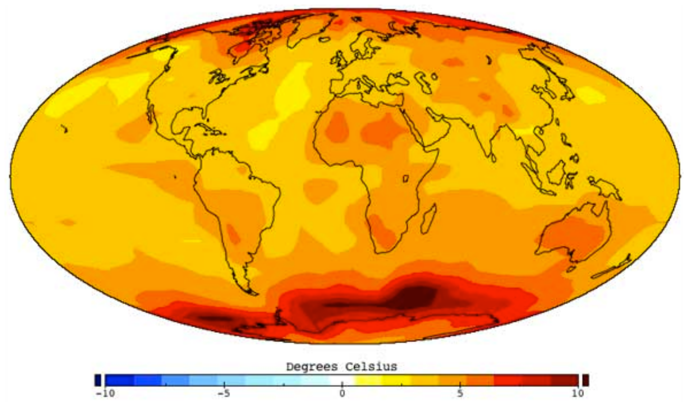
  - NG and storage
- **Modeling for optimum large scale integration of RES**
  - Simulation of RES operation
  - Integration of storage

EU energy strategy

2020, 2030, 2050

Future energy systems

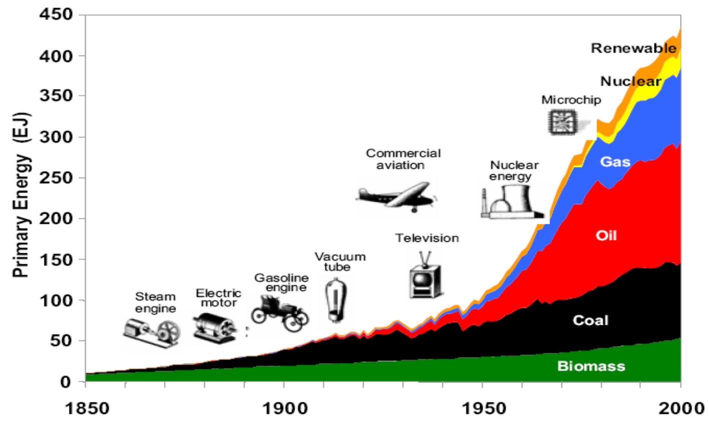
- **Climate change**



- **Third energy revolution**
- **Future energy economics**

EU energy objectives

- greenhouse gas reduction
- sustainable production and consumption
- competition in electricity and natural gas markets
- security of supply



EU medium and long term targets

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2020

- **-20 %** Greenhouse Gas Emissions
- **20%** Renewable Energy
- **20 %** Energy Efficiency
- **10 %** Interconnection

2030

- **≥ - 40 %** Greenhouse Gas Emissions
- **≥27 %** Renewable Energy
- **≥ 27%*** Energy Efficiency
- **15 %** Interconnection

* To be reviewed by 2020, having in mind an EU level of 30%

New governance system + indicators

2050 **-80%** **Greenhouse Gas Emissions**

EU reduction in greenhouse gas emissions

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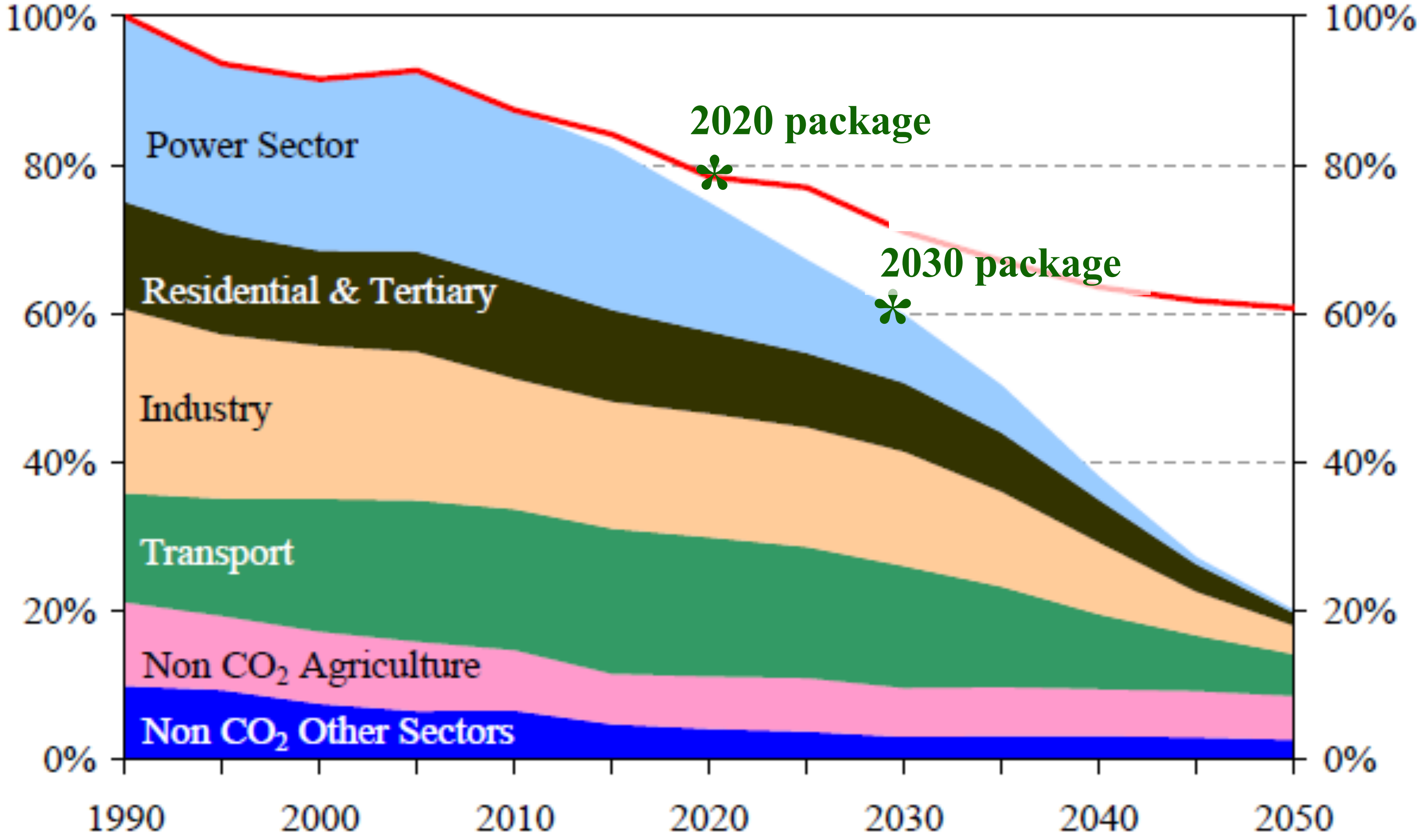

Our 3D energy future

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Decarbonisation:

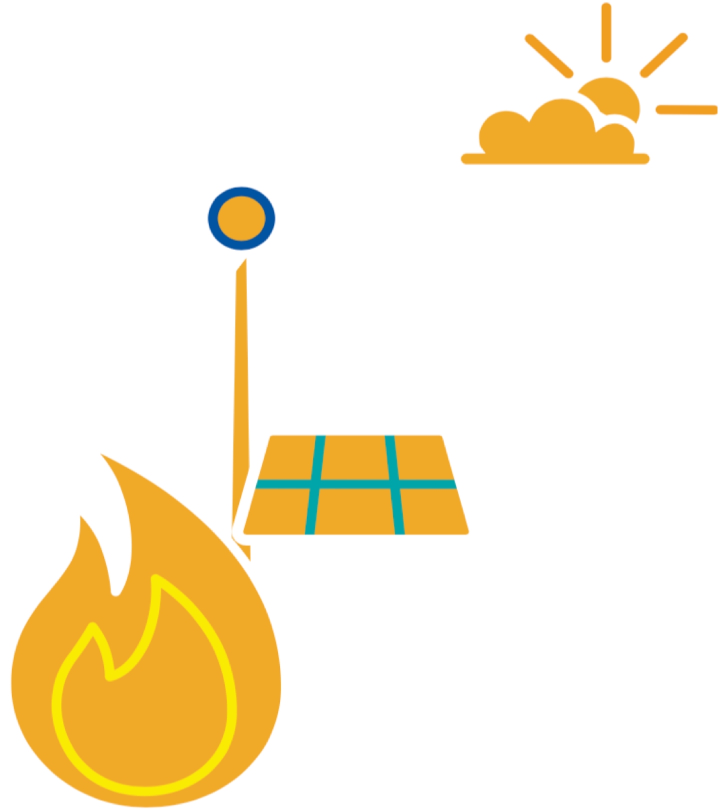
oil/coal-to-gas switch, renewable gas, wind and sun, carbon capture and usage

Decentralisation:

Solar panels, micro-CHPs/fuel cells, storage via power-to-gas and batteries

Digitalisation:

ICT for smart households and smart gas/electricity grids



- **Extrapolating developments of the past does not forecast the future**
- **Gas, wind and sun – providing Europe with clean heat, electricity and transport**

Current energy system

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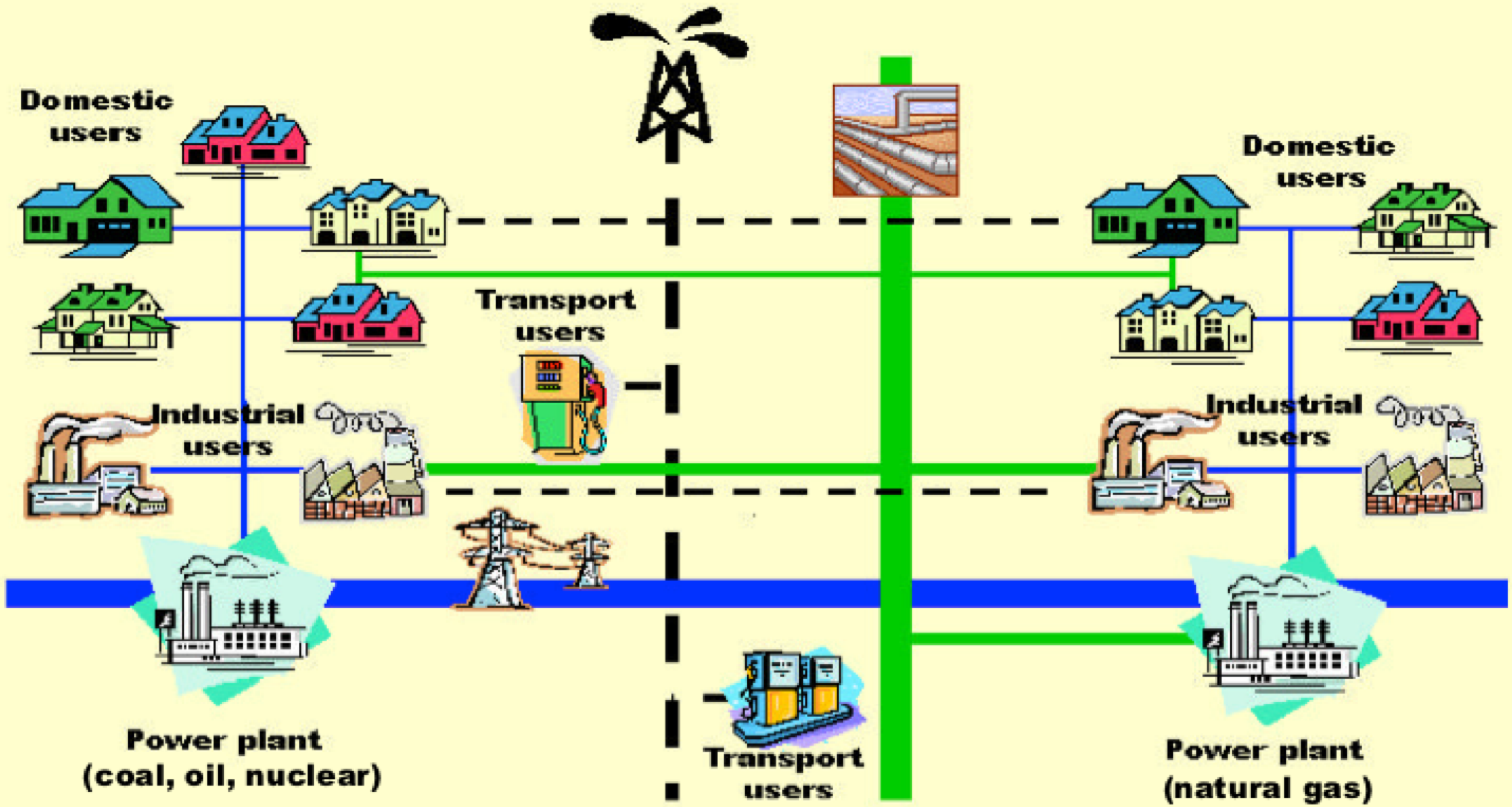
EU energy system today*



* Poullikkas A., 2009, *Introduction to Power Generation Technologies*, ISBN: 978-1-60876-472-3

Future energy systems (optimistic scenario)

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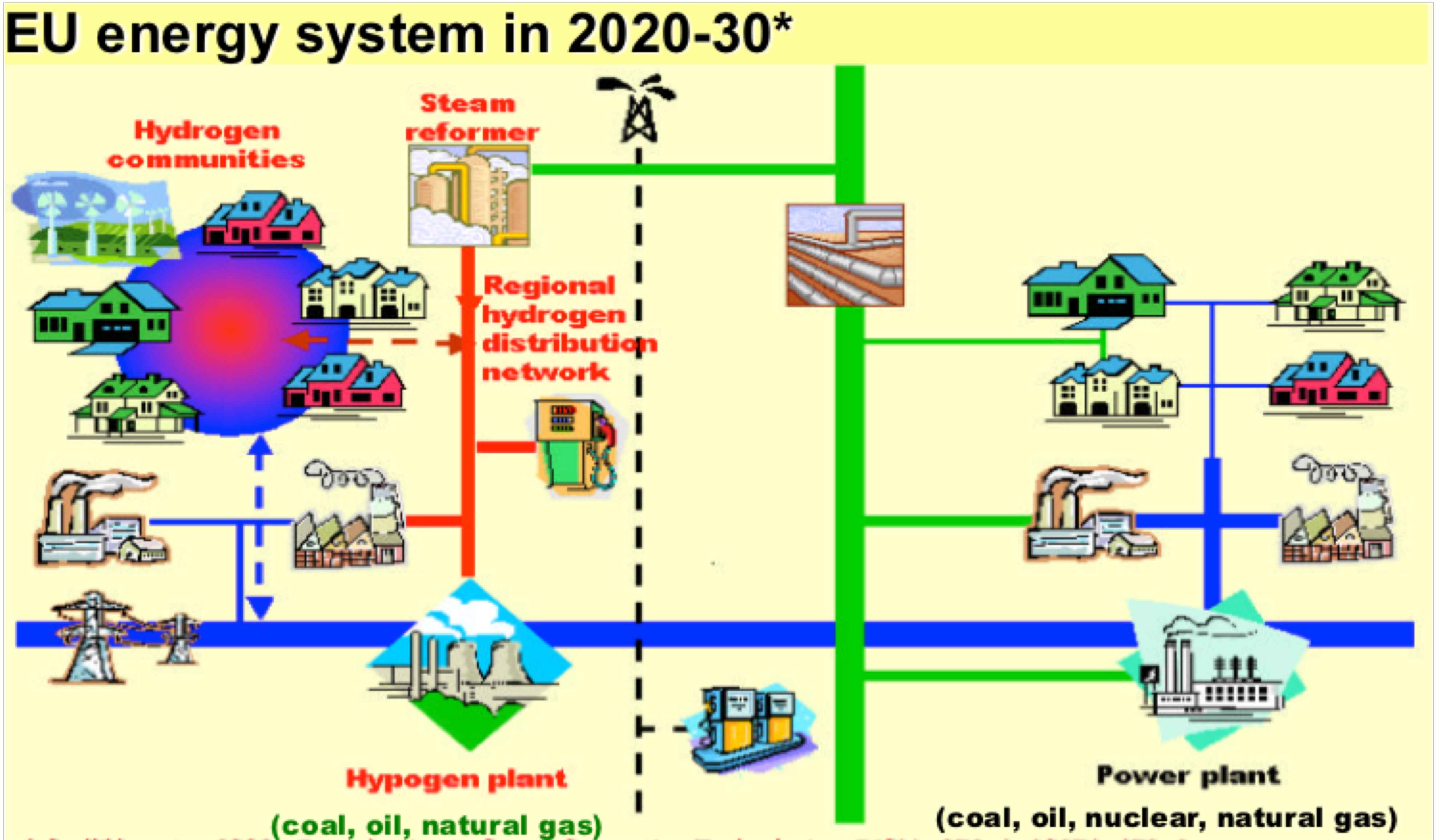

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Future energy systems (optimistic scenario)

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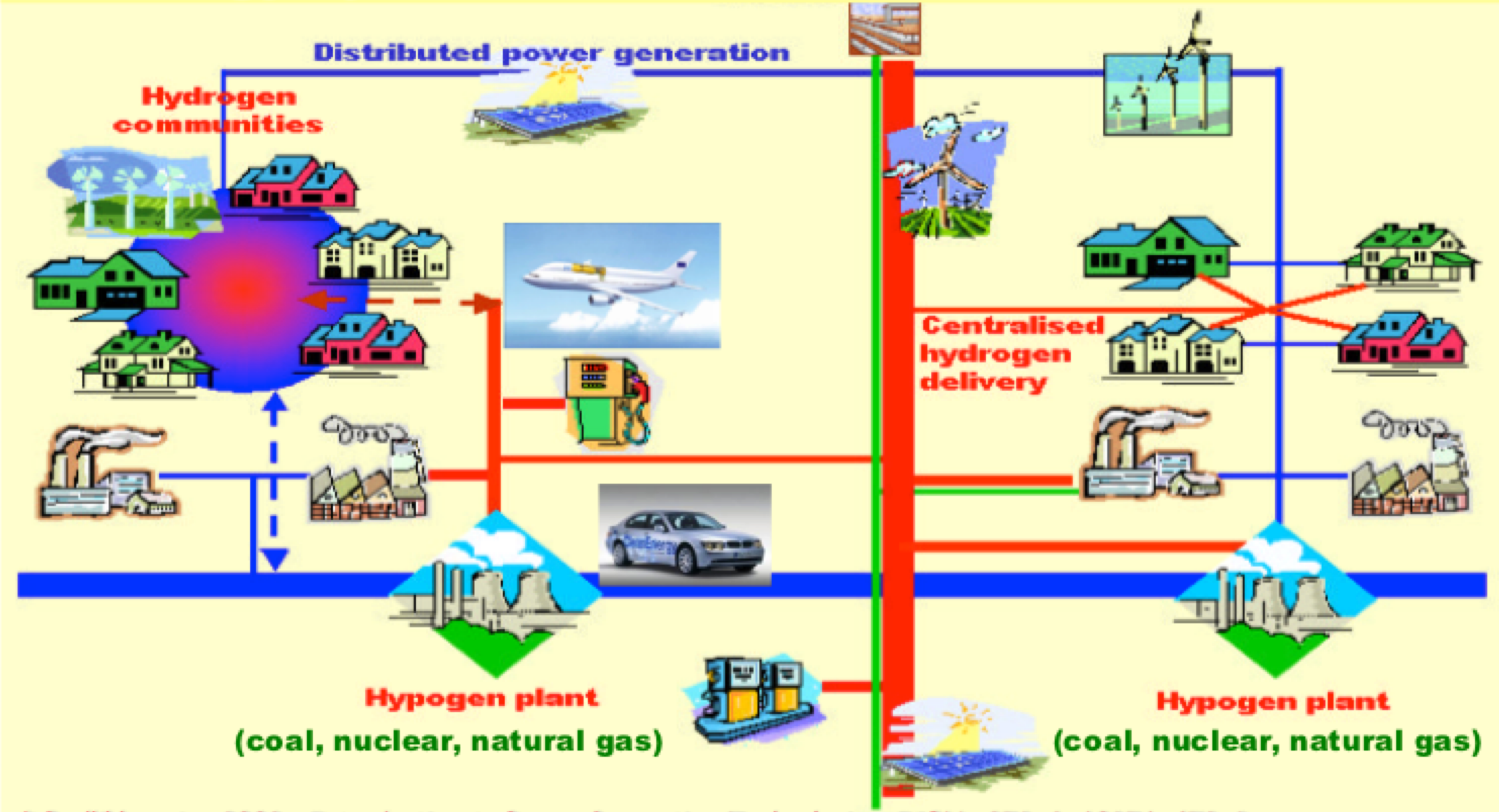
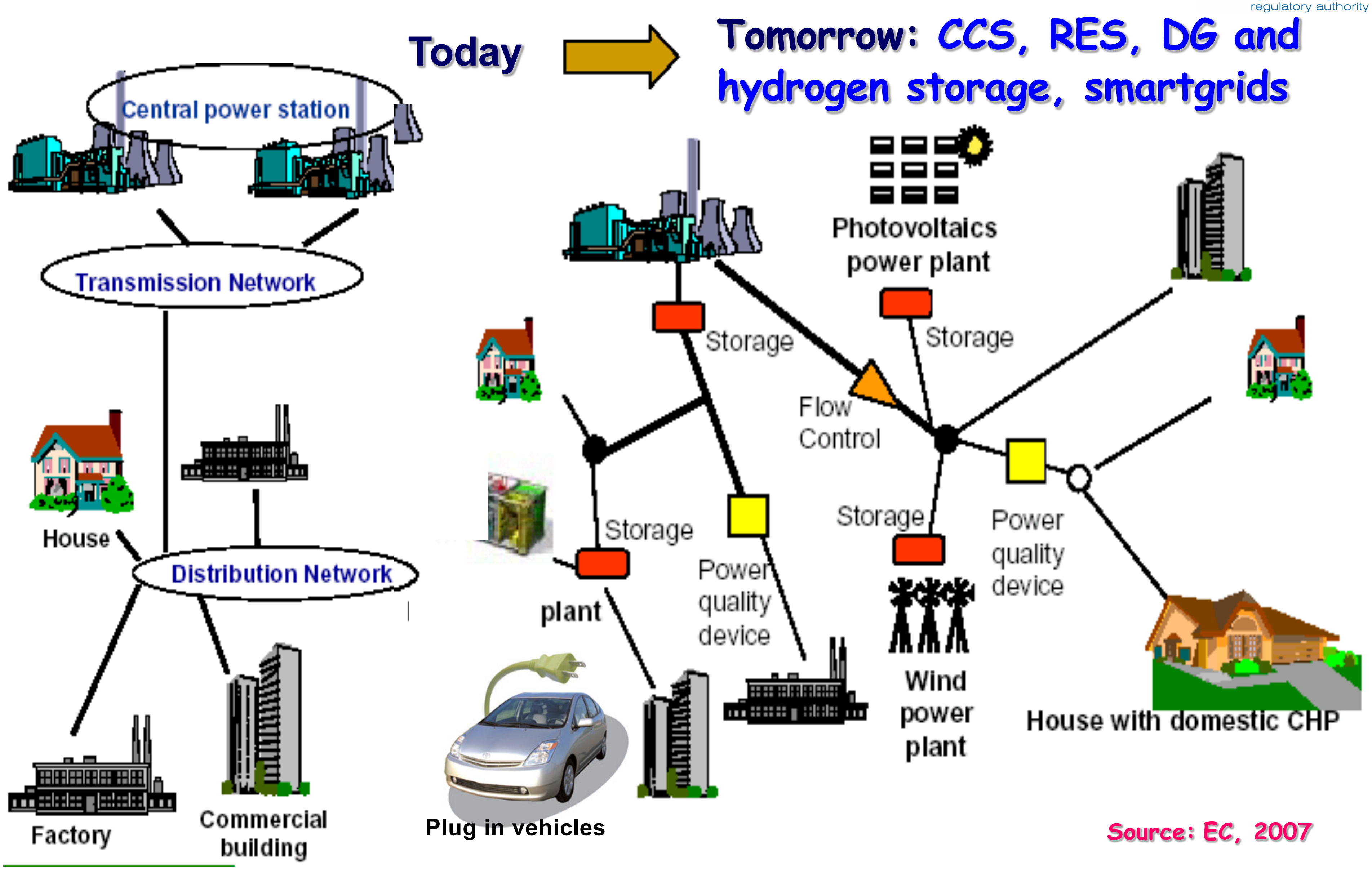
EU energy system in 2040-50*

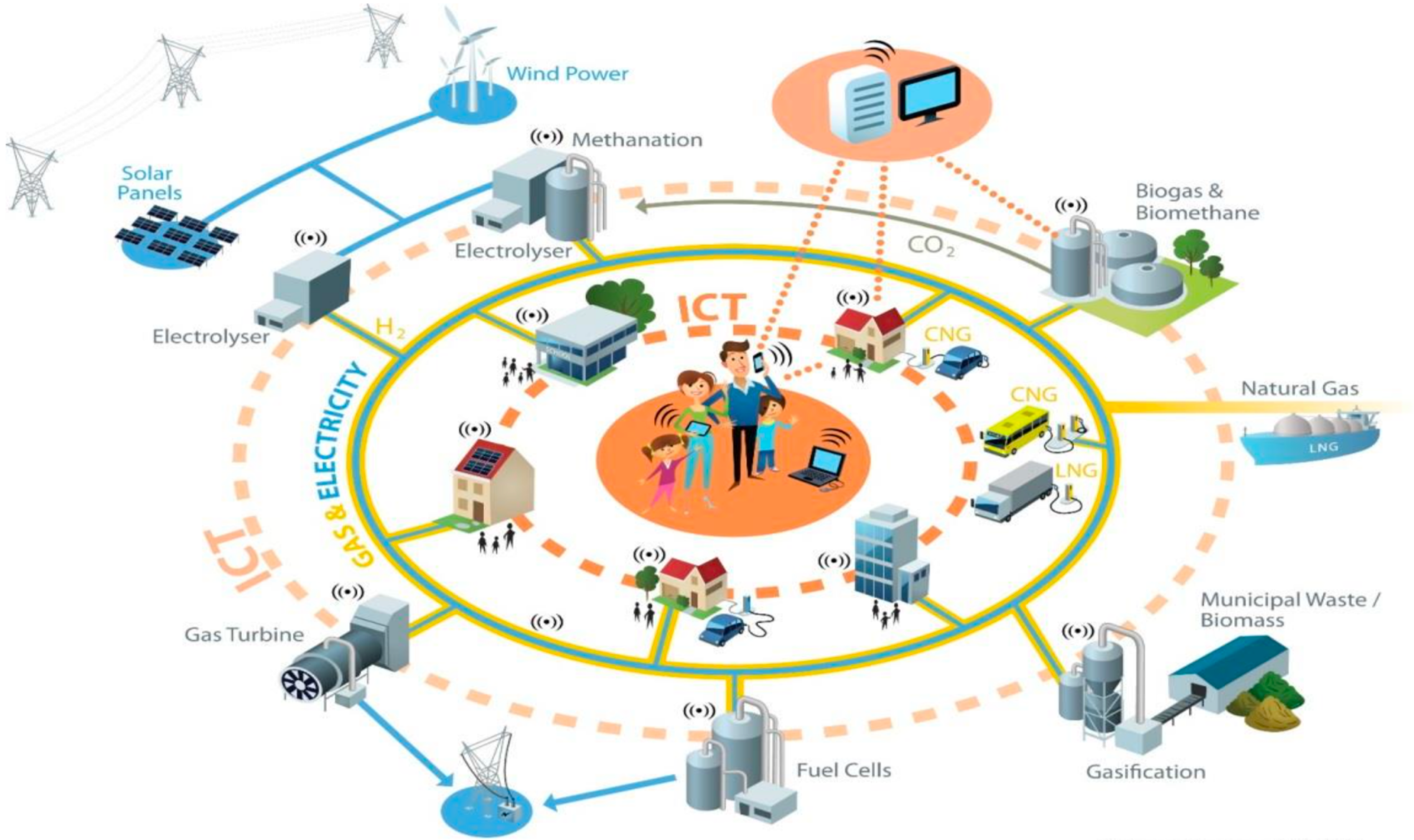


* Poullikkas A., 2009, *Introduction to Power Generation Technologies*, ISBN: 978-1-60876-472-3

Future power systems

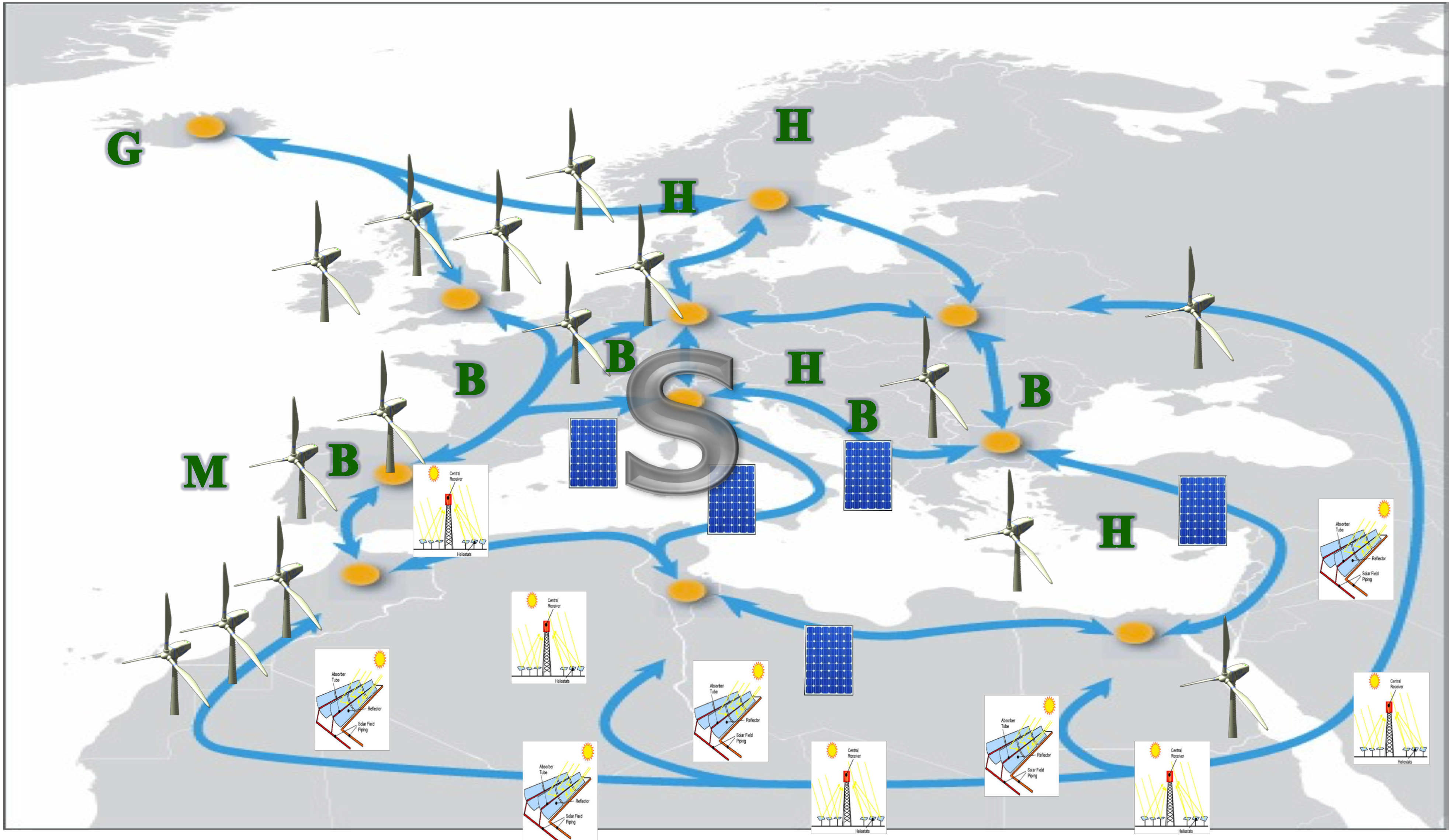


End goal – the smart future



The Super Smart Grid after 2050*

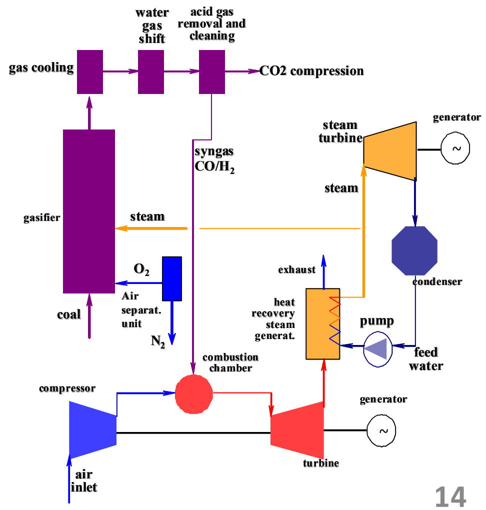
(may allow for 100% RES)



* Poullikkas A., 2013, *Sustainable Energy Development for Cyprus*, ISBN: 978-9963-7355-3-2

Long term EU energy strategy (2050)

- **A vision of carbon free EU**
- **Main ingredients of future sustainable energy systems:**
  - Large scale integration of renewable energy sources
  - Distributed generation
  - Carbon capture and storage
  - Smartgrids
  - Electric vehicles
  - Storage devices
  - Hydrogen

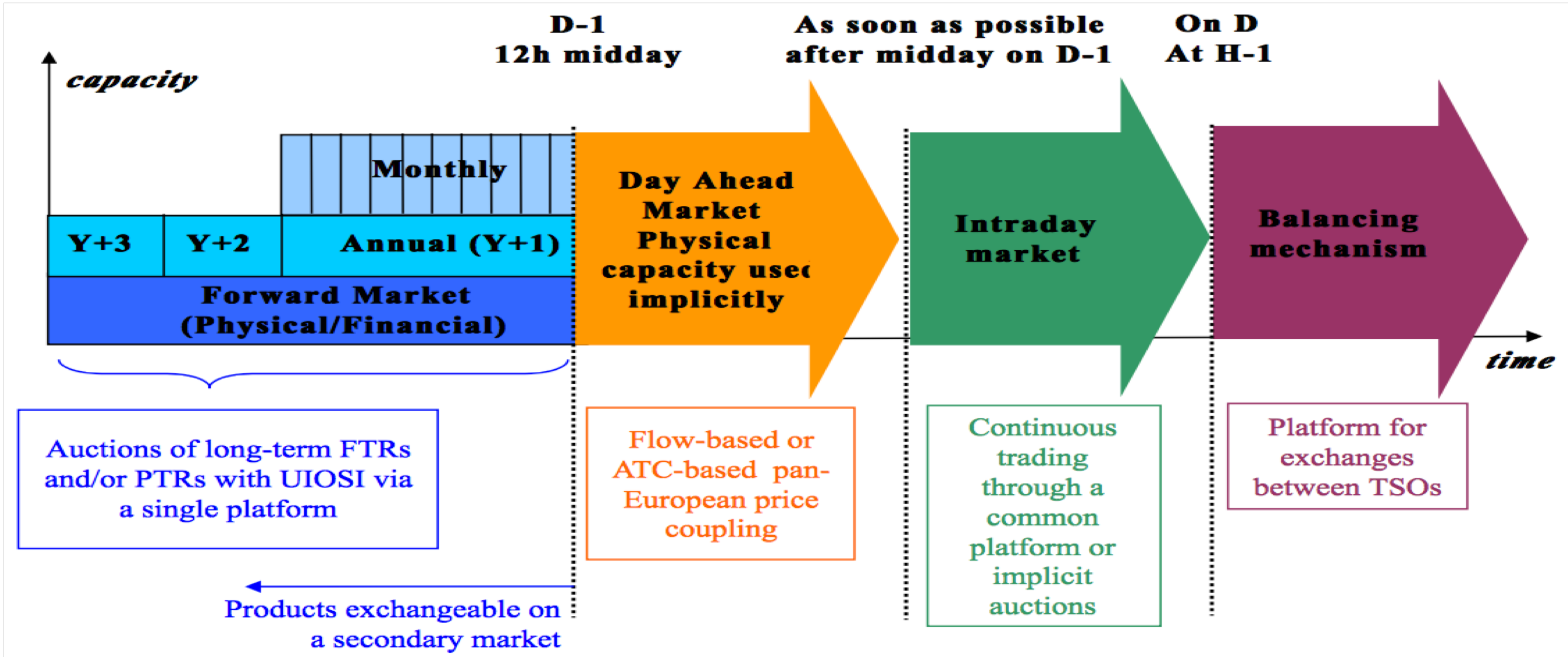


Need to develop advanced simulation tools, new sustainable technologies and infrastructure !!

Challenges in electricity markets

RES integration

EU electricity market target model



Integration of RES: LCOE *vs* Reliability

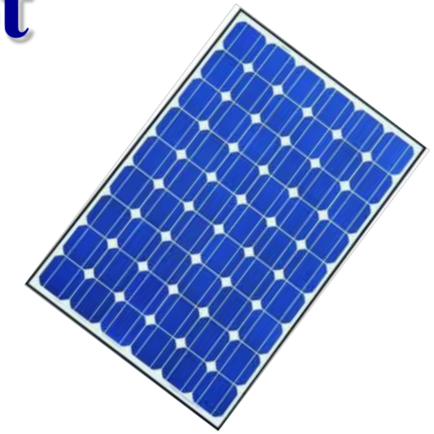
Power system reliability*

- **adequacy**, PS ability to satisfy customers needs both in power and electrical energy
- **security**, PS ability to remain in operation after sudden disturbances

* Poullikkas A., 2016, *Fundamentals of Energy Regulation*, ISBN: 978-9963-7355-8-7

Intermittent energy source*

- Any source of energy that is not continuously available



- May be quite predictable
- Cannot be dispatched to meet the demand of a power system

- For dispatching need storage

* Poullikkas A., 2013, *Renewable Energy: Economics, Emerging Technologies and Global Practices*, ISBN: 978-1-62618-231-8

Daily load curve (the 'camel curve')*

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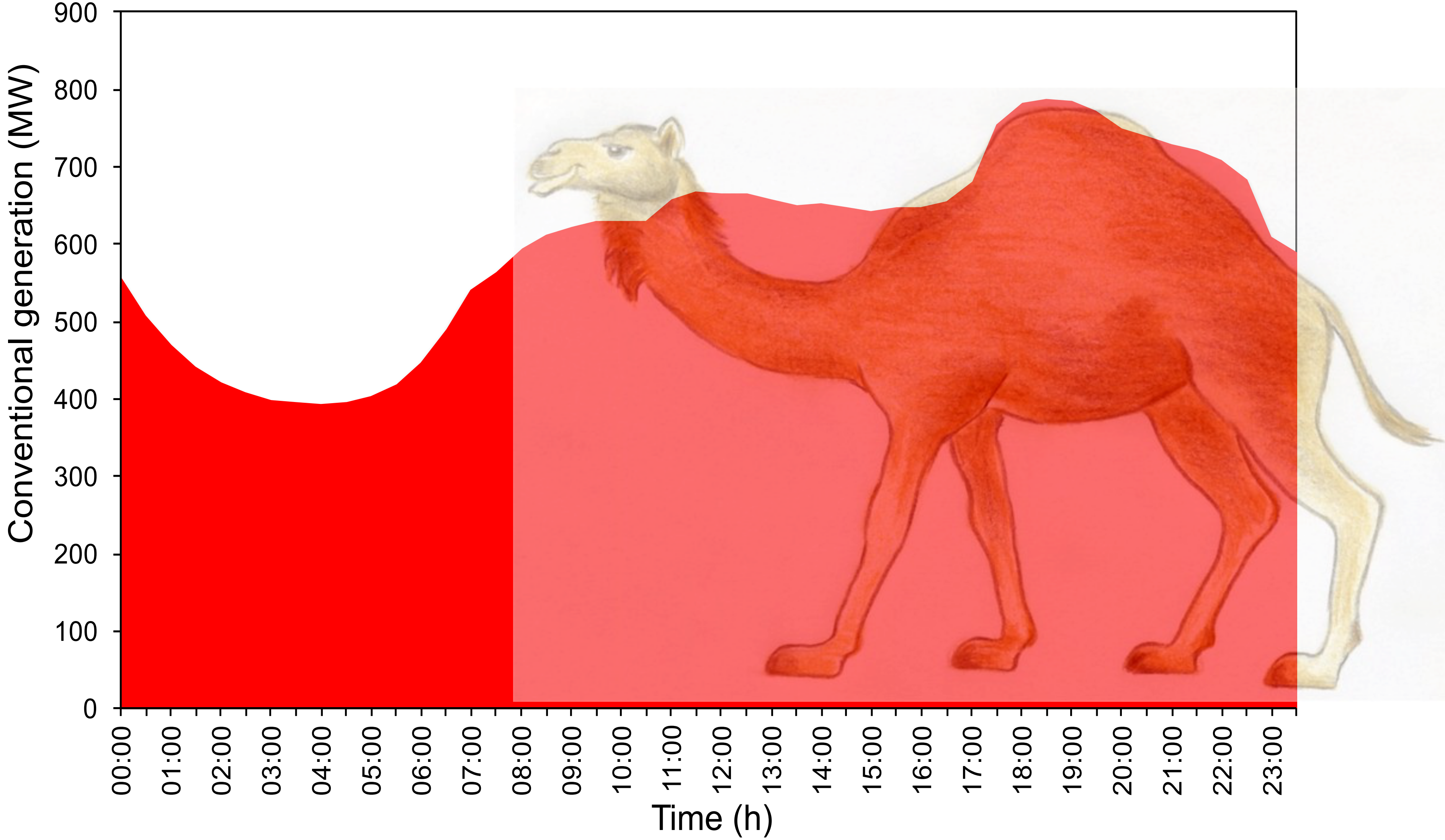

* **Poullikkas A., 2016, "From the 'camel curve' to the 'duck curve' on electric systems with increasing solar power", *Accountancy***

Effect of PV generation on load curve (the 'duck curve')*

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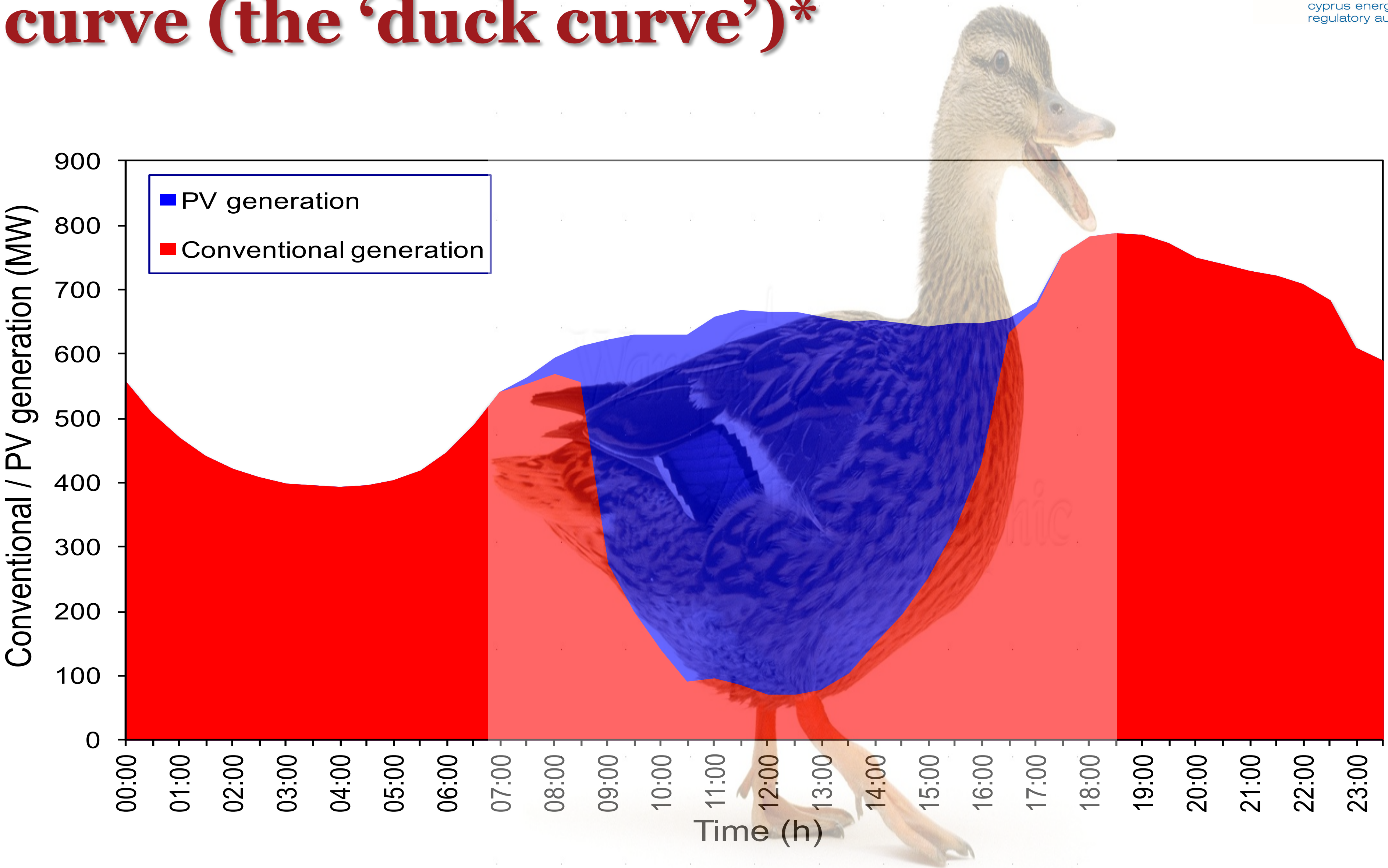
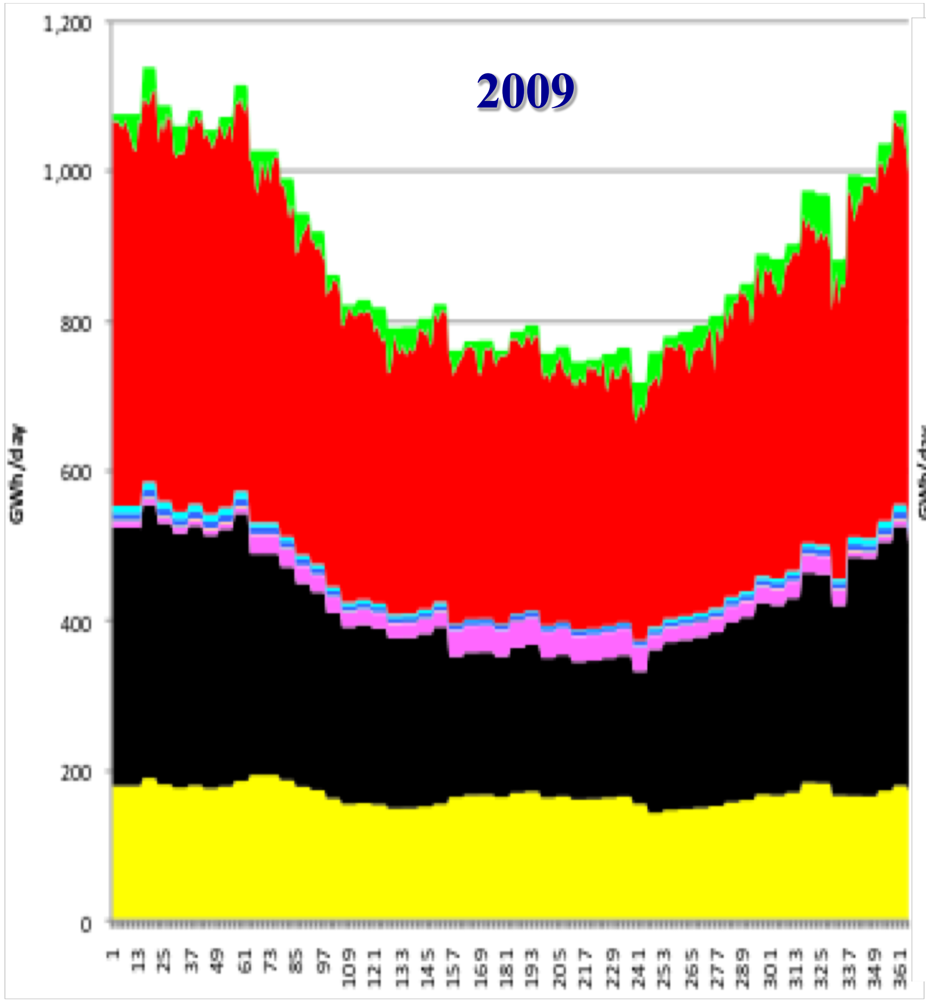
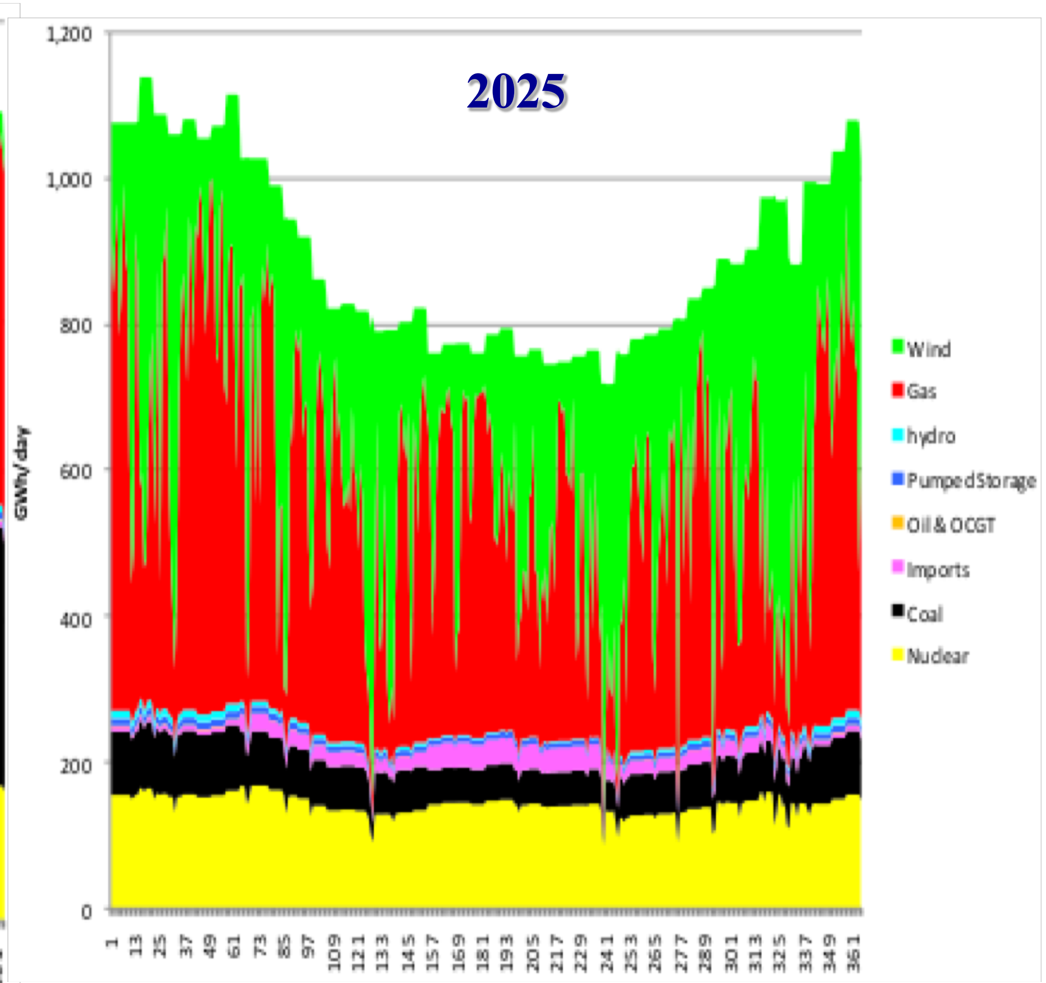


* Poullikkas A., 2016, "From the 'camel curve' to the 'duck curve' on electric systems with increasing solar power", *Accountancy*

Gas is a pillar of renewable energy (power production in UK*)





* H.V. Rogers, 2011, *The Impact of Import Dependence and Wind Generation on UK Gas Demand and Security of Supply to 2025*, The Oxford Institute For Energy Studies

Storage is the missing link

High Temp Storage (HTS)	Redox Flow (RF)	Lithium Lead Carbon (LC)	Lithium Lithium-Iron-Phosphate
Forward Market	Day Ahead Market	Intra Day Market	Balancing Market
Advantage HTS: • Very large storage • 80% DOD • Electricity, heat and AC generation • Lowest Cost • Minimum space • 50 years LT	**Advantage RF:** • Large storage • 50-70% DOD • High Power • Lower cost • No memory effect • 15 to 20 years LT	**Advantage LC:** • Large storage • 50-70% DOD • High power • Lower cost • Efficiency > 85% • 10-15 years LT	**Advantage Lithium:** • Fast response • Quick Service • 80% DOD • High Power • Efficiency > 95% • No Memory effect • Highest energy density • 15 to 20 years LT
Disadvantage: No fast response E-Efficiency 40% H-Efficiency 40%	**Disadvantage:** Low Energy Density No fast response Efficiency < 80%	**Disadvantage:** Medium Energy Density High Weight Efficiency 80%	**Disadvantage:** High Cost
Size: 3 - 50MWh	Size: 1 - 10MWh	Size: 0,1 - 10MWh	Size: 0,1 - 10MWh

Modeling for optimum large scale integration of RES

Advanced simulation tools

The problem

The need

- Large scale integration of RES
  - e.g., EU RES targets by 2020, 2030

Main objective

- Assessment of the increase (or benefit) in the cost of electricity of a given power generation system at different RES-E penetration levels

Model capabilities

- Use of unit commitment algorithms
- Energy mix and include storage
- Cost or benefit in the cost of electricity
- Price of FiT, FiP, etc
- Green tax (if necessary)

Objective function*

- **Minimizing total cost**

$$\min C = \min \sum_{i=1}^{n} x_i(c_i)$$

- **satisfy constraints**
  - Load demand
  - Unit capacity
  - Available capacity
  - Reserve margin
  - Spinning reserve
  - Fuel constraints
  - Environmental constraints
  - Power transmission constraints, etc

$$P_{D(t)} = \sum_i I_{(i,t)} P_{(i,t)}$$

$$P_{g,\min(i)} \le P_{(i,t)} \le P_{g,\max(i)}$$

$$R_{O(t)} \le \sum_i r_{o(i,t)} I_{(i,t)} \qquad r_{o(i,t)} = \begin{cases} q_i\text{, if unit } i \text{ is OFF} \\ r_{s(i,t)}\text{, if unit } i \text{ is ON} \end{cases}$$

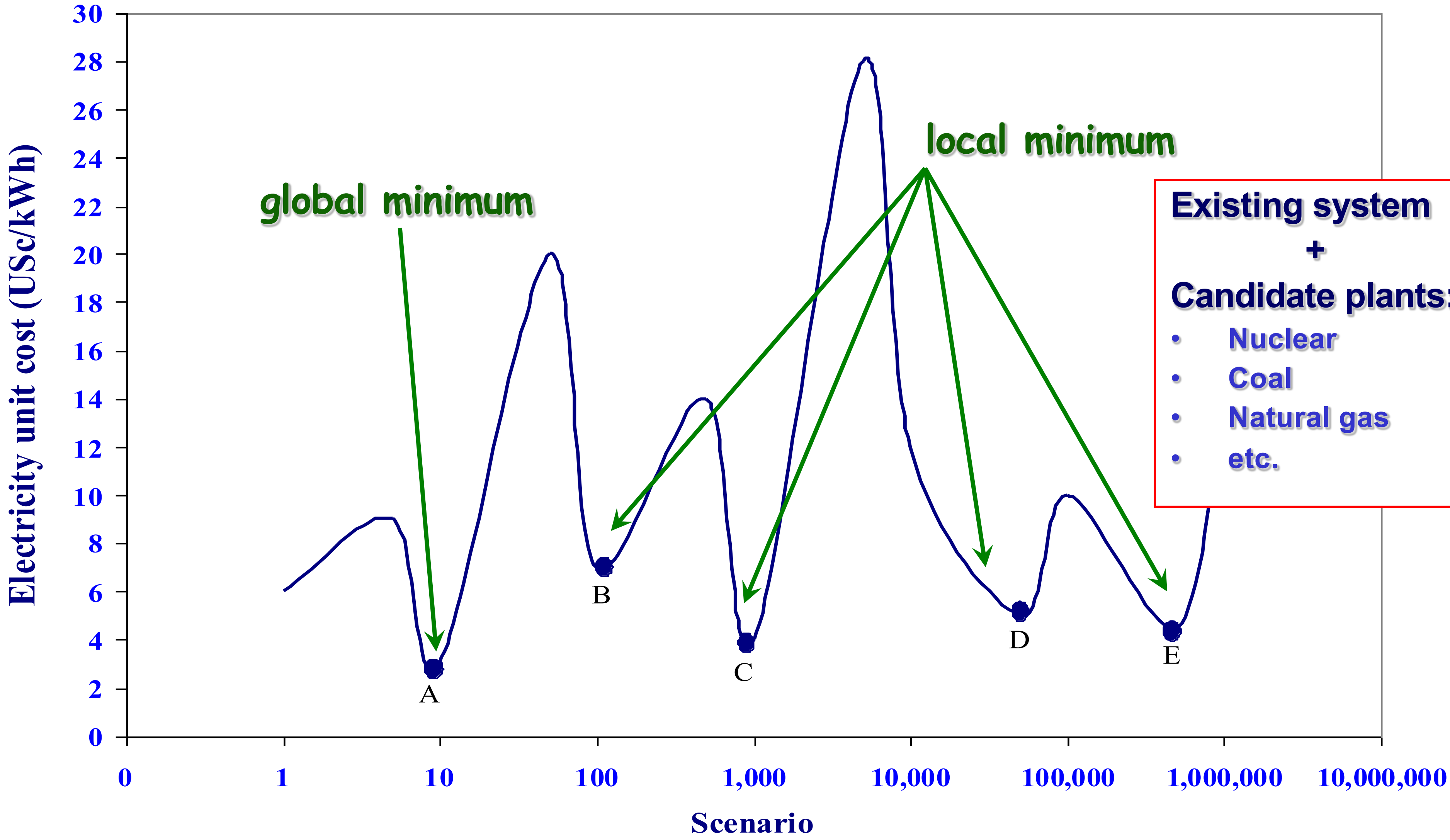
$$R_{S(t)} \le \sum_i r_{s(i,t)} I_{(i,t)} \qquad r_{s(i,t)} = \min\left[10MSR_i, P_{g,\max(i)} - P_{(i,t)}\right]$$

$$\sum_i \sum_t C_{ei}\left[P_{(i,t)} I_{(i,t)}\right] + S_{e(i,t)} \le E_{\max}$$

$$-P_{km}^{\max} \le P_{km(t)} = f\left[\mathbf{B}_{(t)}, \varphi_{(t)}\right] \le P_{km}^{\max}$$

* Poullikkas A., 2009, "A decouple optimization method for power technology selection in competitive markets", *Energy Sources*

Typical shape of objective function*

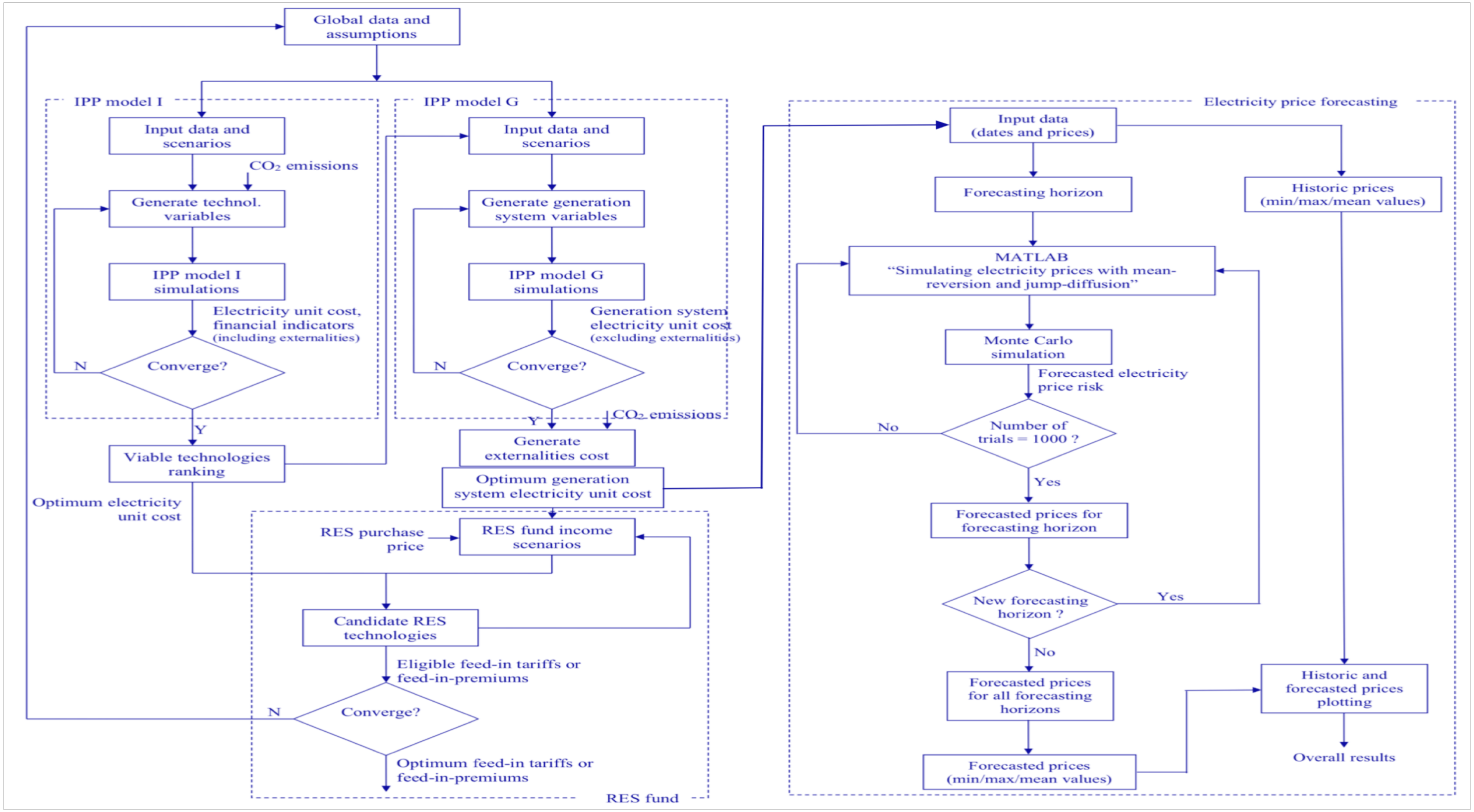


Existing system
+
Candidate plants:

- Nuclear
- Coal
- Natural gas
- etc.

* Poullikkas A., 2009, "A decouple optimization method for power technology selection in competitive markets", *Energy Sources*

Optimization model*,**



* Poullikkas A., Kourtis G., Hadjipaschalis I., 2011, "A hybrid model for the optimum integration of renewable technologies in power generation systems", *Energy Policy*

** Poullikkas A., 2018, "An adaptive longterm electricity price risk modelling using Monte Carlo simulation", *Journal of Power Technologies*

Decoupled objective function*

Capital ($) — Fuel ($) — Fixed O&M ($) — Variable O&M ($)

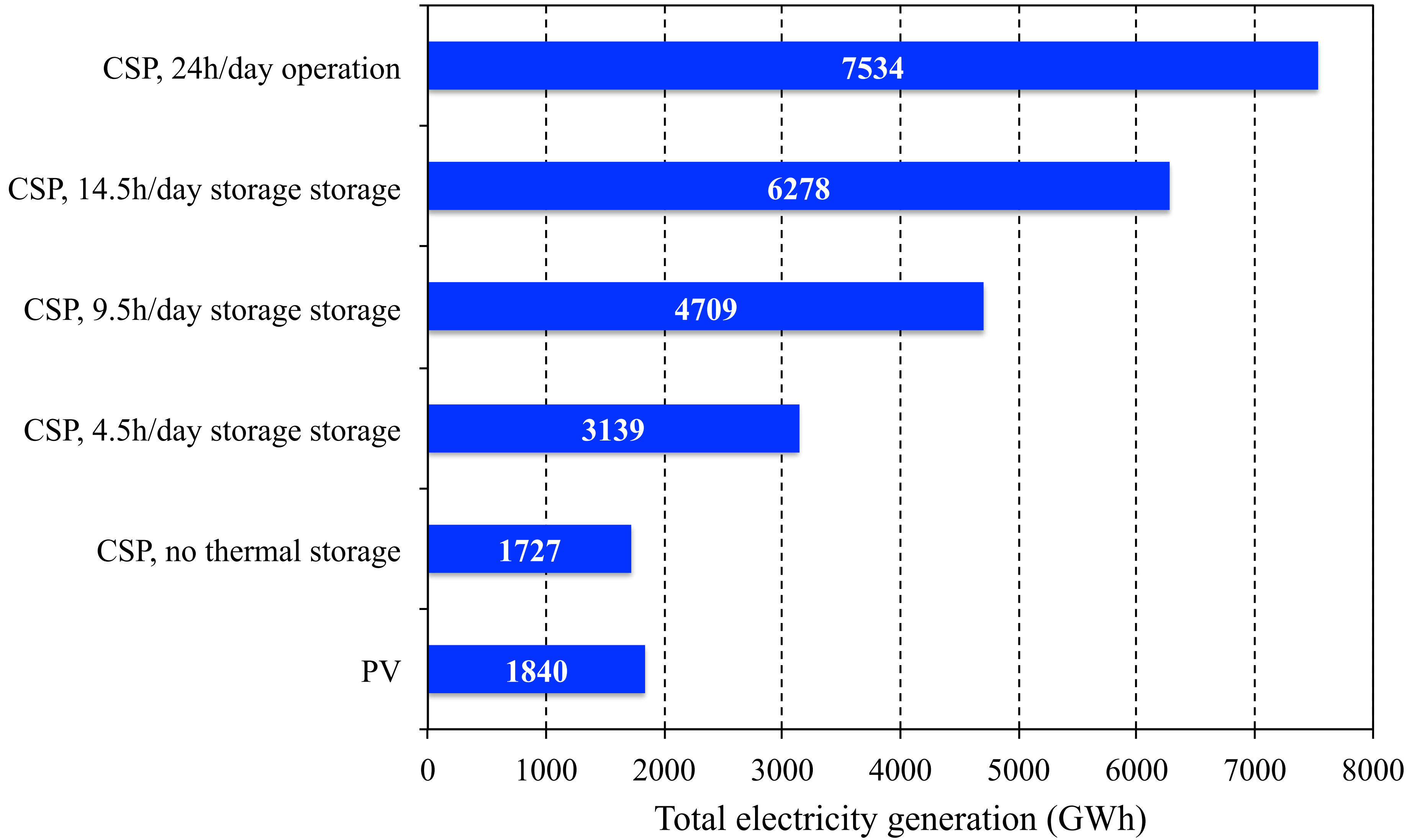
$$\min\left(\frac{\partial c}{\partial k}\right) = \min\left\{ \frac{\sum_{j=0}^{N}\left[\frac{\frac{\partial C_{Cj}}{\partial k}+\frac{\partial C_{Fj}}{\partial k}+\frac{\partial C_{OMFj}}{\partial k}+\frac{\partial C_{OMVj}}{\partial k}}{(1+i)^j}\right]}{\sum_{j=0}^{N}\left[\frac{\frac{\partial P_j}{\partial k}}{(1+i)^j}\right]} \right\}$$

Electricity unit cost ($c/kWh)

Energy (kWh)

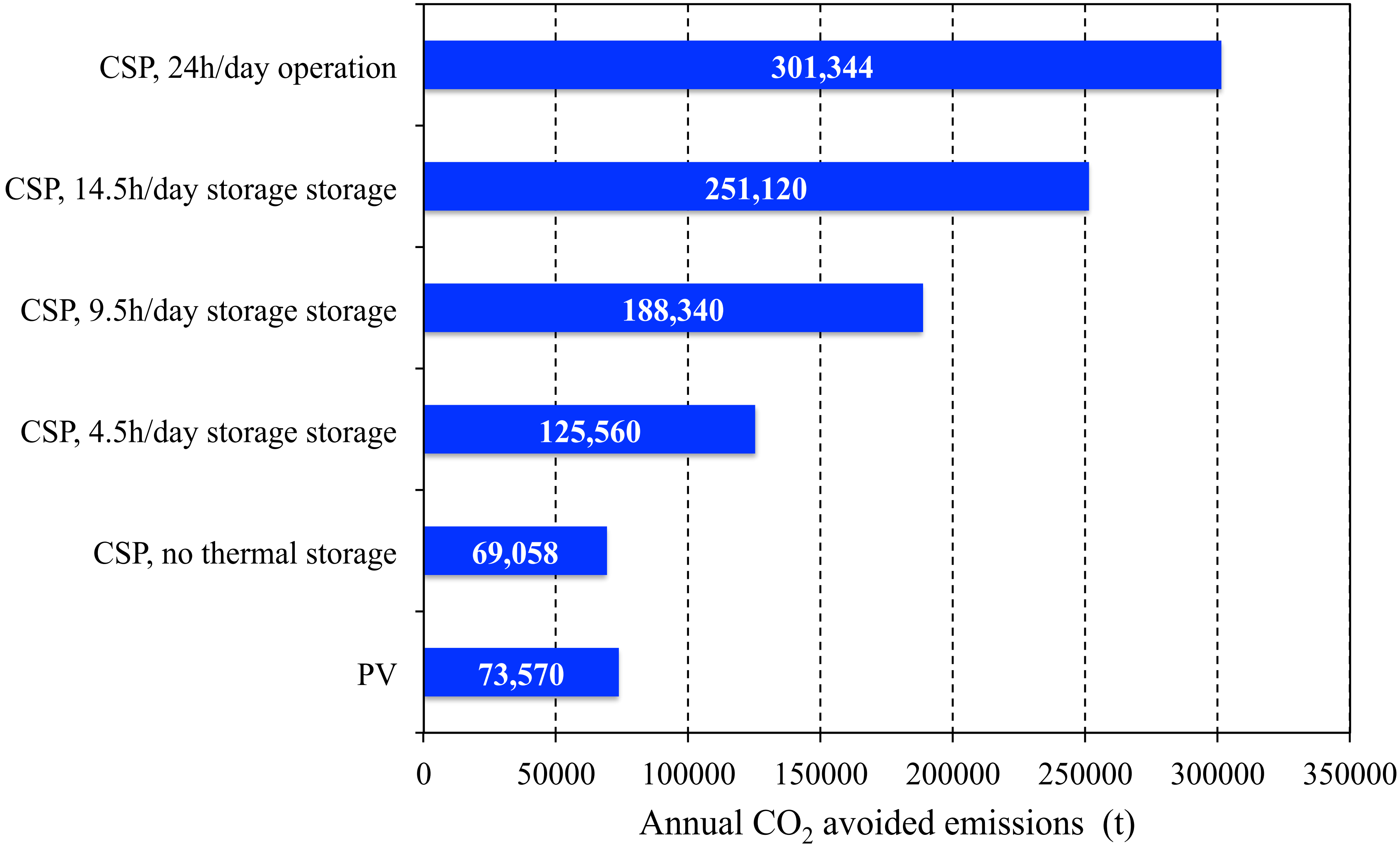
* Poullikkas A., *IPP algorithm version 2.1*, User manual, © 2000-2006

Total electricity generation for 50MW (20y)*



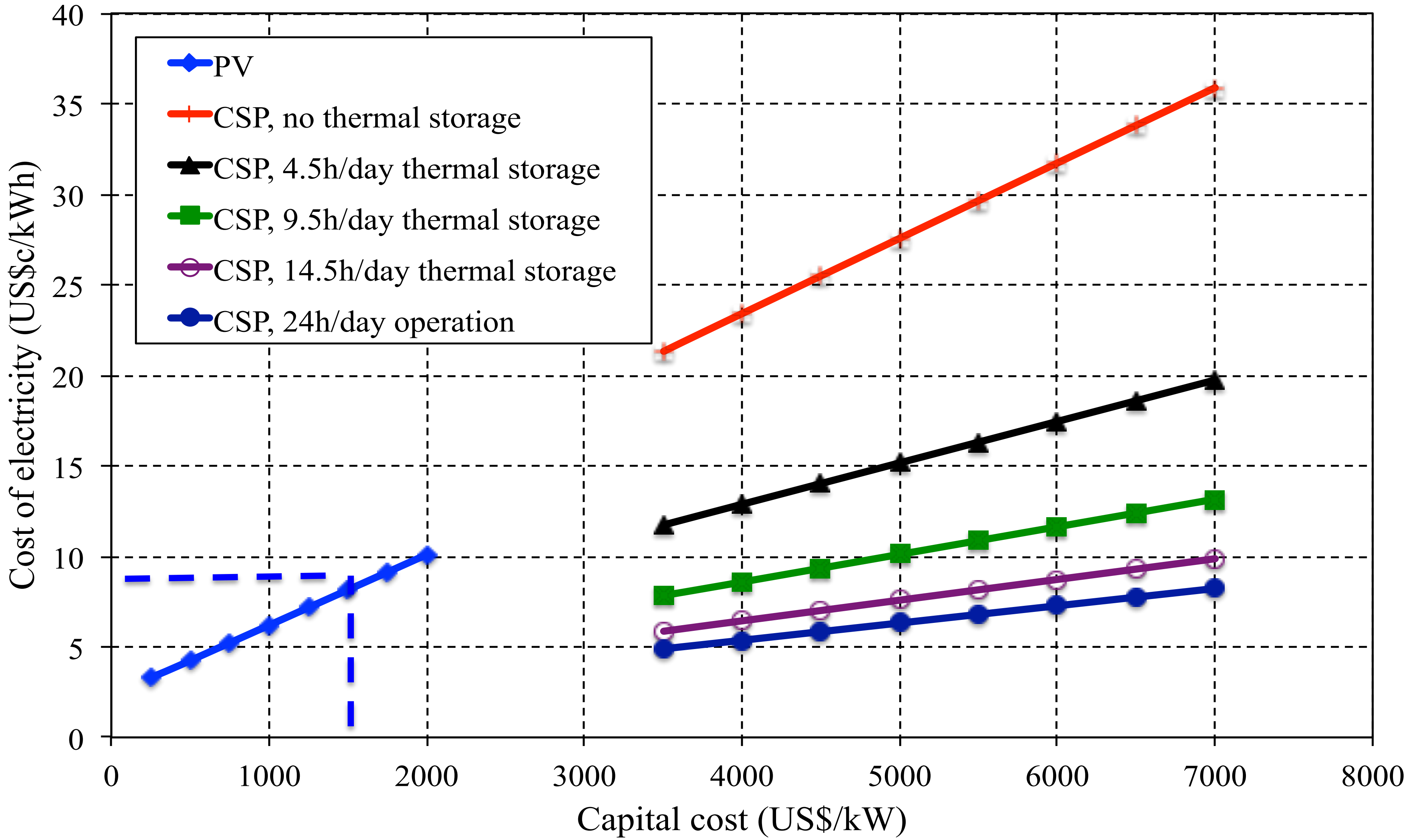
* **Poullikkas A., Gadalla M., 2013, "Assessment of solar electricity production in United Arab Emirates", *International Journal of Sustainable Energy***

Annual CO2 avoided emissions*



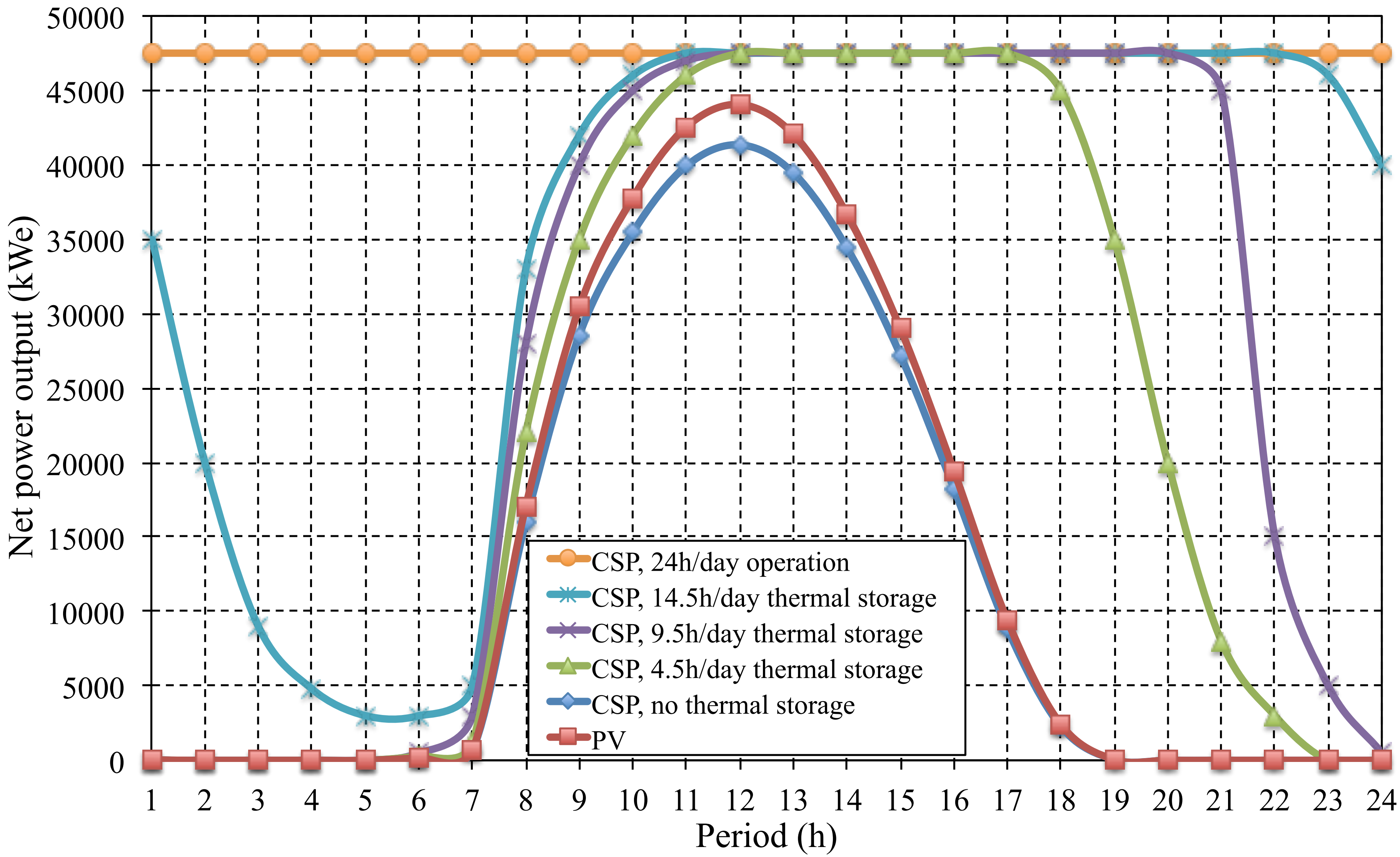
* Poullikkas A., Gadalla M., 2013, "Assessment of solar electricity production in United Arab Emirates", *International Journal of Sustainable Energy*

LCOE parametric curves*



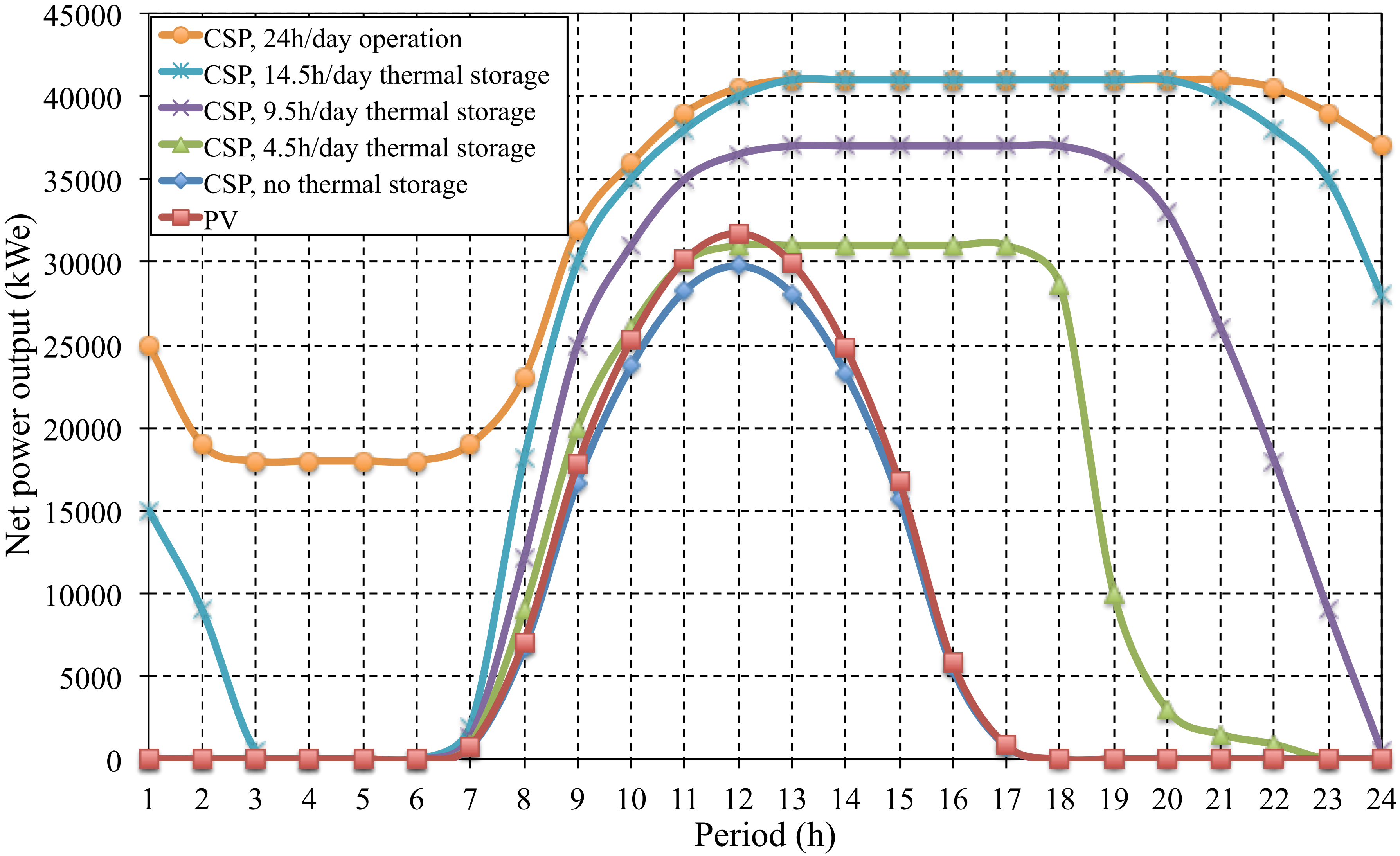
* Poullikkas A., Zueter A.F., Dirar M.H., 2014, "Prospective scenarios for the adoption of sustainable power generation technologies in United Arab Emirates", *International Journal of Sustainable Energy*

Typical net power output profile during summer*



* **Poullikkas A., Gadalla M., 2013, "Assessment of solar electricity production in United Arab Emirates", *International Journal of Sustainable Energy***

Typical net power output profile during winter*



* **Poullikkas A., Gadalla M., 2013, "Assessment of solar electricity production in United Arab Emirates", *International Journal of Sustainable Energy***

Cost of reserves with RES production*

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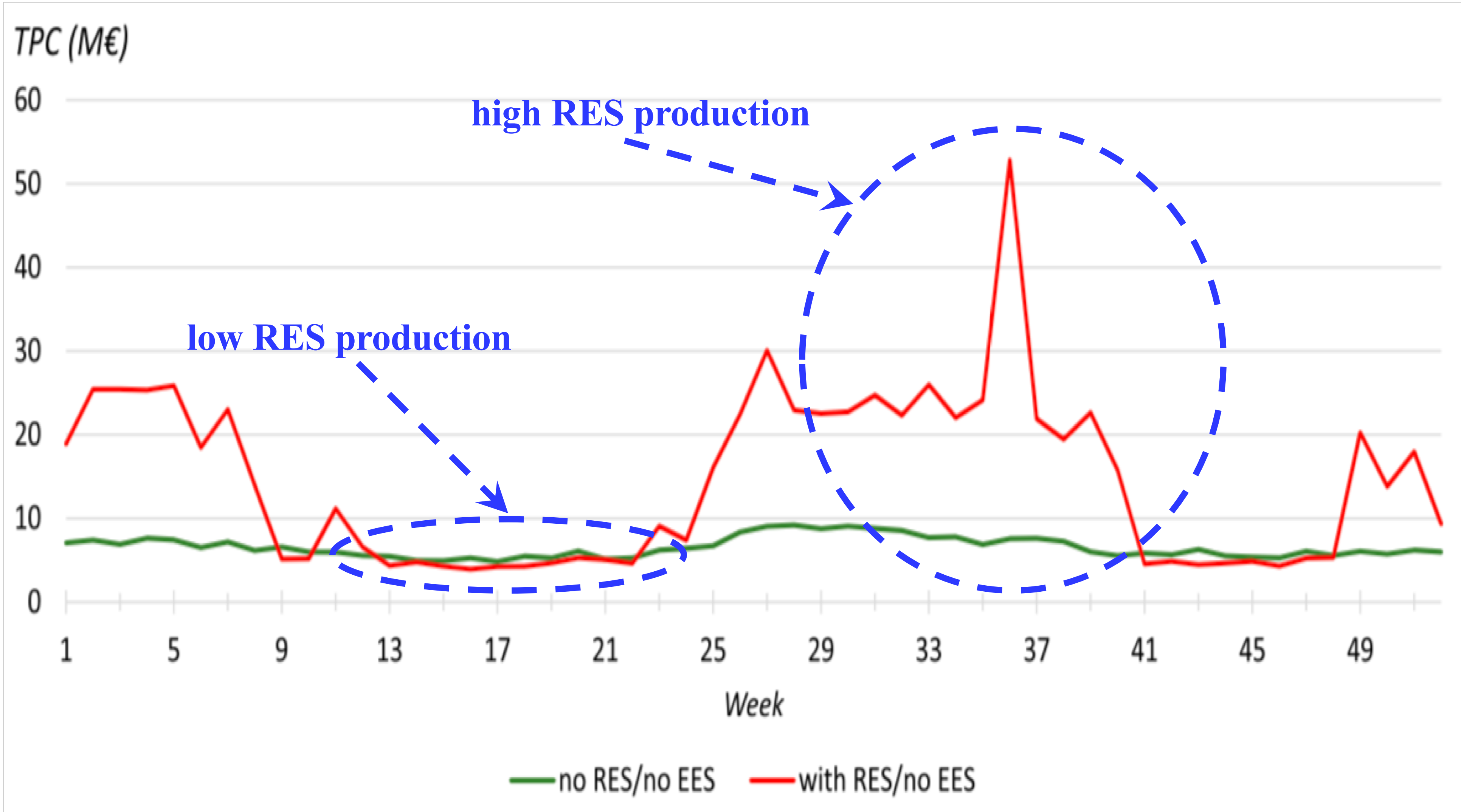
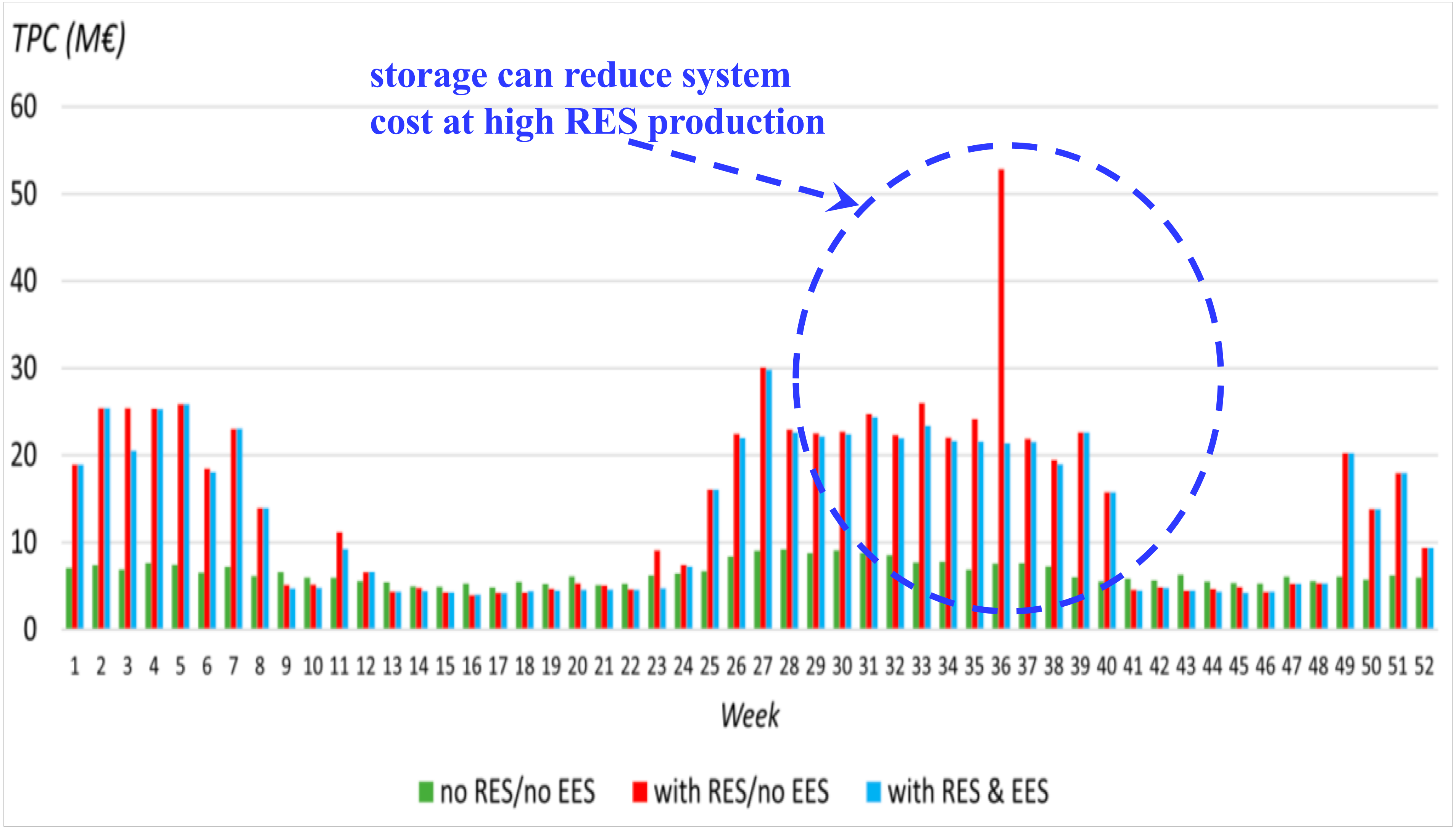


* Nicolaidis P., Chatzis S., Poullikkas A., 2018, "Renewable energy integration through optimal unit commitment and electricity storage in weak power networks", *International Journal of Sustainable Energy*

Integration of storage*



* **Nicolaidis P., Chatzis S., Poullikkas A., 2018, "Renewable energy integration through optimal unit commitment and electricity storage in weak power networks", *International Journal of Sustainable Energy***