Plenary Speech

Future Sustainable Energy Systems Towards 2050

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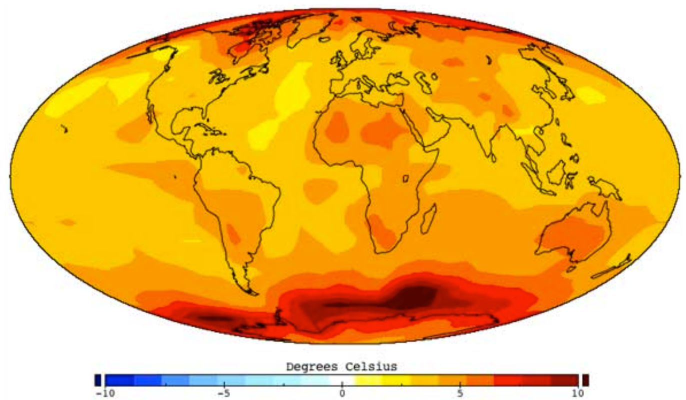
- **Energy cost**
- **Modeling for optimum large scale integration of RES**
  - Simulation of RES operation
  - Integration of storage

EU energy strategy

2020, 2030, 2050

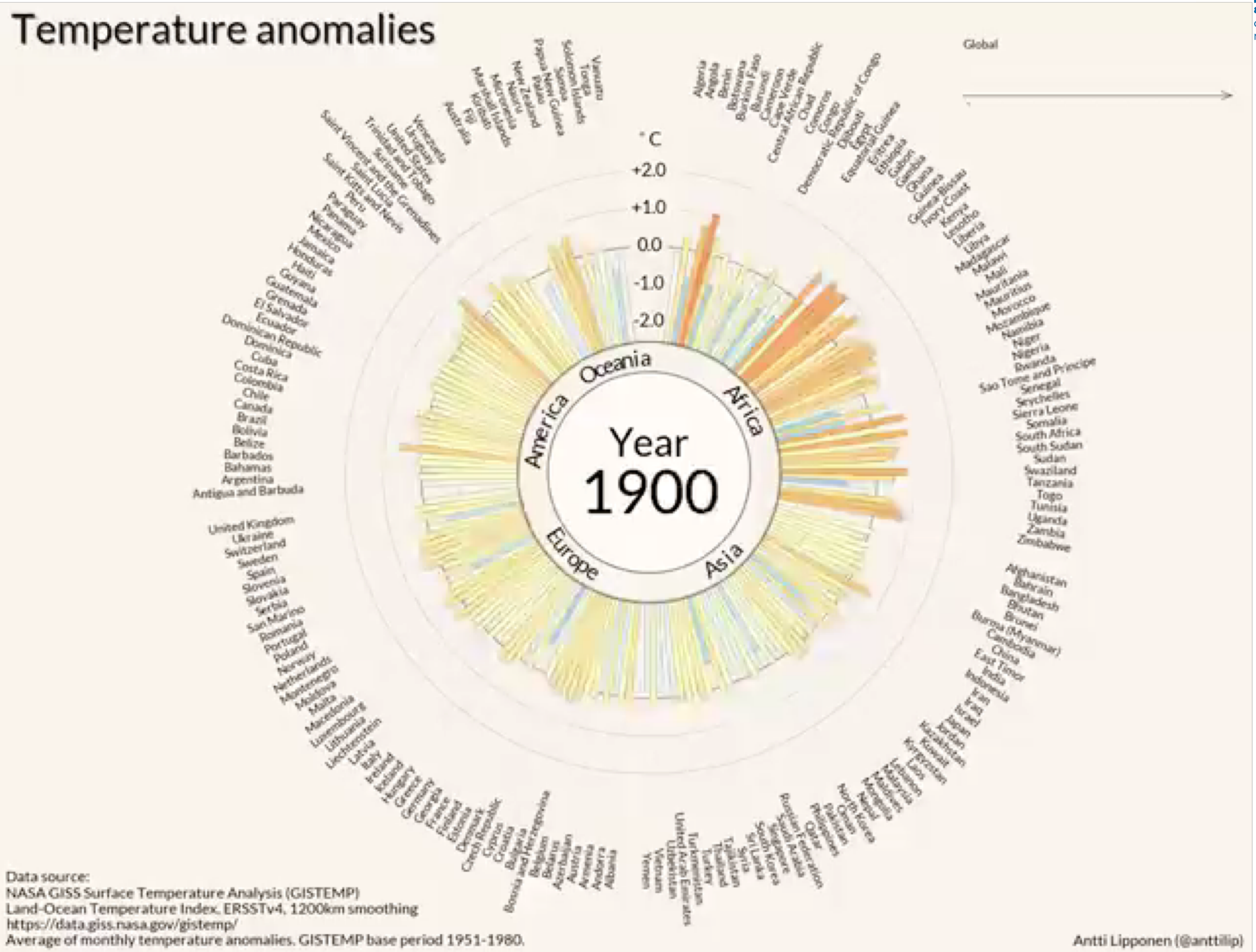
Future energy systems

- **Climate change**



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

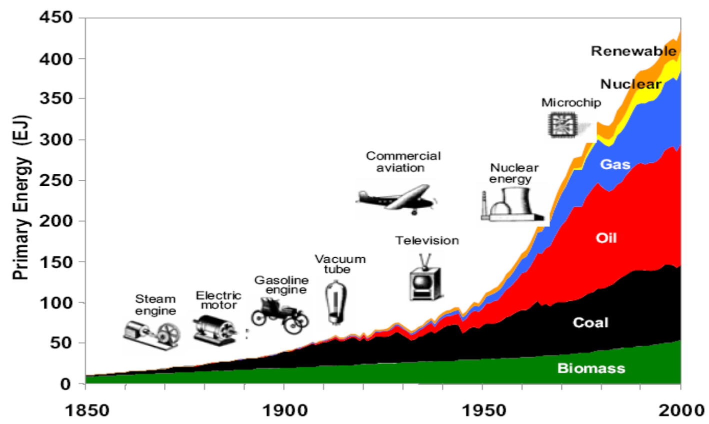
Temperature anomalies *



*** UN Environment, 2017.**

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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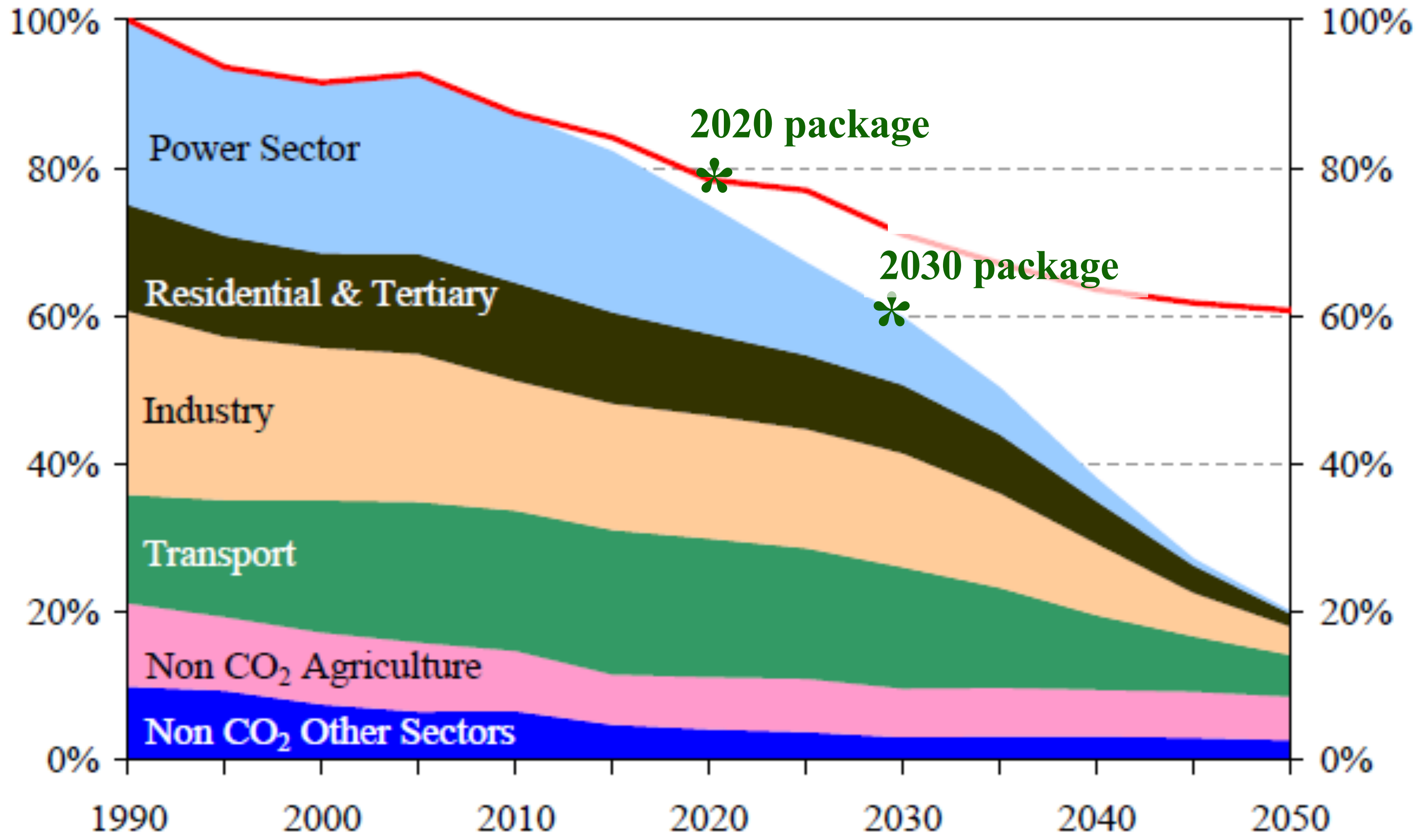
2020	**-20 %** Greenhouse Gas Emissions	**20%** Renewable Energy	**20 %** Energy Efficiency	**10 %** Interconnection
2030	**≥ - 40 %** Greenhouse Gas Emissions	**≥32 %** Renewable Energy	**≥ 32,5%** Energy Efficiency	**15 %** Interconnection

New governance system + indicators

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

EU reduction in greenhouse gas emissions



Our 3D energy future

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Decarbonisation:

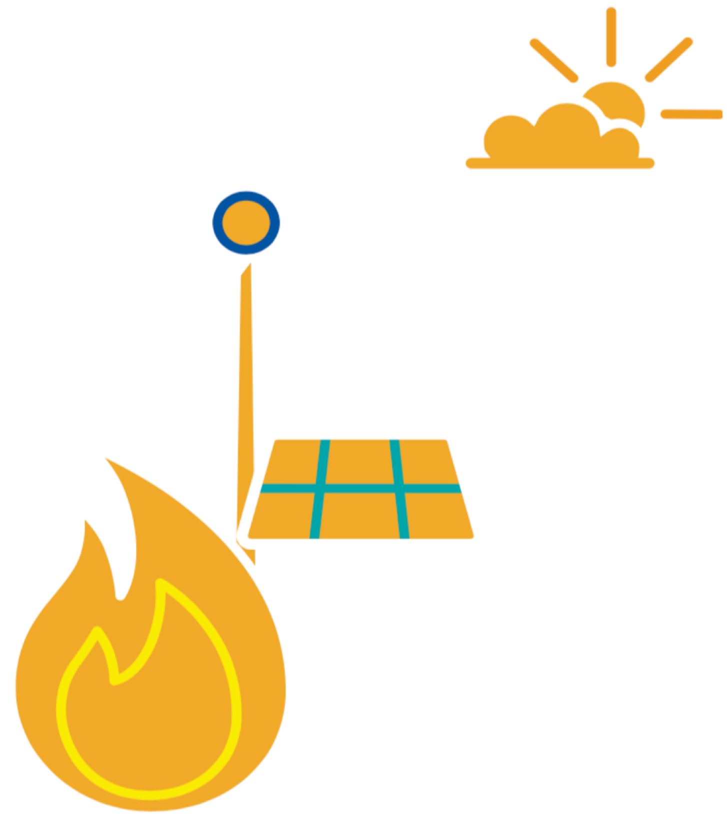
oil/coal-to-gas switch, renewable gas, wind and sun, carbon capture and usage

Decentralisation:

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

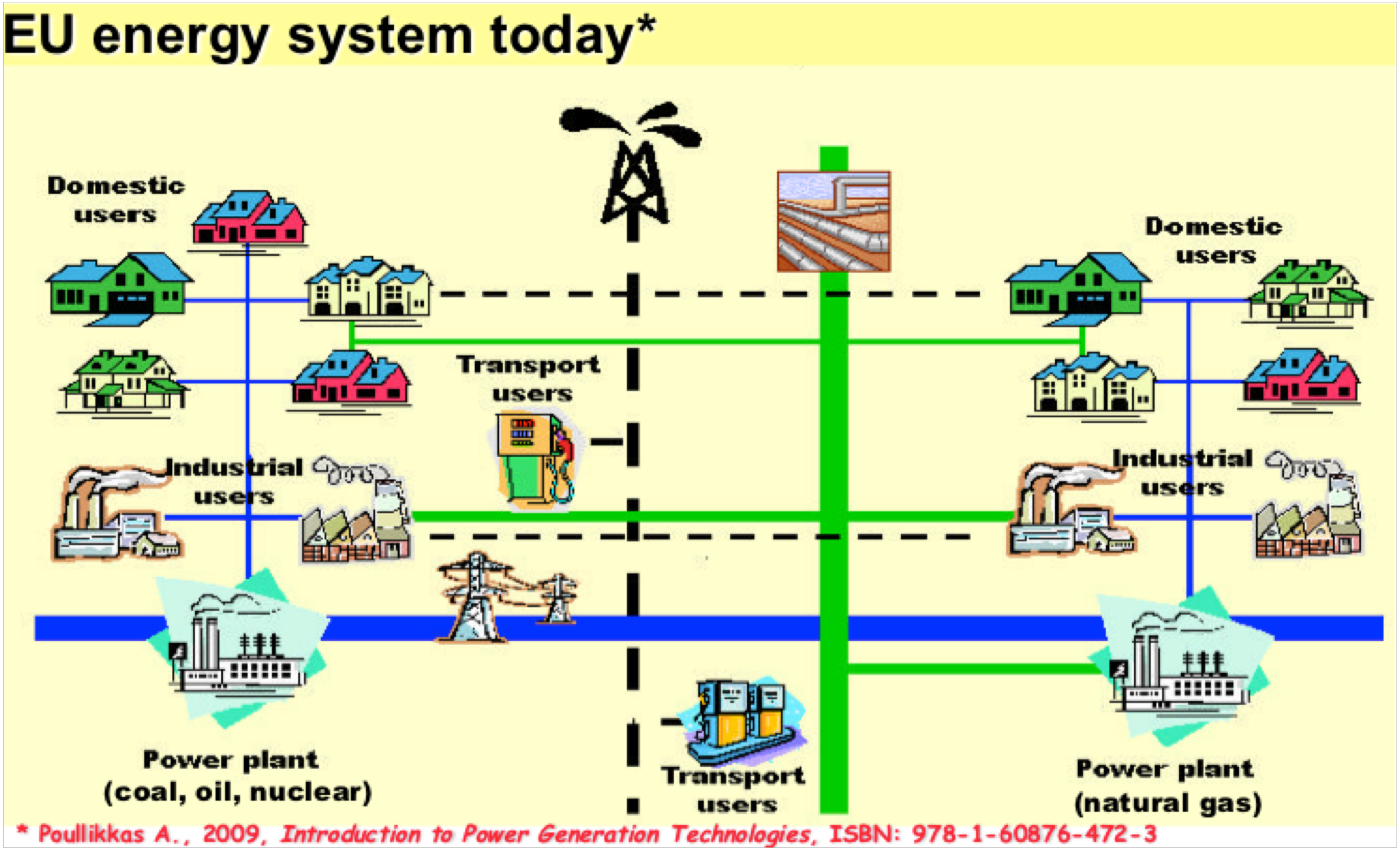
Digitalisation:

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



Future energy systems (optimistic scenario)

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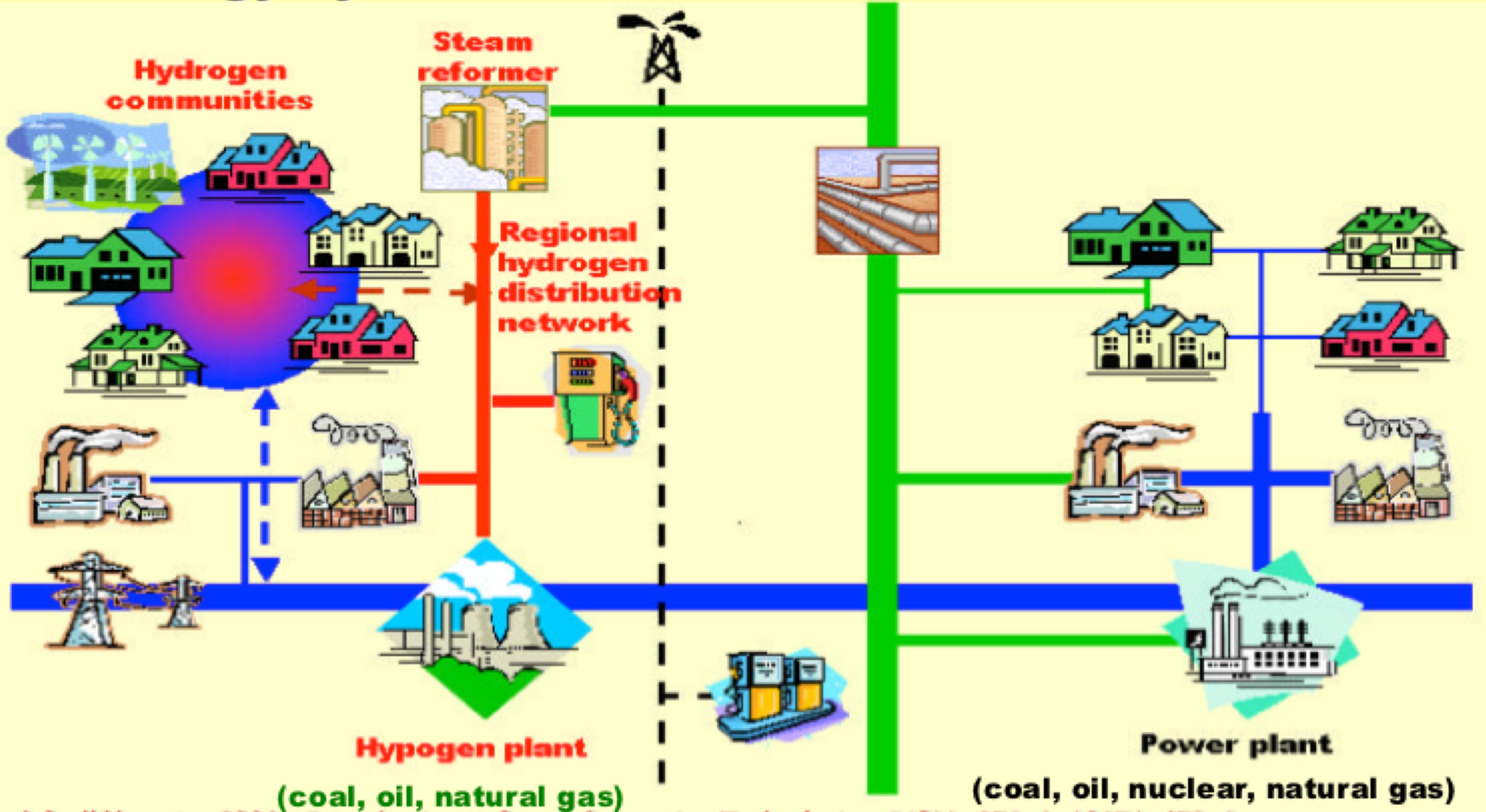
EU energy system in 2020-30*



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

Future energy systems (optimistic scenario)

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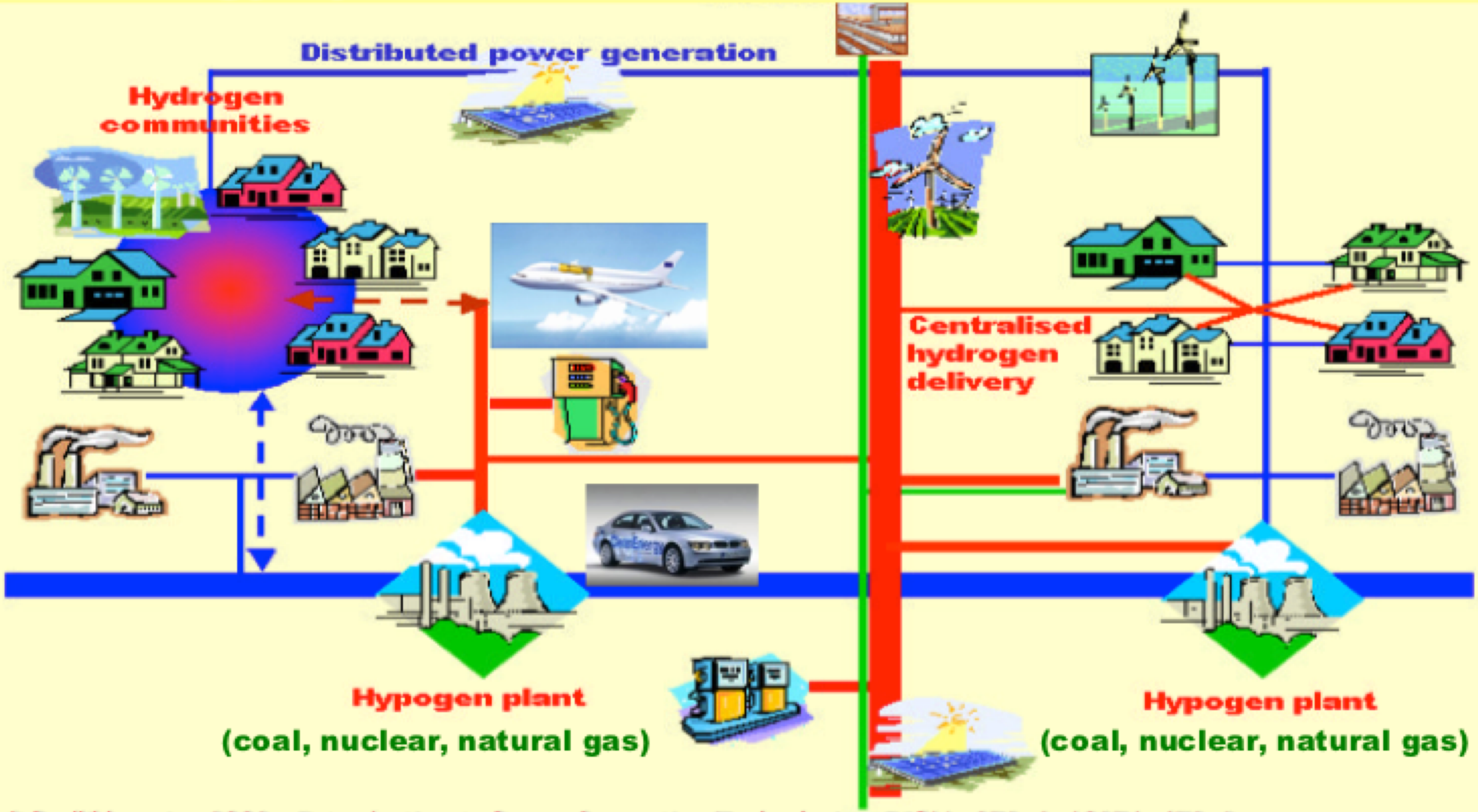
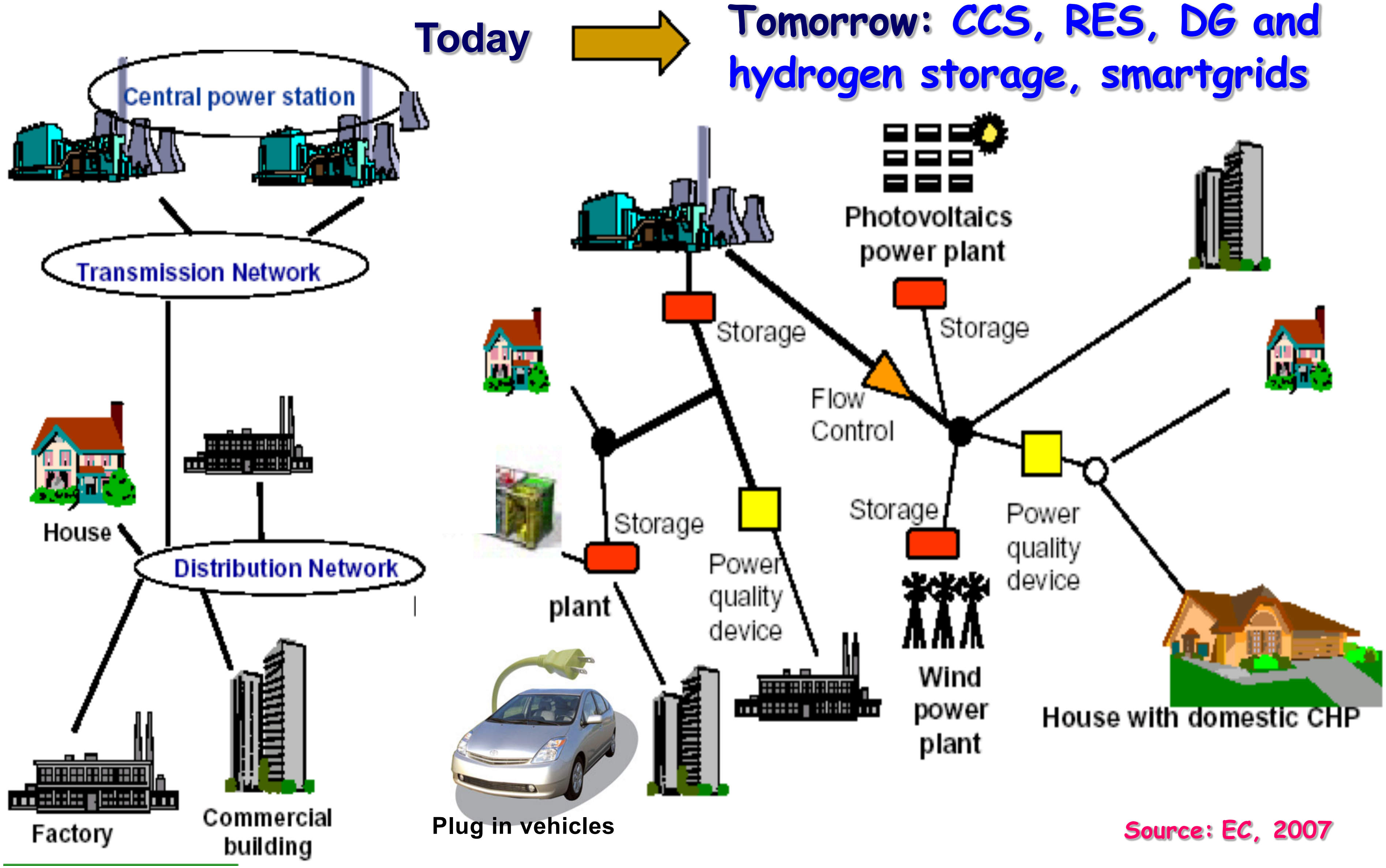
EU energy system in 2040-50*



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

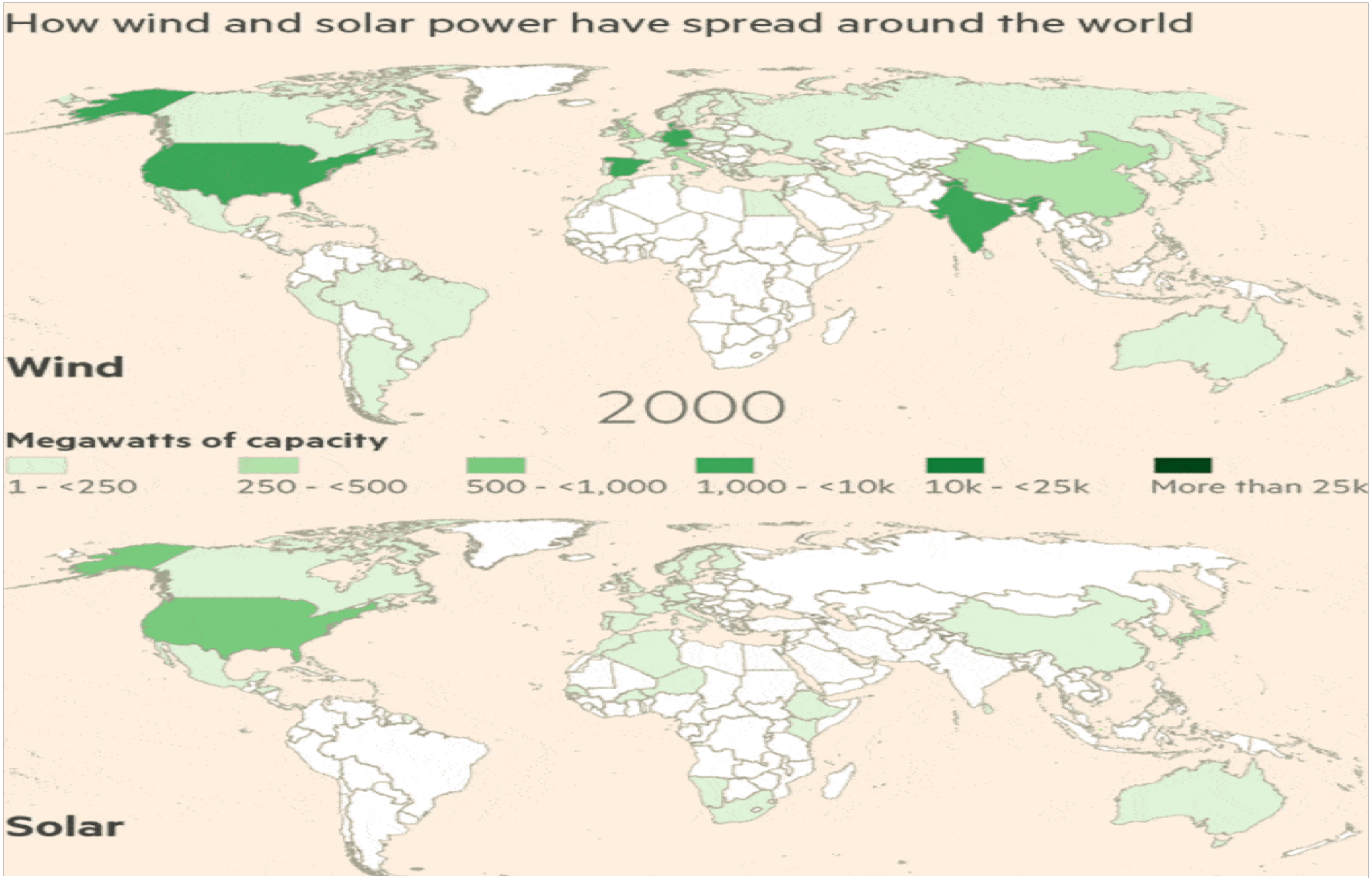
Future power systems

Today → **Tomorrow: CCS, RES, DG and hydrogen storage, smartgrids**



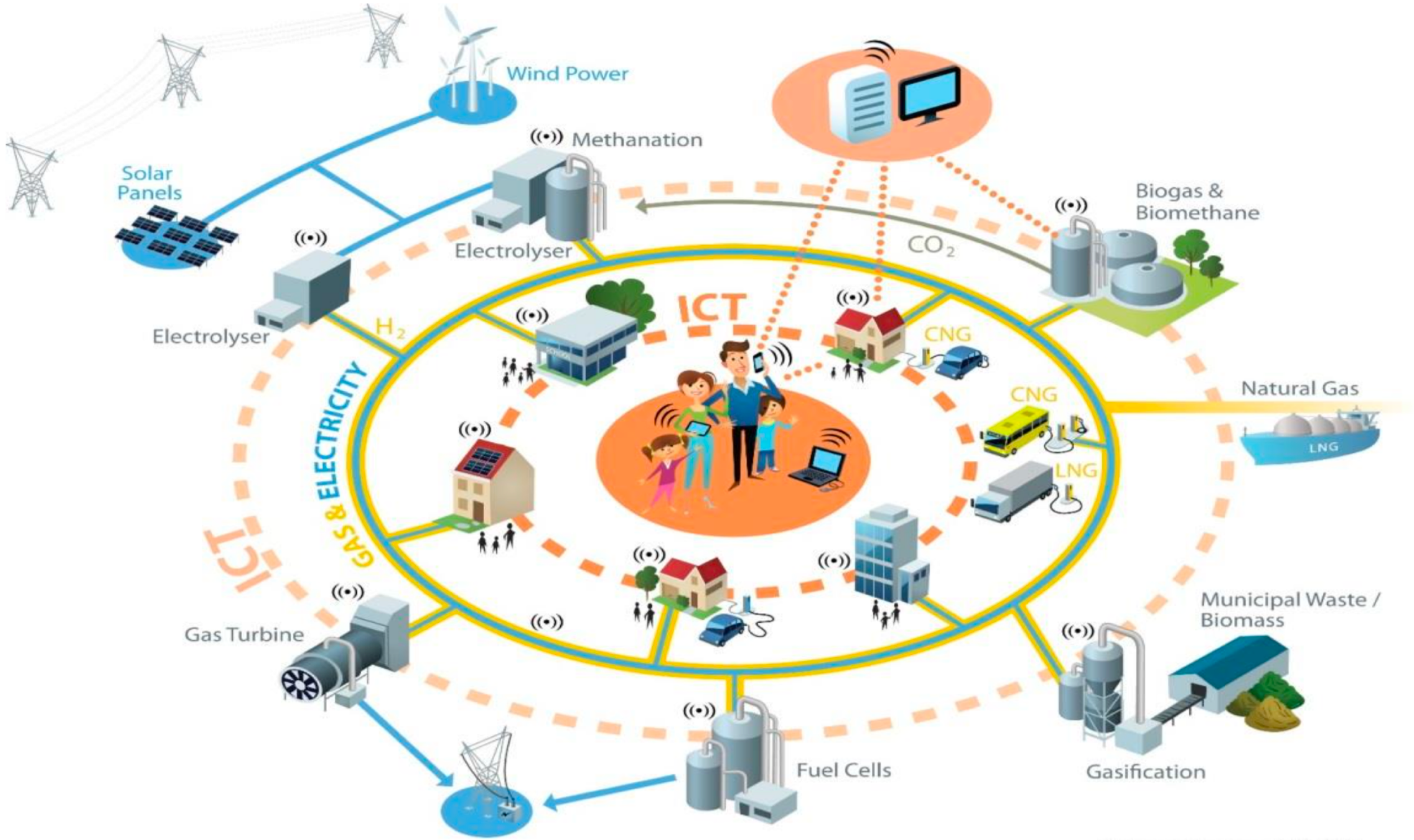
Source: EC, 2007

Development of wind and solar power *



* International Renewables Energy Agency

End goal – the smart future



The Super Smart Grid after 2050*

(may allow for 100% RES)

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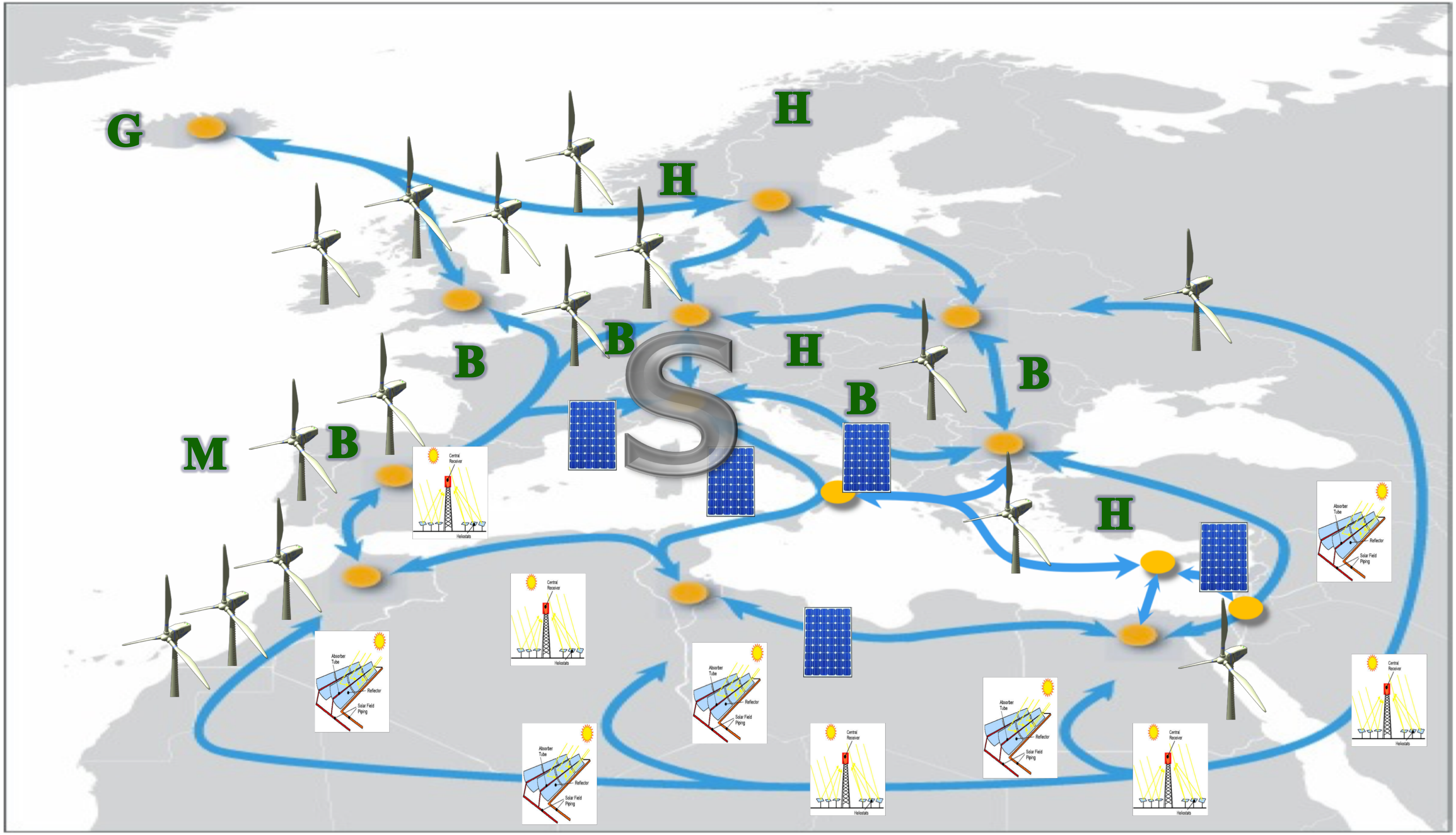
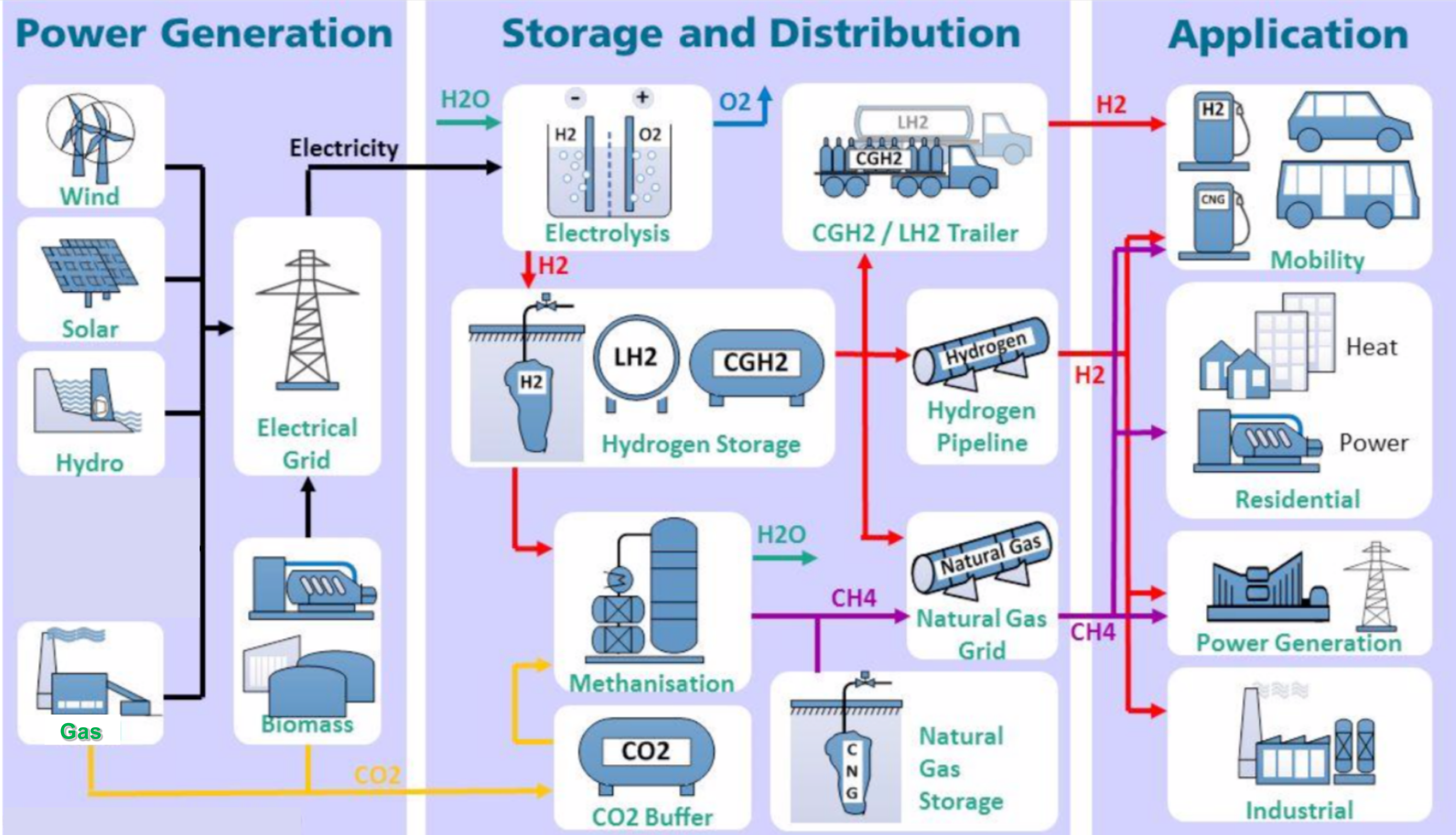


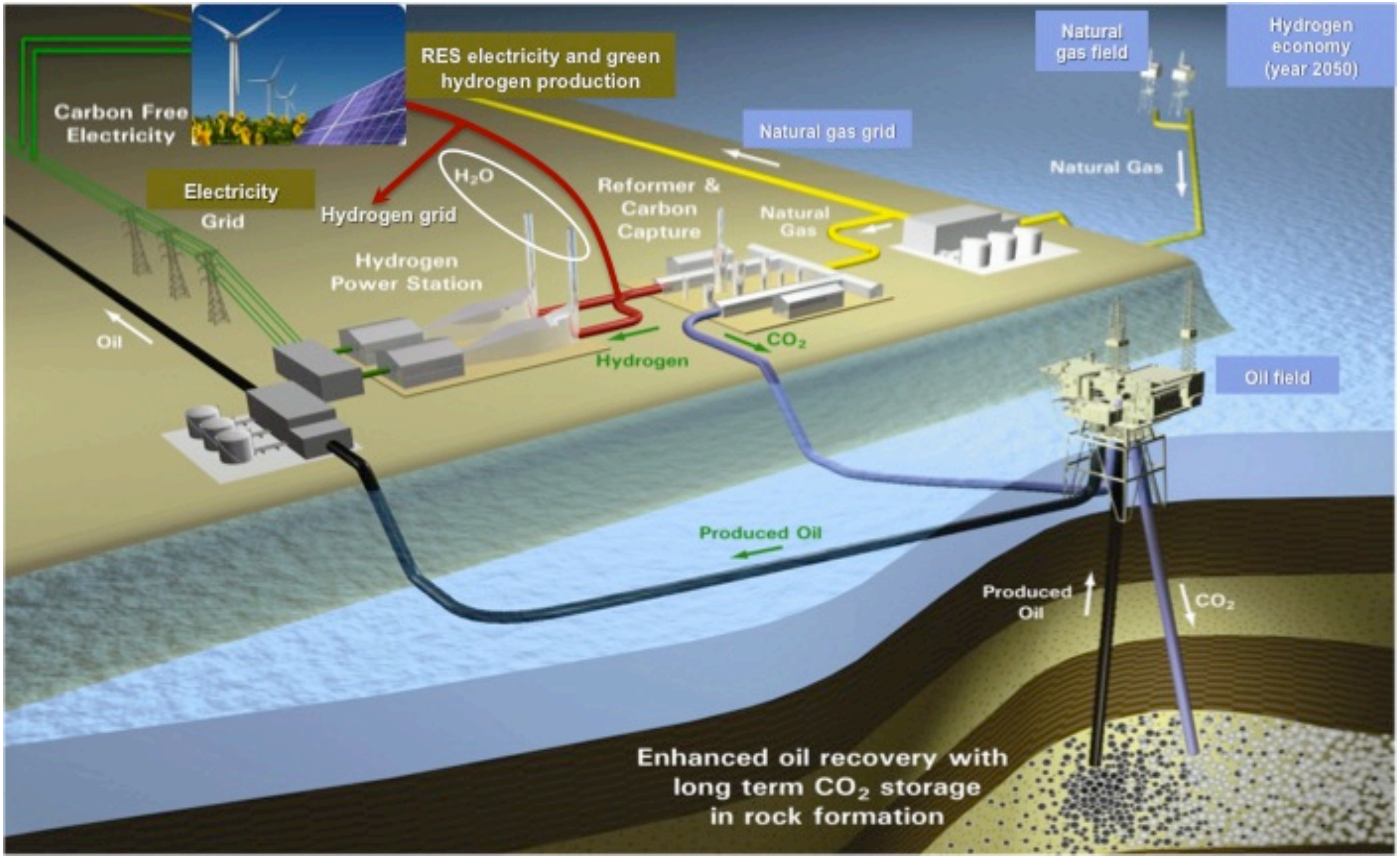
* Poullikkas A., 2013, *Sustainable Energy Development for Cyprus*, ISBN: 978-9963-7355-3-2

Potential role of hydrogen in the energy transition



Source: EU, 2019

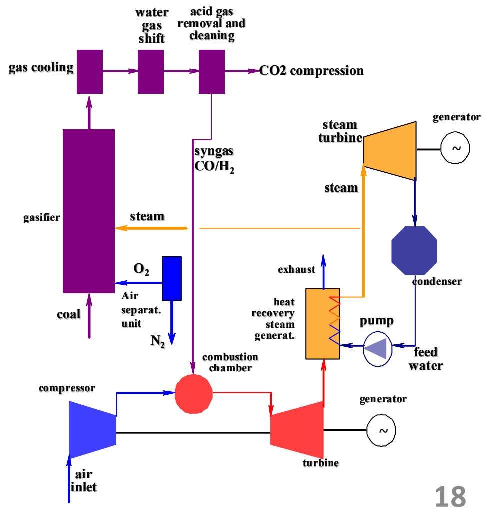
Towards hydrogen economy*



* 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

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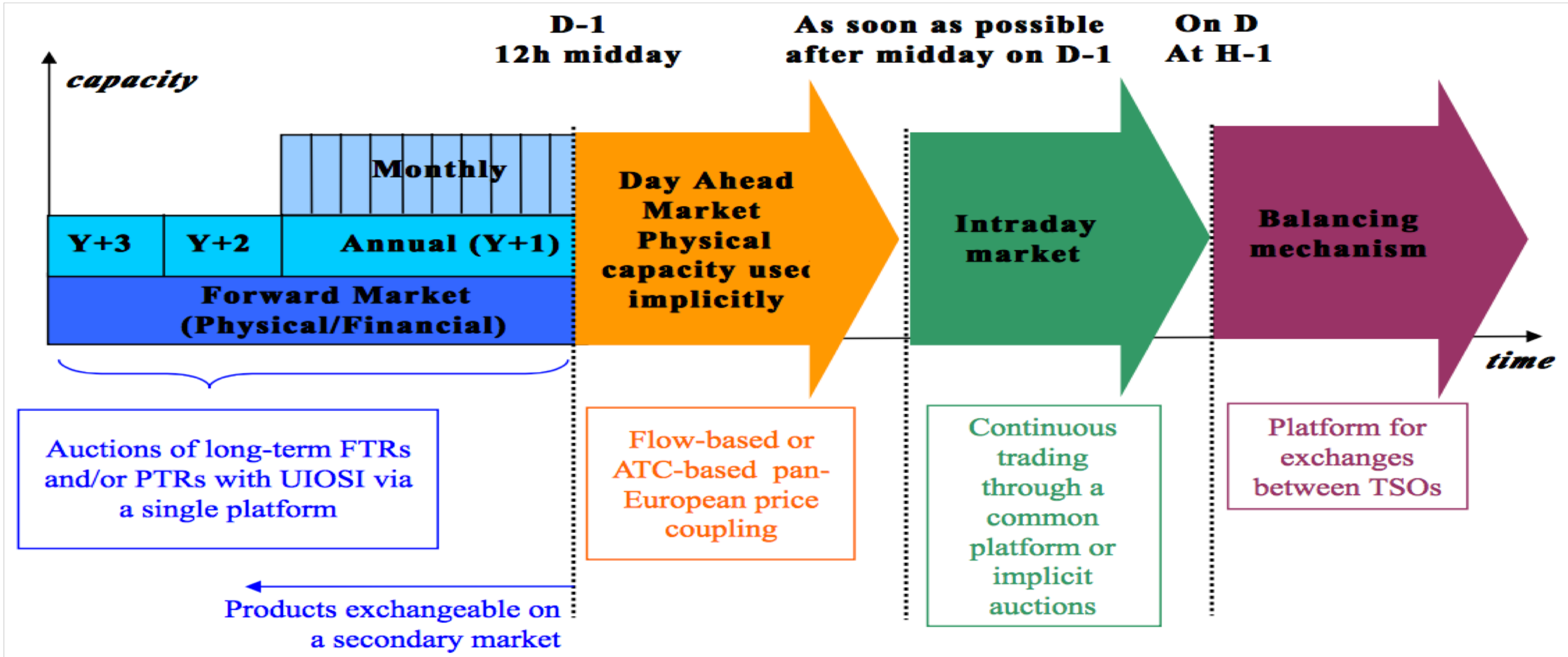


Integration of RES: LCOE *vs* Reliability

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

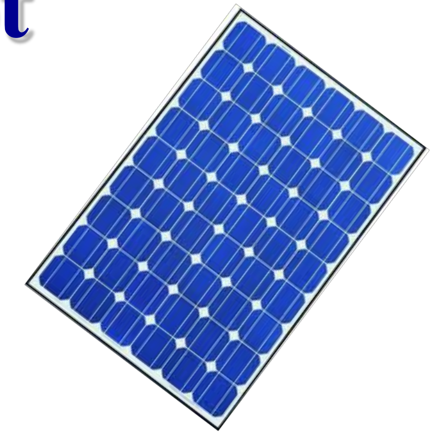
Power system reliability*
(the 6 must)

- Generation capacity **must** be greater than load
- Transmission **must** not be overloaded
- Voltages **must** be within limits
- **Must** be able to withstand loss of generator
- **Must** be able to withstand loss of transmission line
- **Must** not lose stability during short-circuit

* 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**

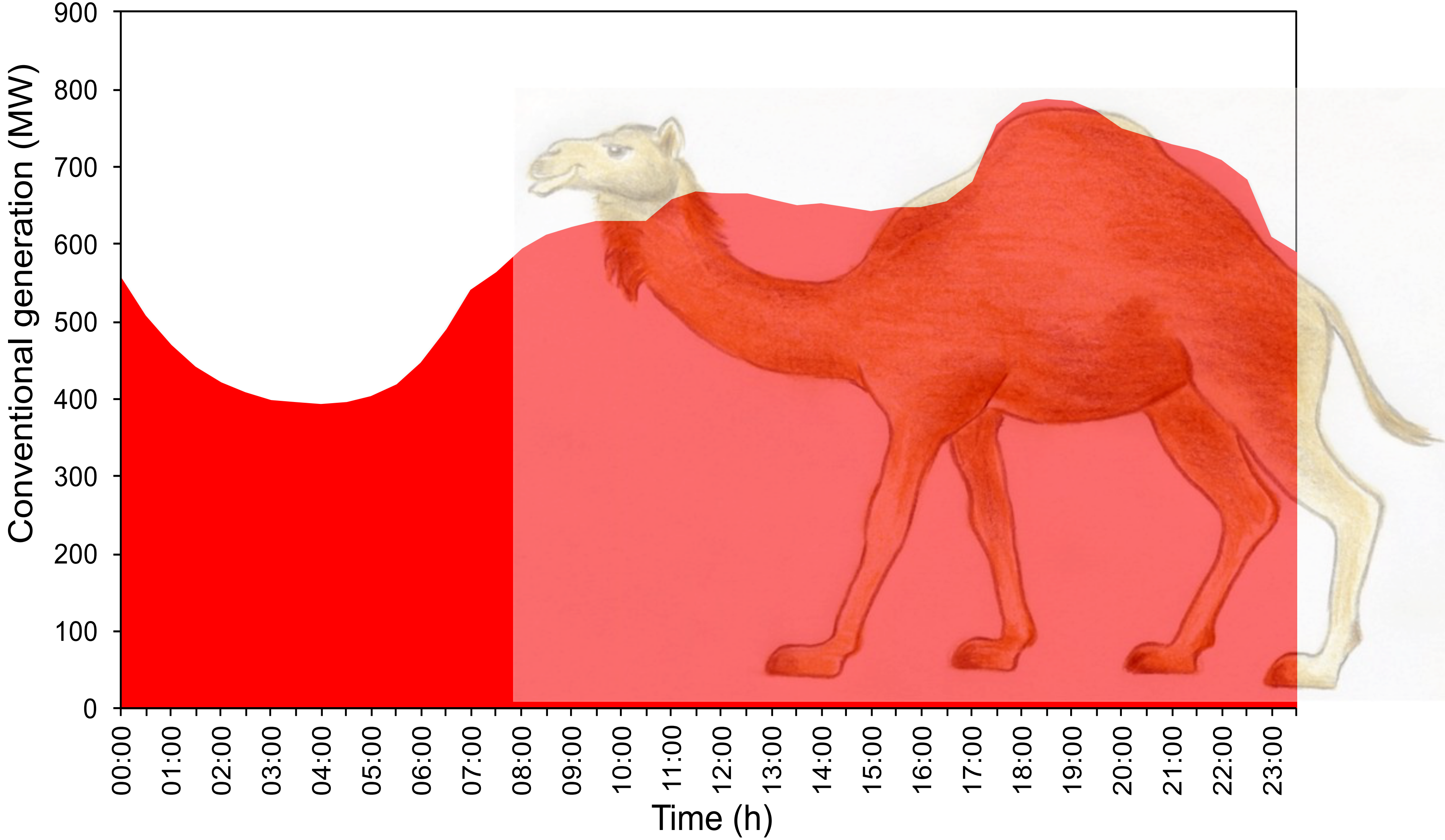


- **May be quite predictable**
- **Cannot be dispatched to meet the demand of a power system**

- **For dispatching need storage**

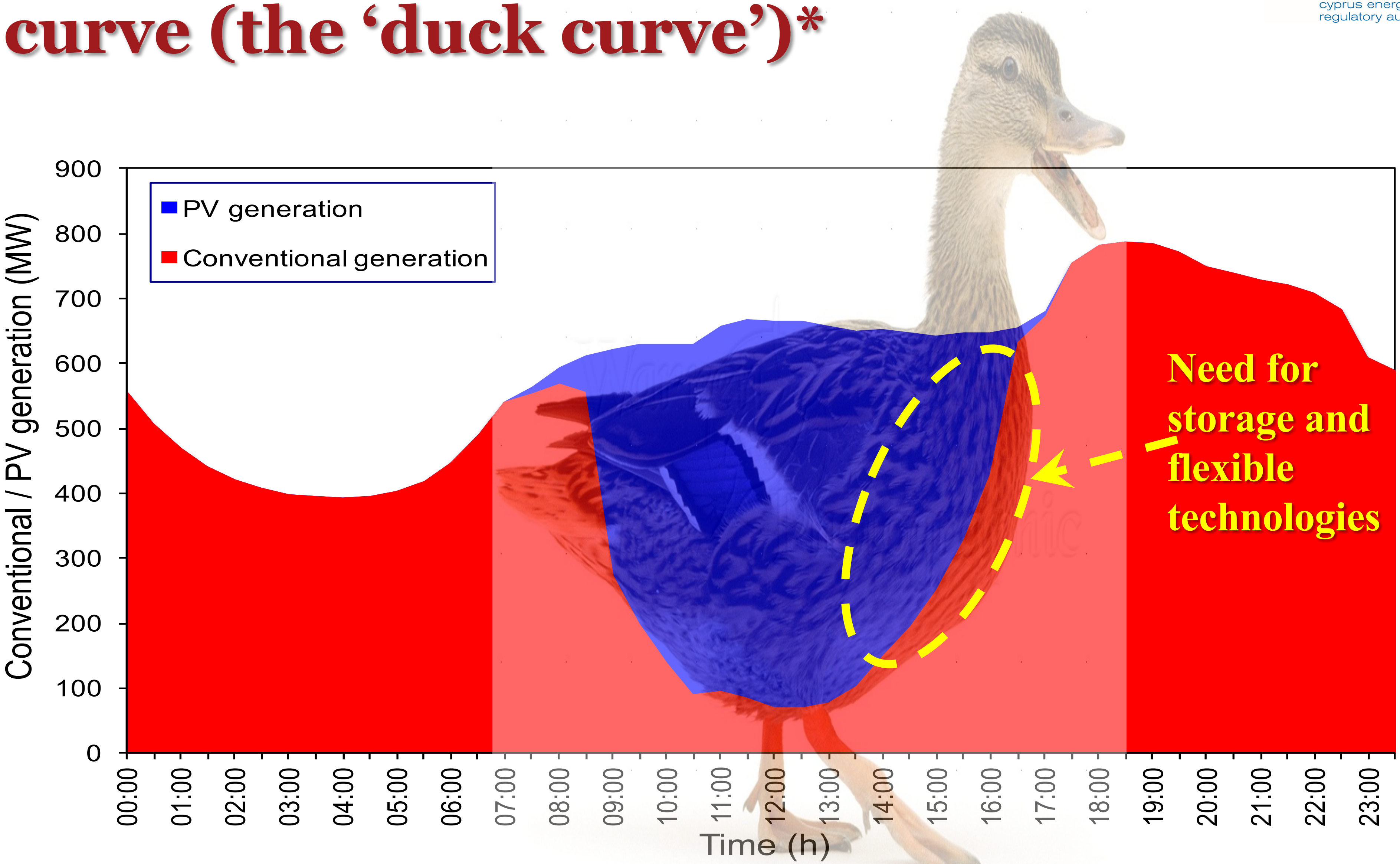
* Poullikkas A., 2013, *Renewable Energy: Economics, Emerging Technologies and Global Practices*, ISBN: 978-1-62618-231-8

Daily load curve (the ‘camel curve’)*



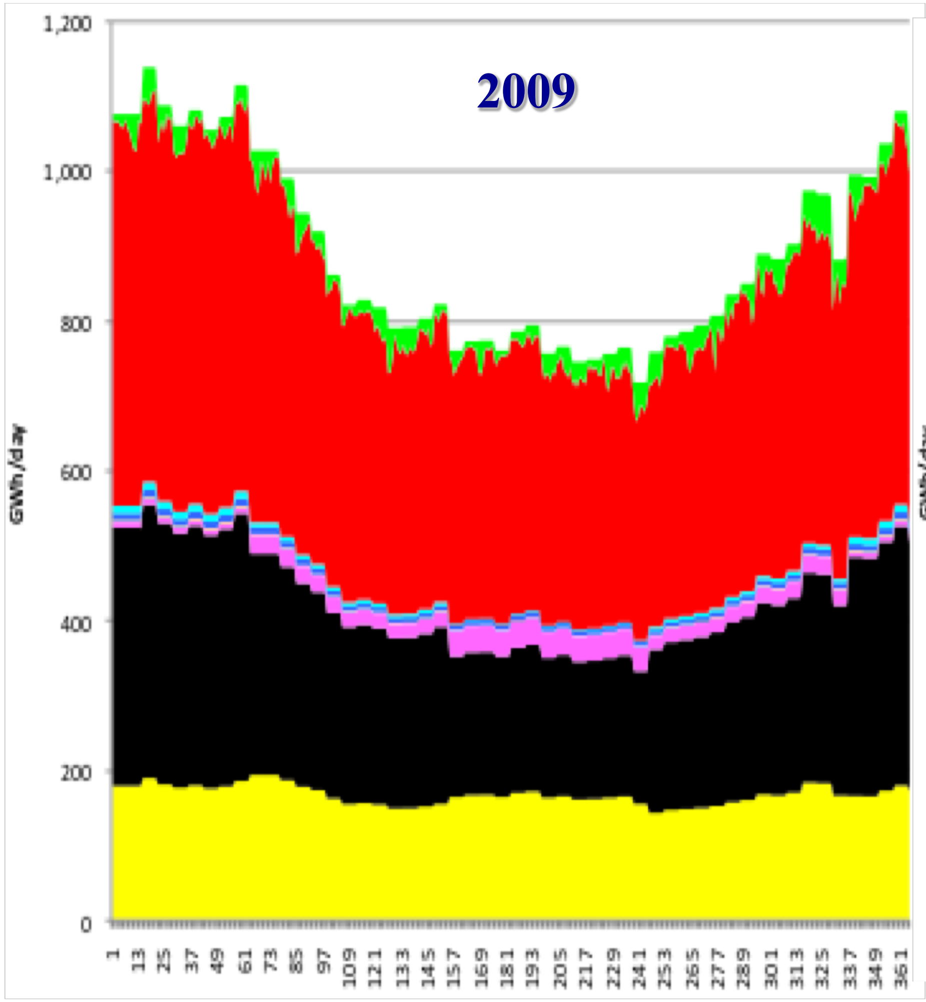
* **Poullikkas A., 2016, “From the ‘camel curve’ to the ‘duck curve’ on electric systems with increasing solar power”, *Accountancy***

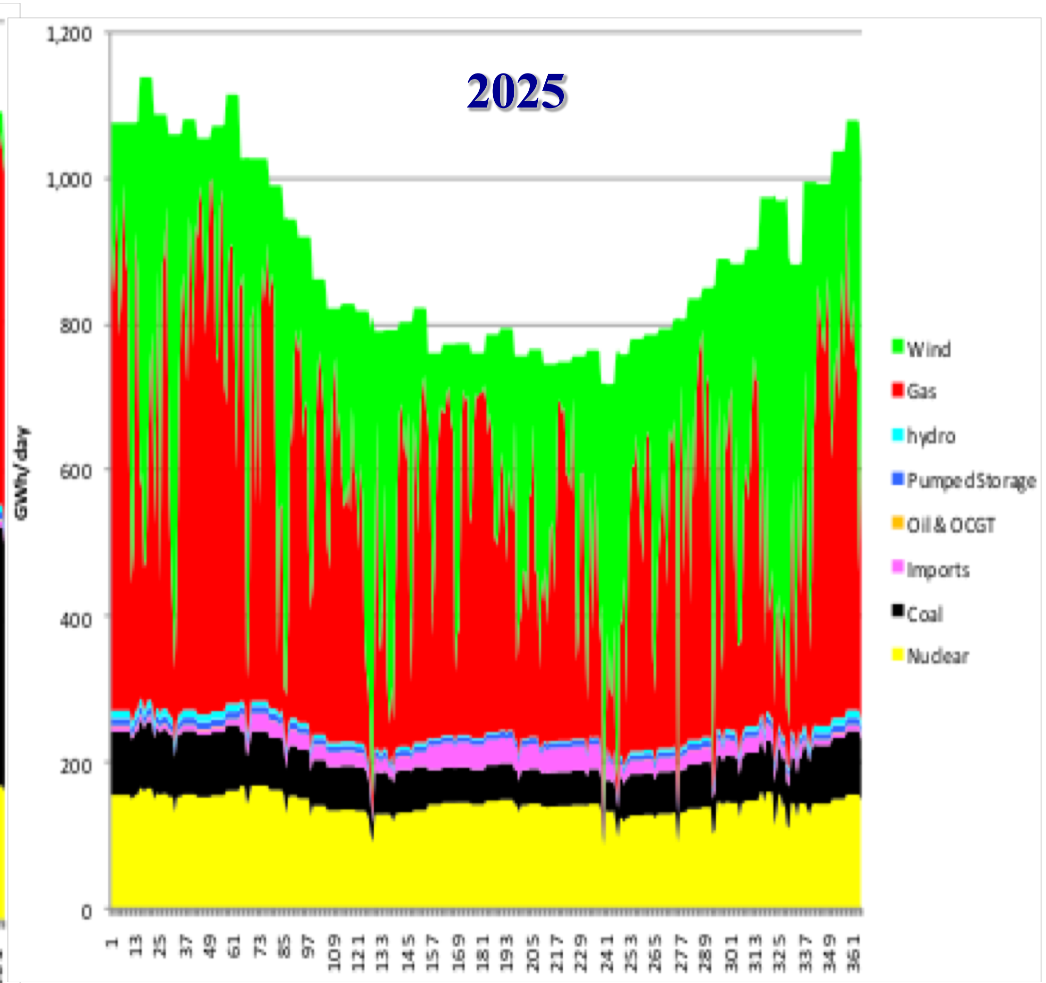
Effect of PV generation on load curve (the 'duck curve')*



* 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*)

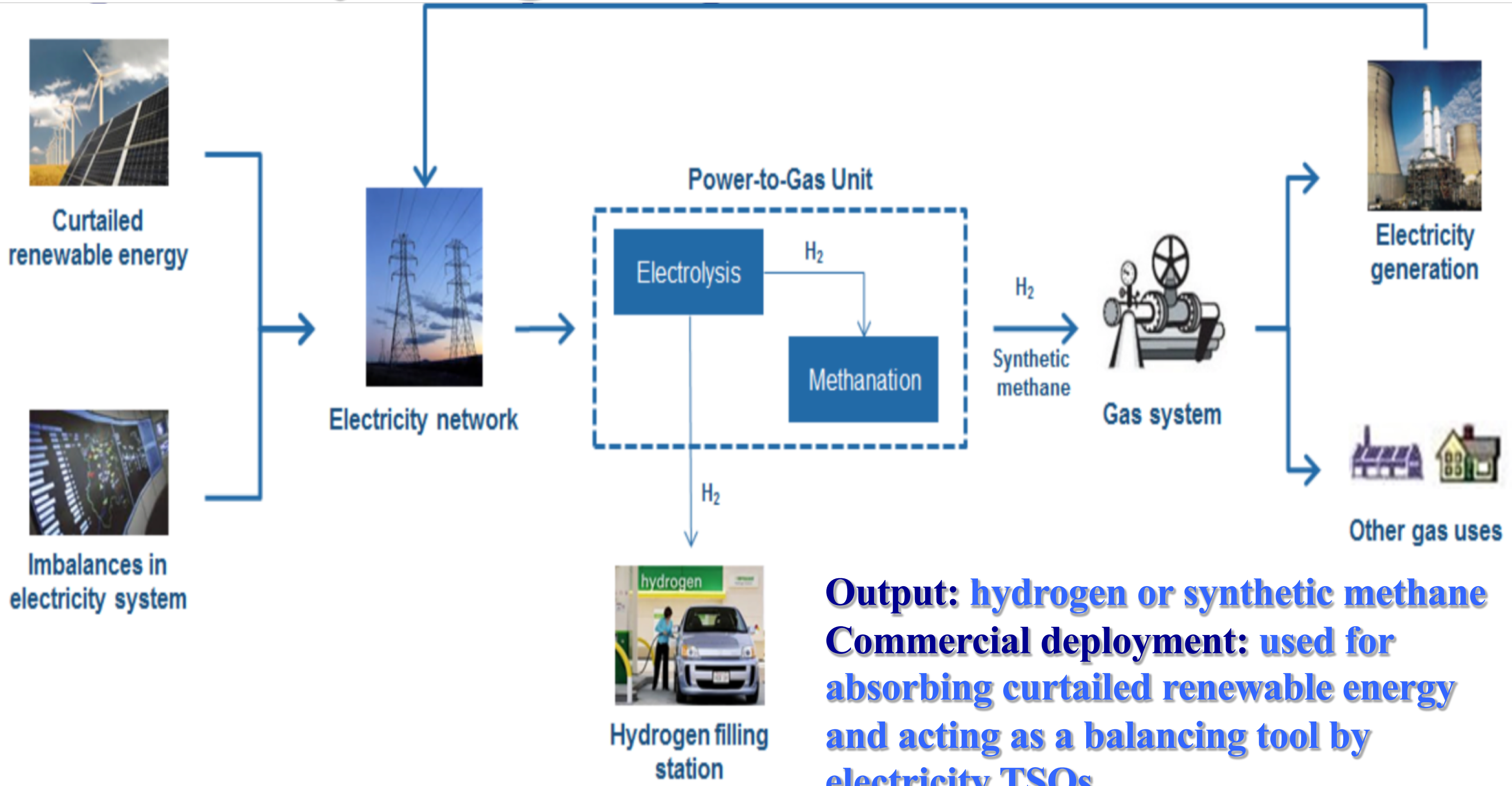




* H.V. Rogers, 2011, *The Impact of Import Dependence and Wind Generation on UK Gas Demand and Security of Supply to 2025*, The Oxford Institute For Energy Studies

Power-to-Gas (P2G)

- **energy storage technology linking the electricity and gas infrastructure**



Output: hydrogen or synthetic methane
Commercial deployment: used for absorbing curtailed renewable energy and acting as a balancing tool by electricity TSOs

Storage is the missing link

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High Temp Storage (HTS)	Redox Flow (RF)	Lithium Lead Carbon (LC)	Lithium Lithium-Iron-Phosphate

Advantage HTS:
- Very large storage
- 80% DOD
- Electricity, heat and AC generation
- Lowest Cost
- Minimum space
- 50 years LT

Disadvantage:
No fast response
E-Efficiency 40%
H-Efficiency 40%

Size: 3 - 50MWh

Advantage RF:
- Large storage
- 50-70% DOD
- High Power
- Lower cost
- No memory effect
- 15 to 20 years LT

Disadvantage:
Low Energy Density
No fast response
Efficiency < 80%

Size: 1 - 10MWh

Advantage LC:
- Large storage
- 50-70% DOD
- High power
- Lower cost
- Efficiency > 85%
- 10-15 years LT

Disadvantage:
Medium Energy Density
High Weight
Efficiency 80%

Size: 0,1 - 10MWh

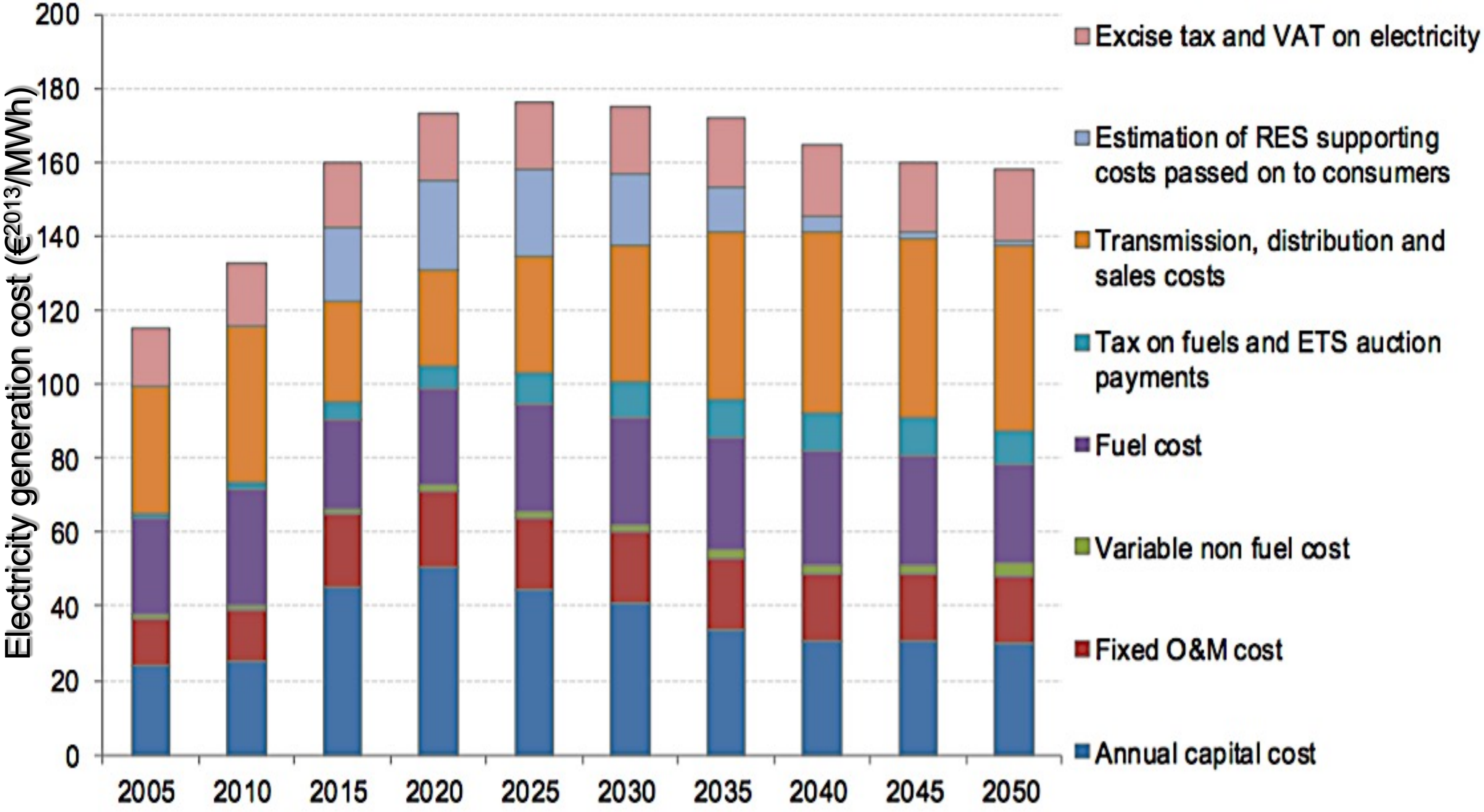
Advantage Lithium:
- Fast response
- Quick Service
- 80% DOD
- High Power
- Efficiency > 95%
- No Memory effect
- Highest energy density
- 15 to 20 years LT

Disadvantage:
High Cost

Size: 0,1 - 10MWh

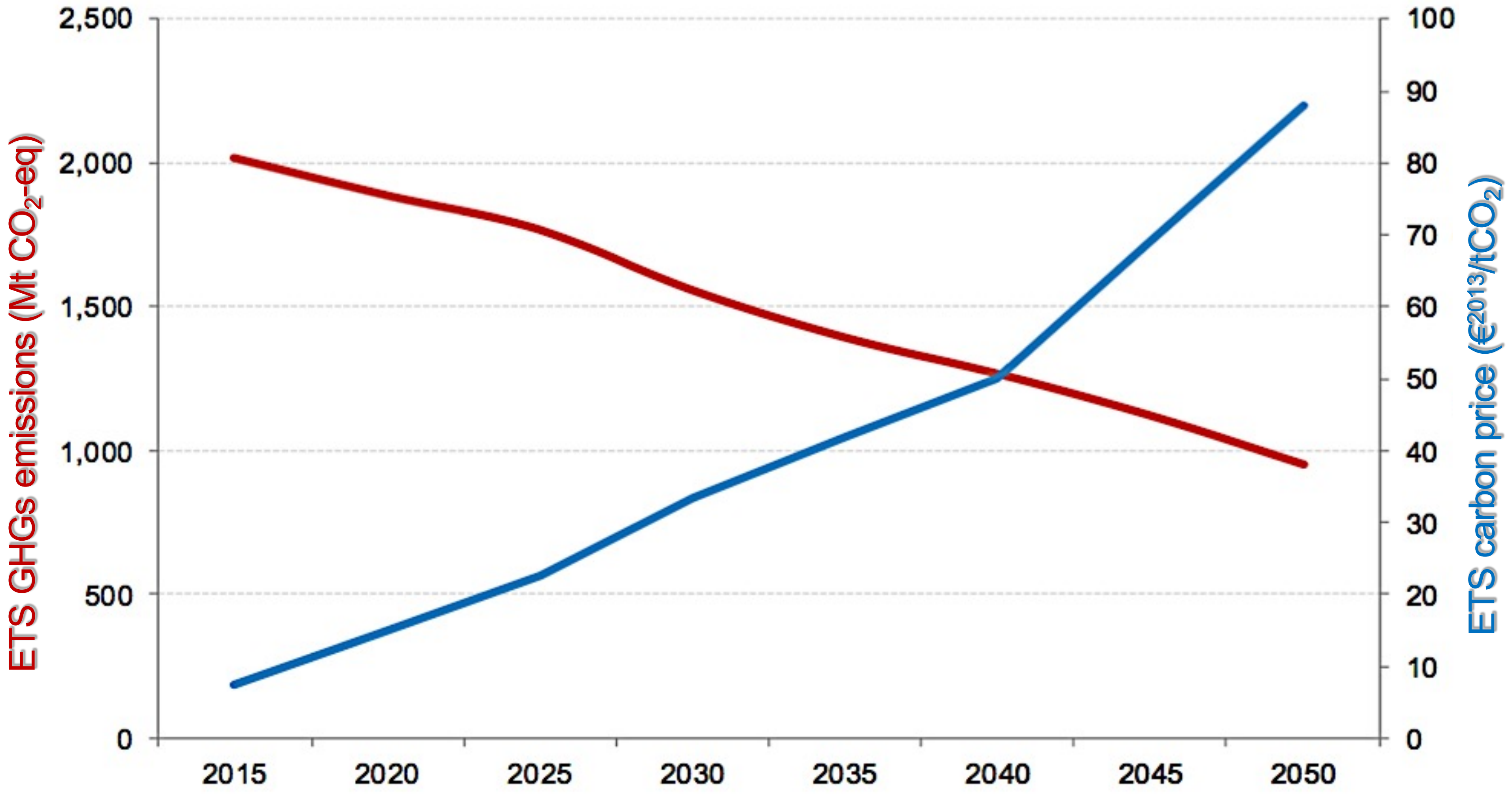
Energy cost

EU reference scenario 2016



Source: PRIMES

EU reference scenario 2016



Source: PRIMES, GAINS

Power generation cost (year 2010)*

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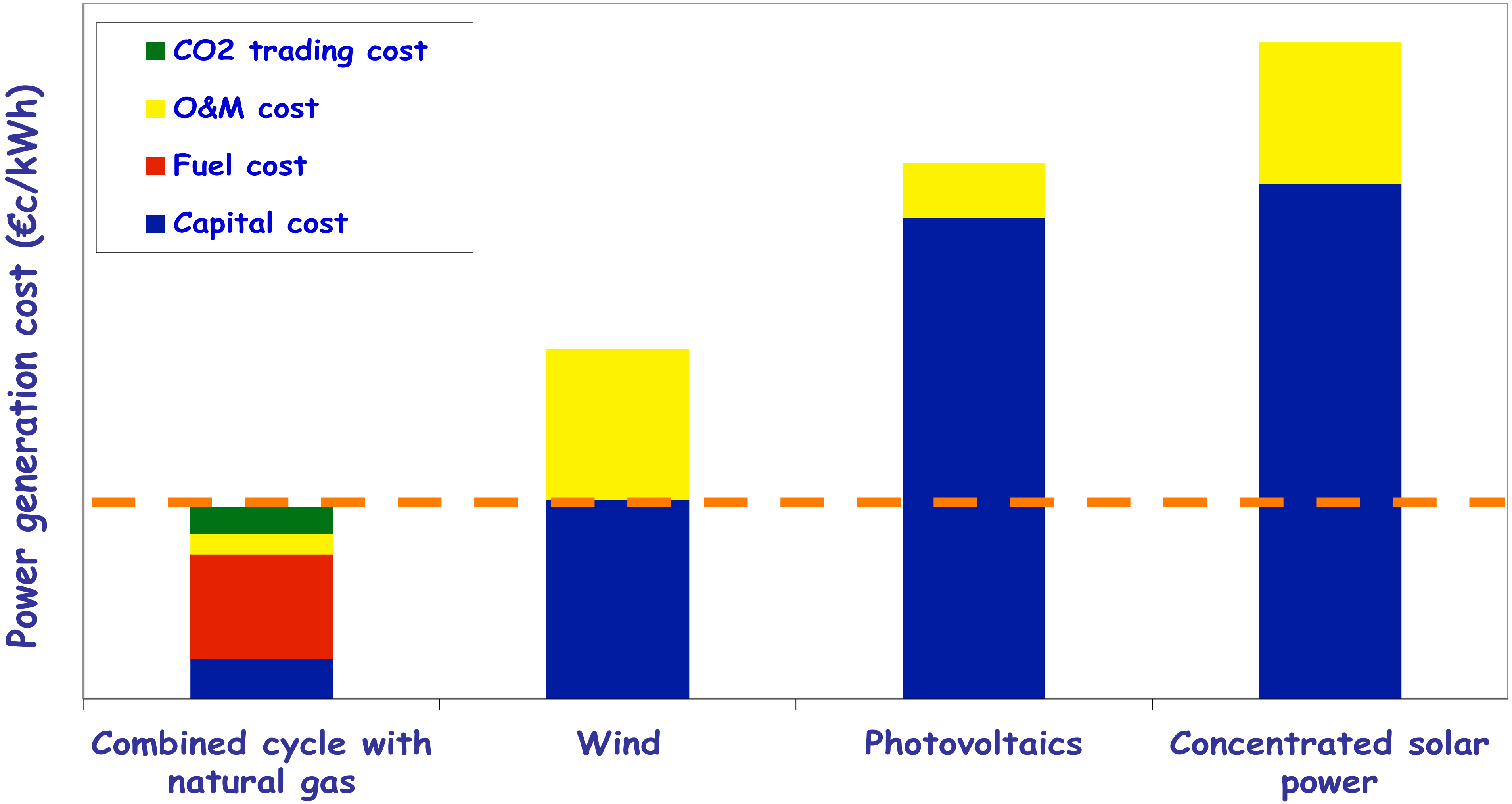
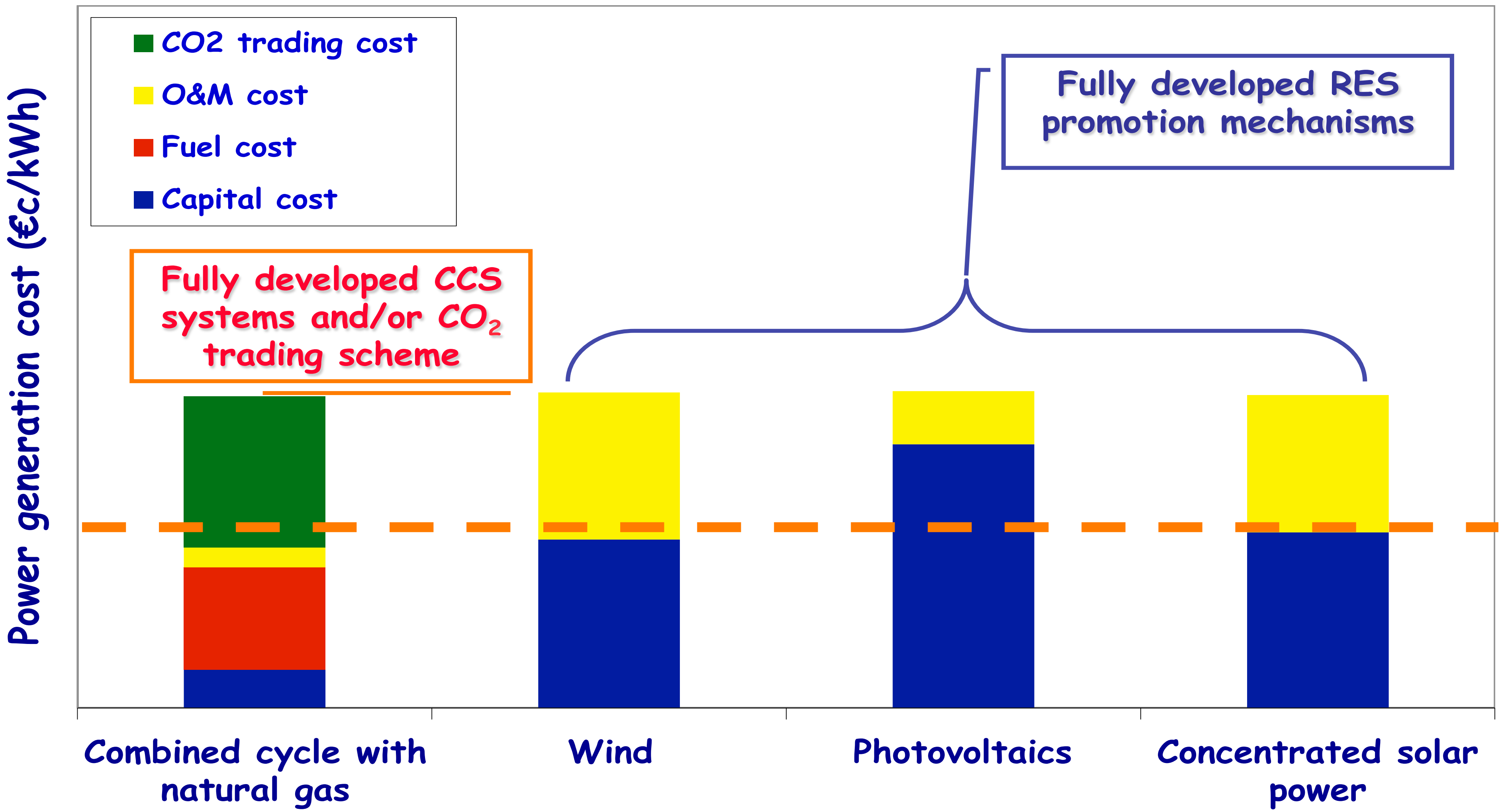


* Poullikkas A., 2010, "The cost of integration of renewable energy sources", *Accountancy*

Power generation cost (year 2020-30)*



* Poullikkas A., 2010, "The cost of integration of renewable energy sources", *Accountancy*

Power generation cost (year 2040-50)*

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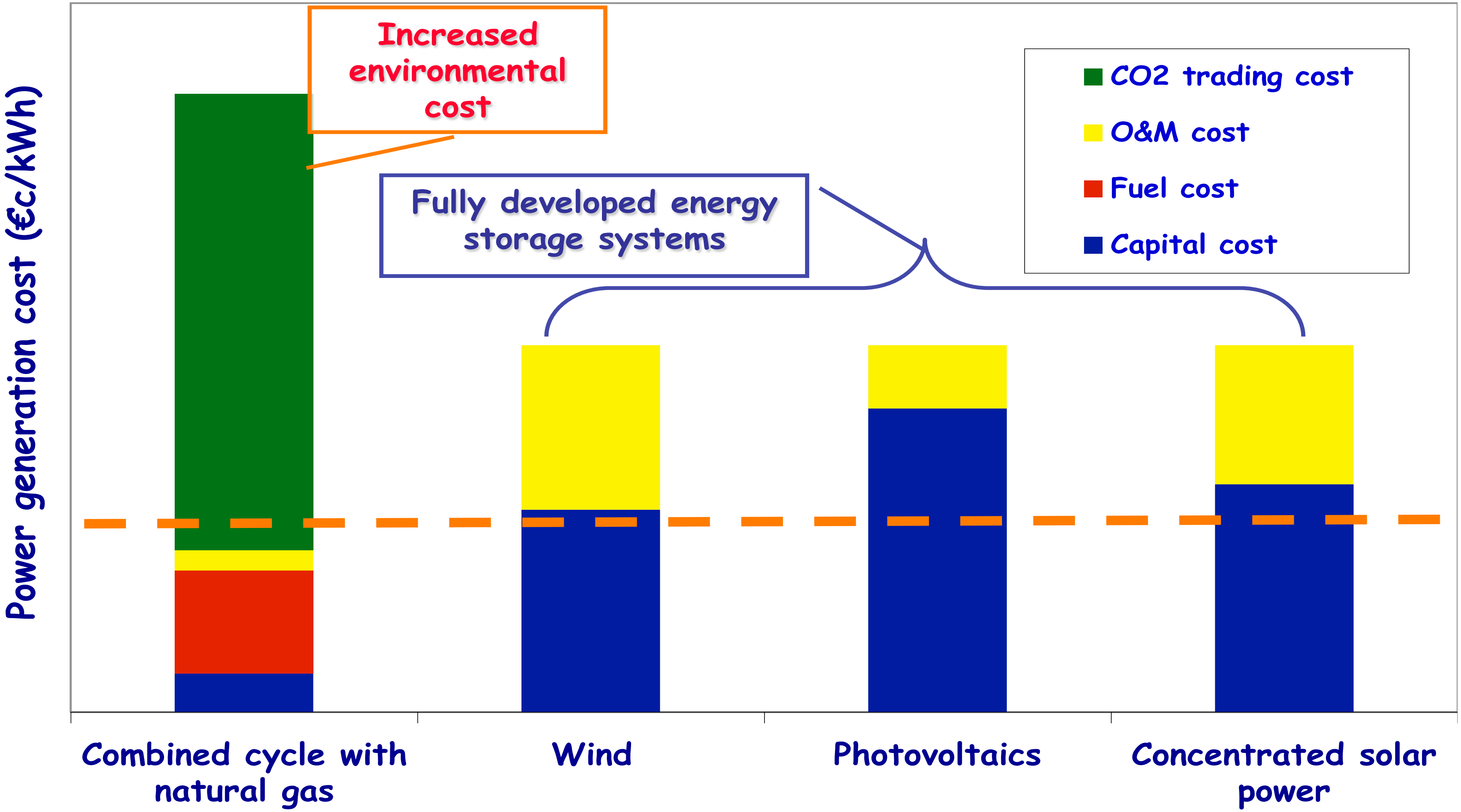
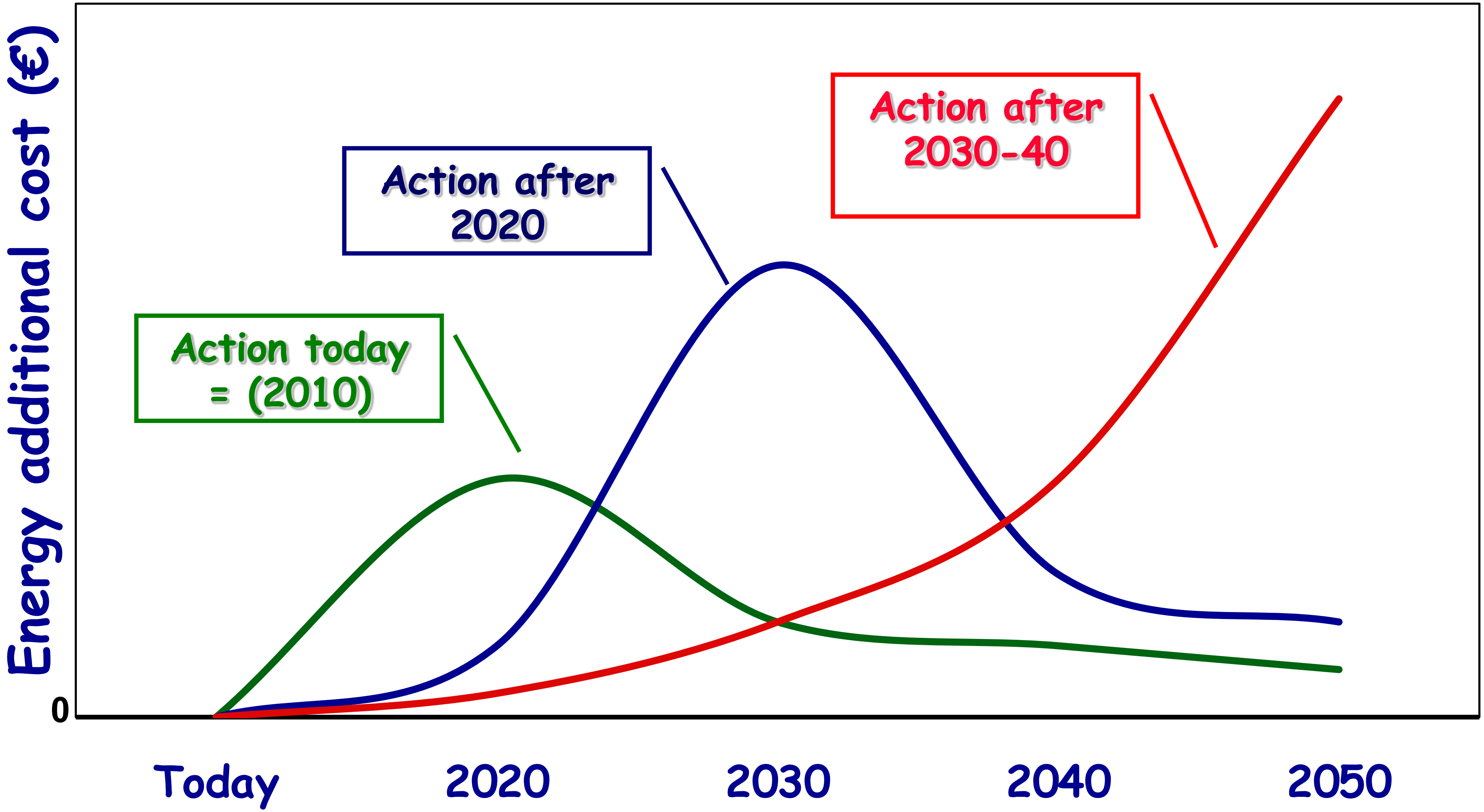


* Poullikkas A., 2010, "The cost of integration of renewable energy sources", *Accountancy*

Future energy cost* (for EU only)



* Poullikkas A., 2010, "The cost of integration of renewable energy sources", *Accountancy*

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

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

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

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

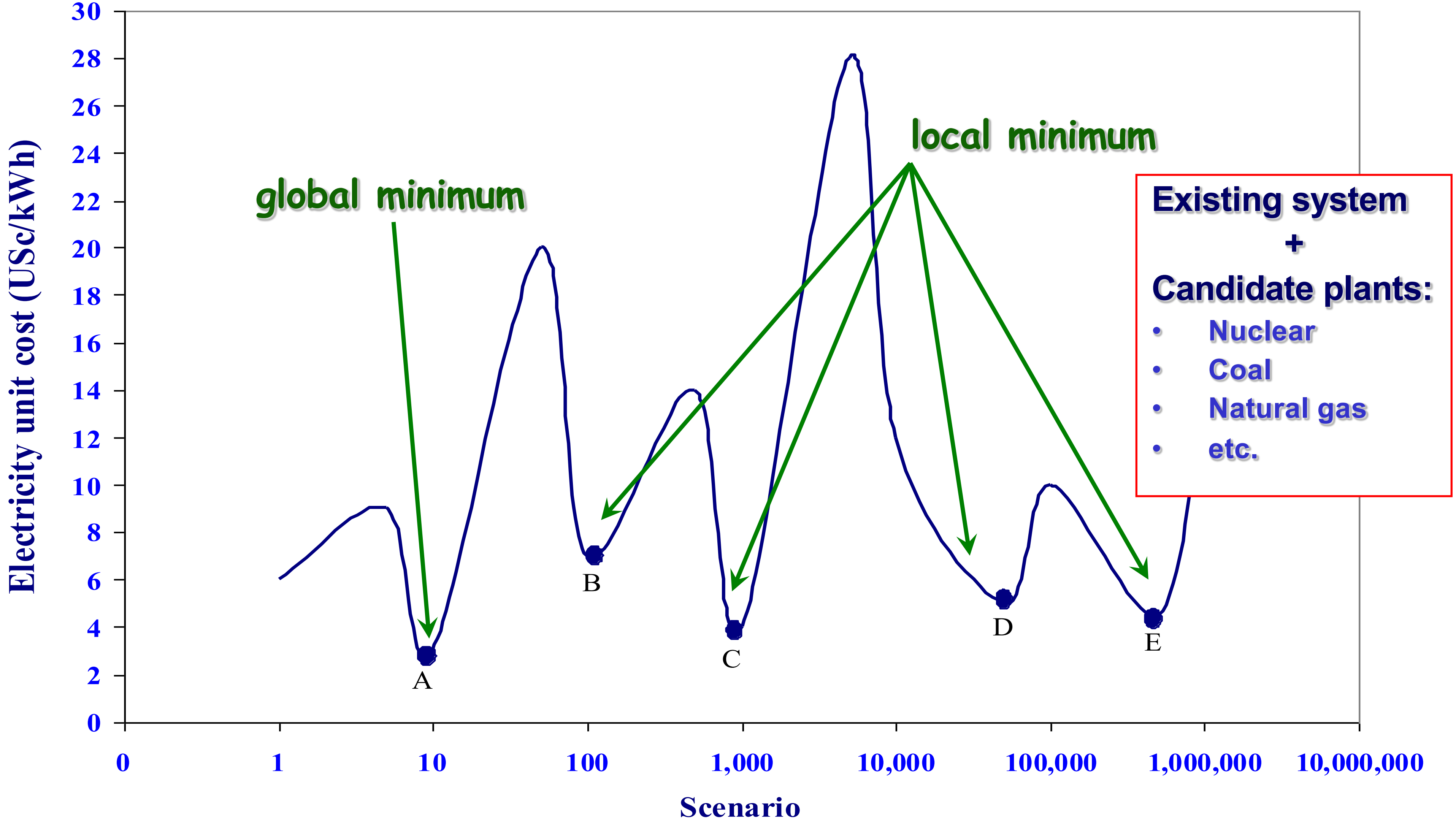
$$R_{S(t)} \le \sum_i r_{s(i,t)} I_{(i,t)} \qquad r_{s(i,t)} = \min\left[10MSR_i , P_{g,\max(i)} - P_{(i,t)}\right]$$

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

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

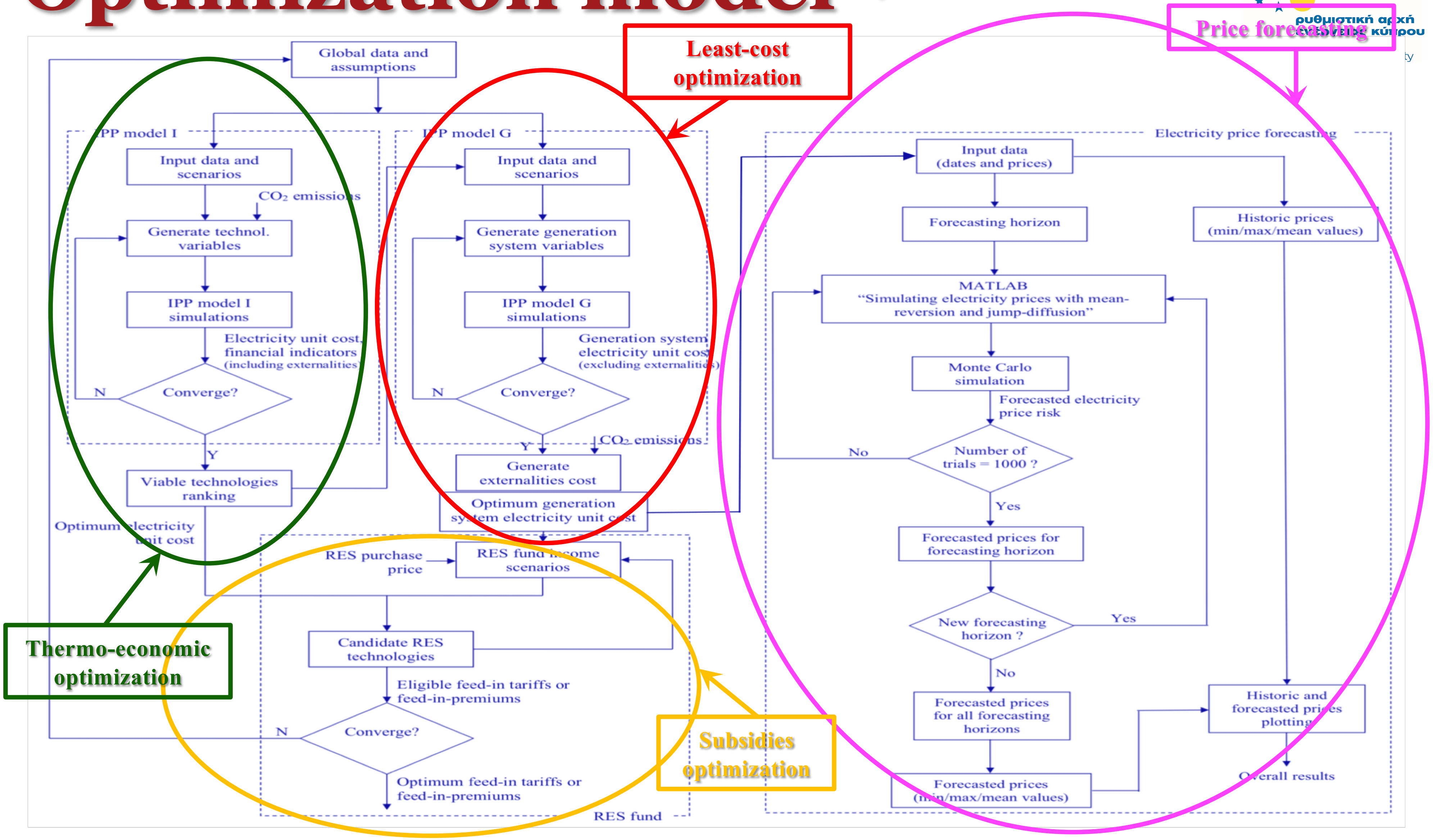
* Poullikkas A., 2009, "A decouple optimization method for power technology selection in competitive markets", *Energy Sources*

Typical shape of objective function*



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

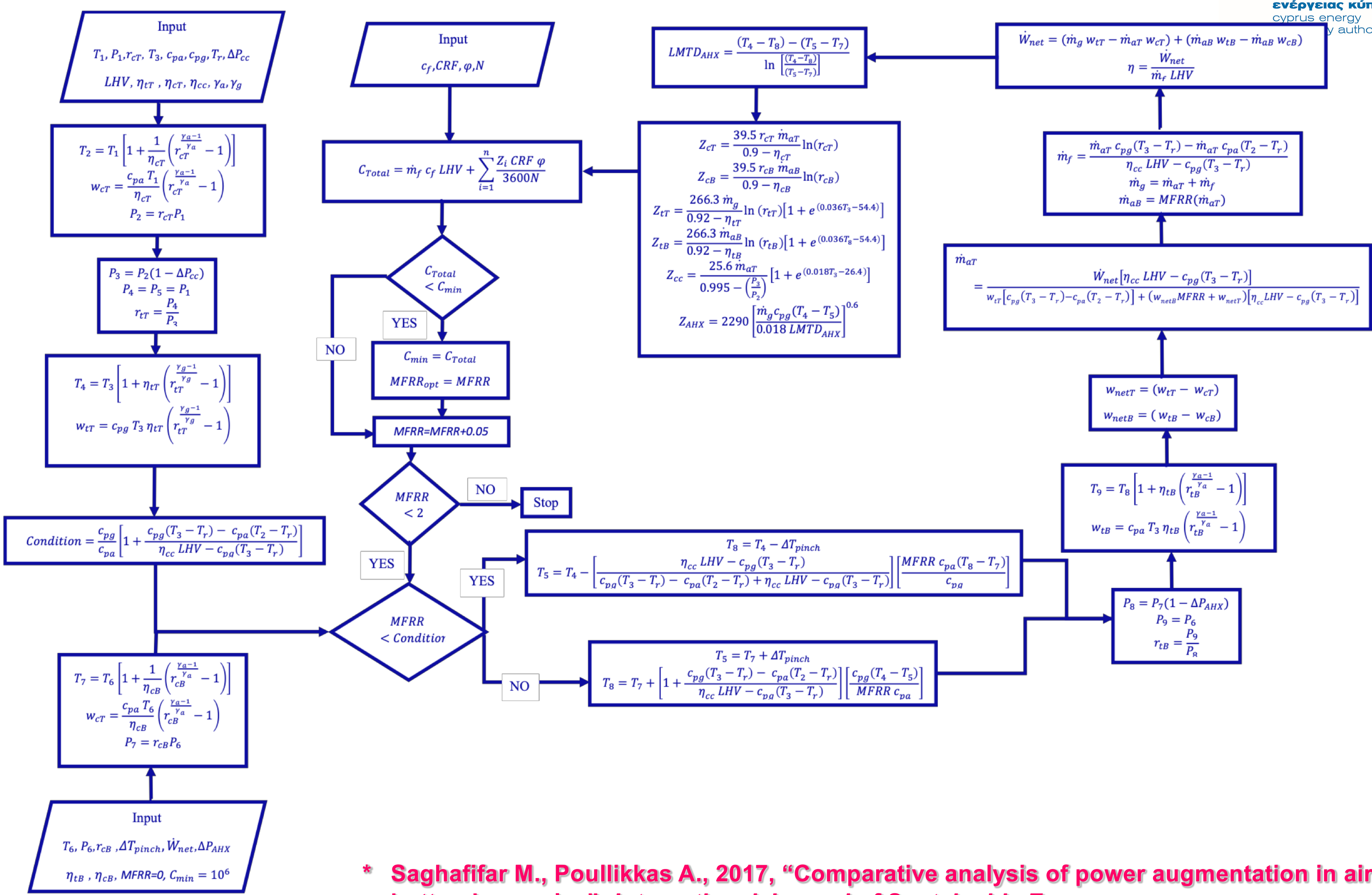
Optimization model*,**



* 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*

Example of thermo-economic optimization*



* **Saghafifar M., Poullikkas A., 2017, "Comparative analysis of power augmentation in air bottoming cycles", *International Journal of Sustainable Energy*.**

Decoupled objective function*

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

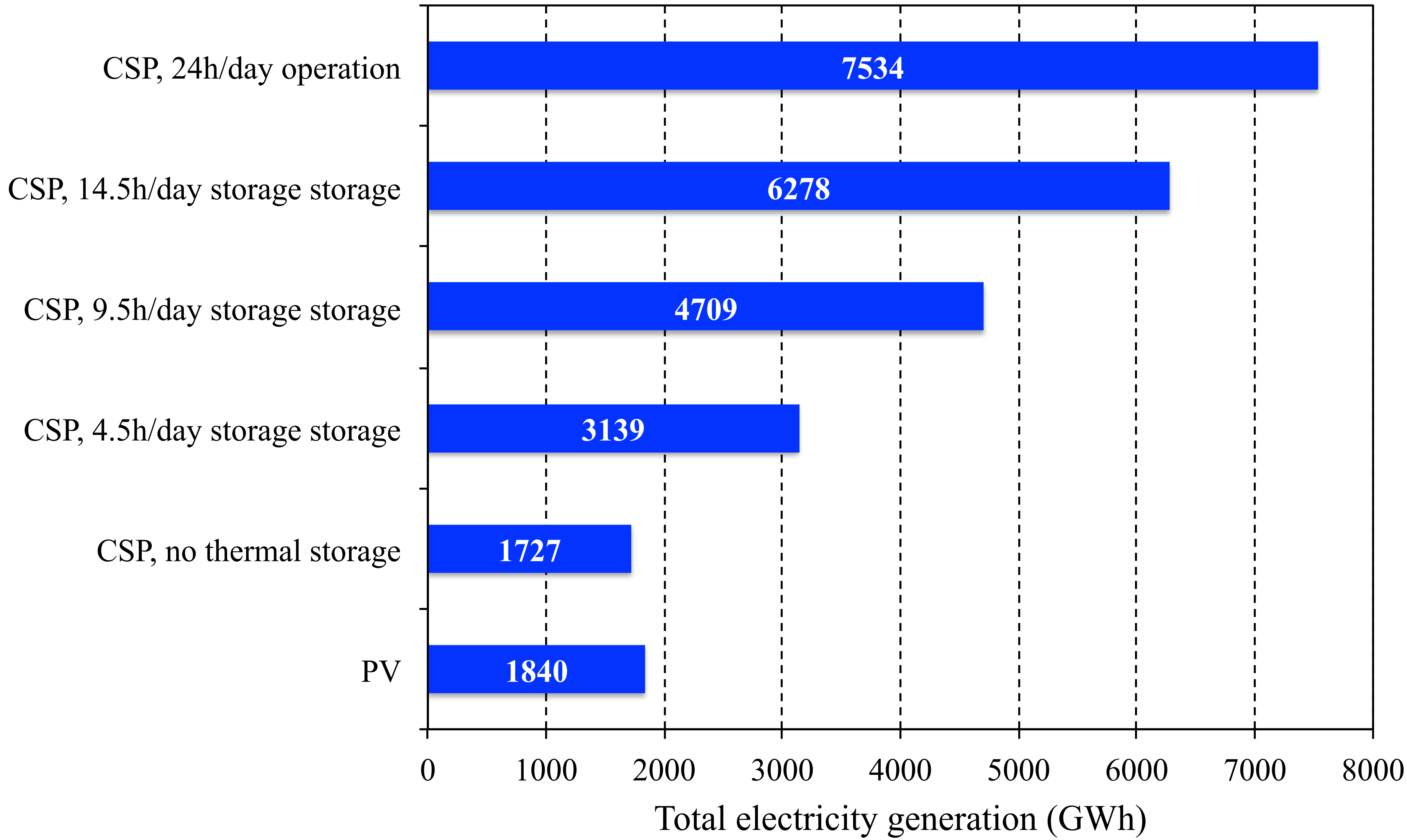
$$\min\left(\frac{\partial c}{\partial k}\right) = \min\left\{ \frac{\sum_{j=0}^{N}\left[\frac{\frac{\partial C_{Cj}}{\partial k} + \frac{\partial C_{Fj}}{\partial k} + \frac{\partial C_{OMFj}}{\partial k} + \frac{\partial C_{OMVj}}{\partial k}}{(1+i)^{j}}\right]}{\sum_{j=0}^{N}\left[\frac{\frac{\partial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

Electricity unit cost ($c/kWh)

Energy (kWh)

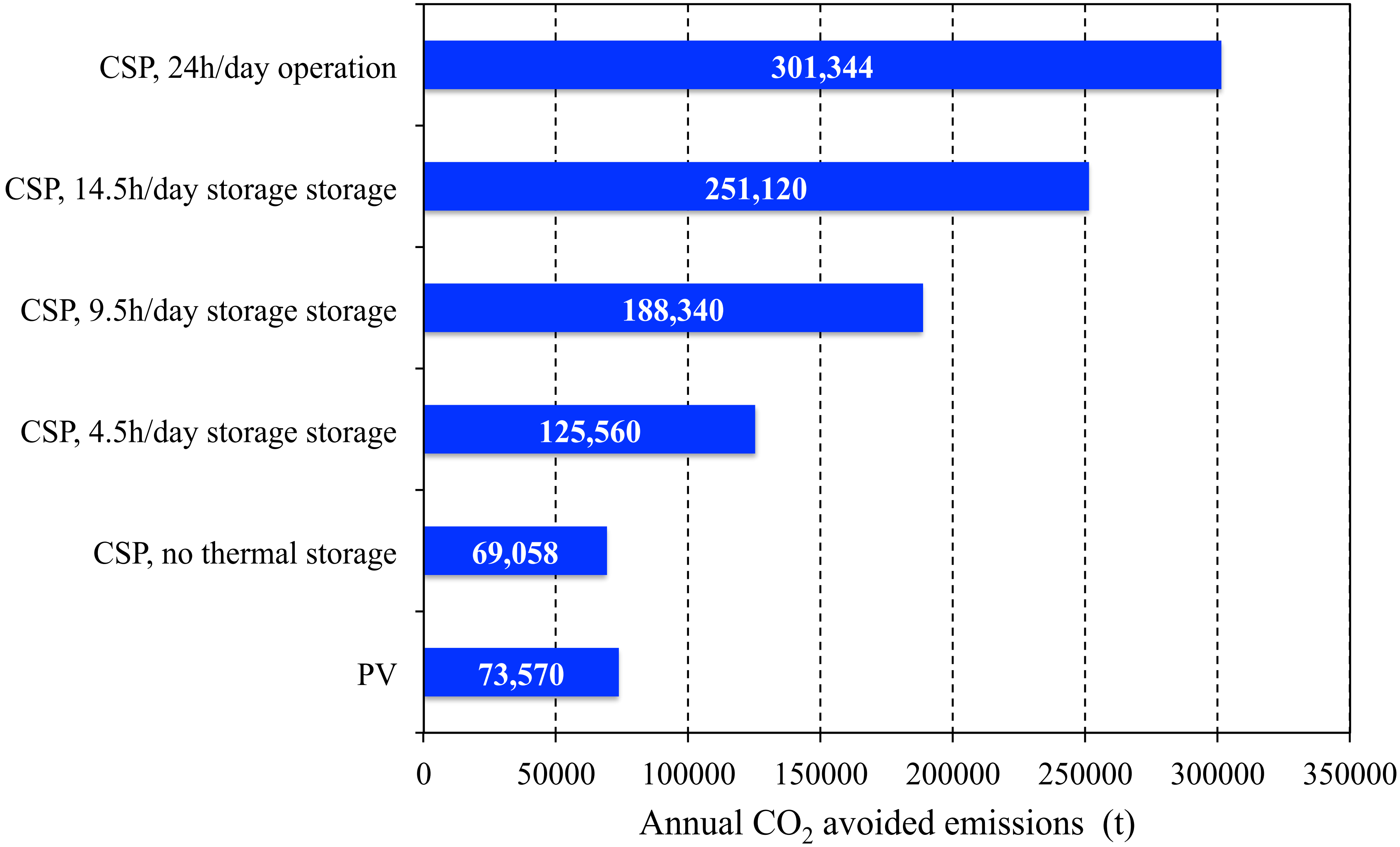
* Poullikkas A., *IPP algorithm version 2.1*, User manual, © 2000-2006

Total electricity generation for 50MW (20y)*



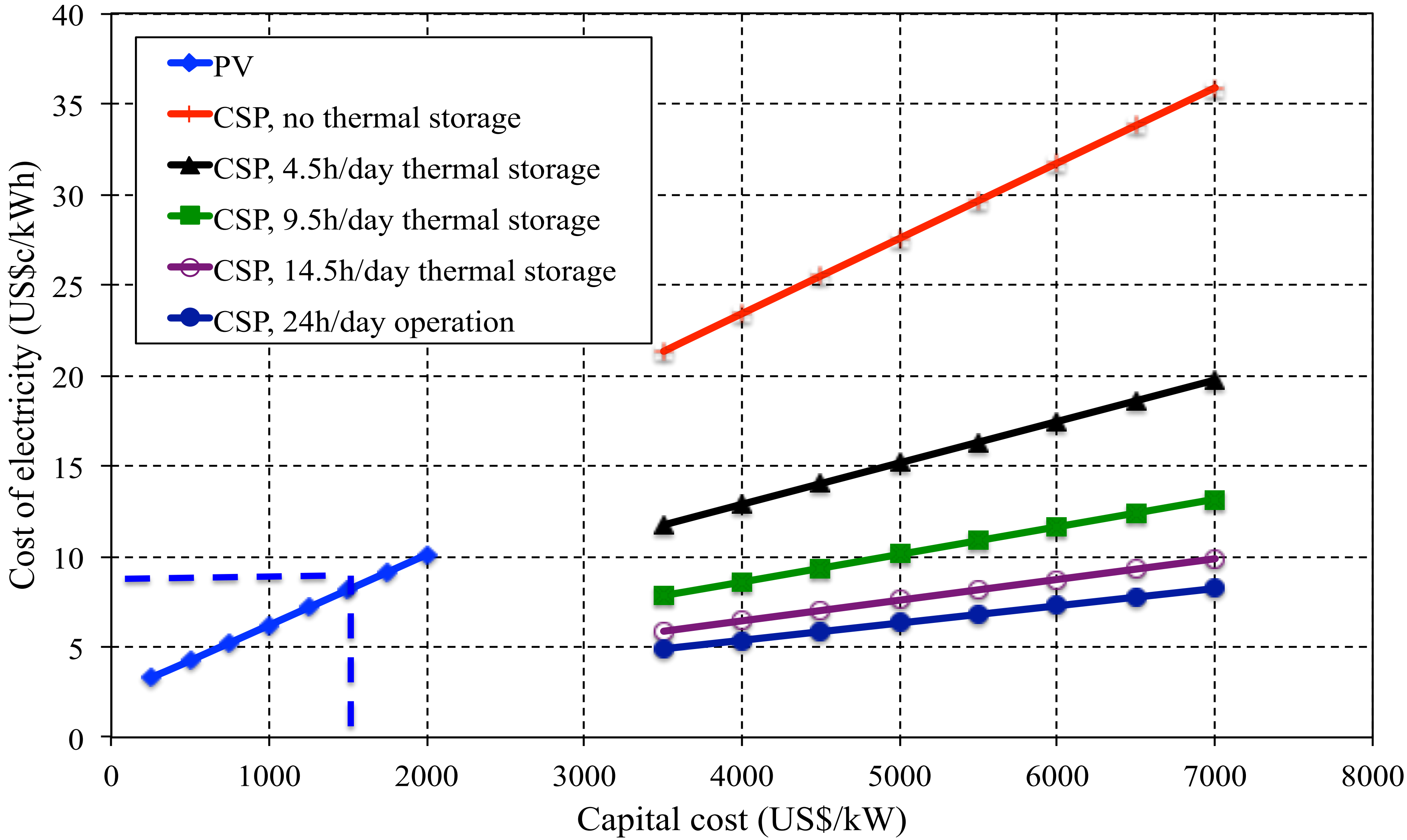
* Poullikkas A., Gadalla M., 2013, "Assessment of solar electricity production in United Arab Emirates", *International Journal of Sustainable Energy*

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*

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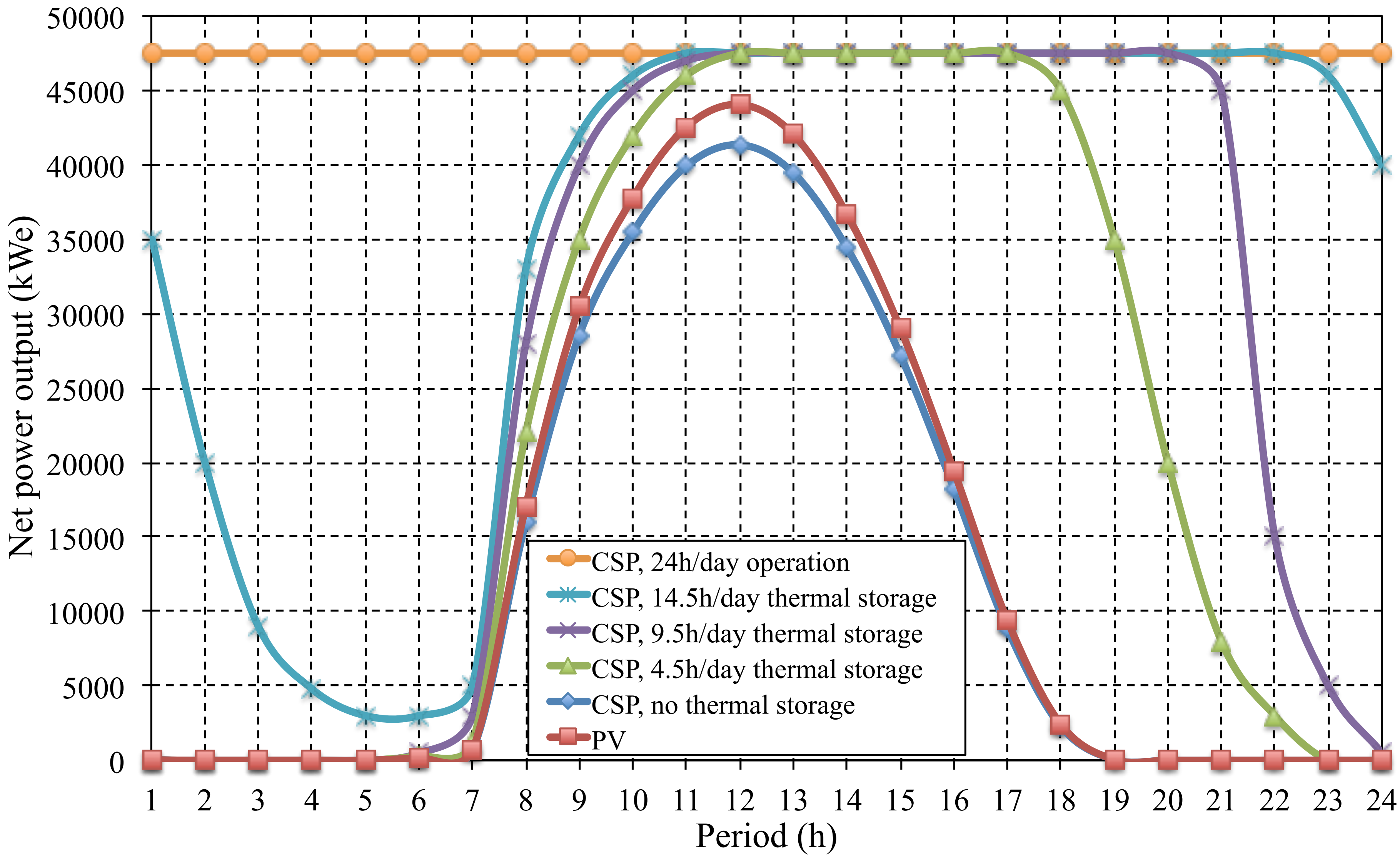
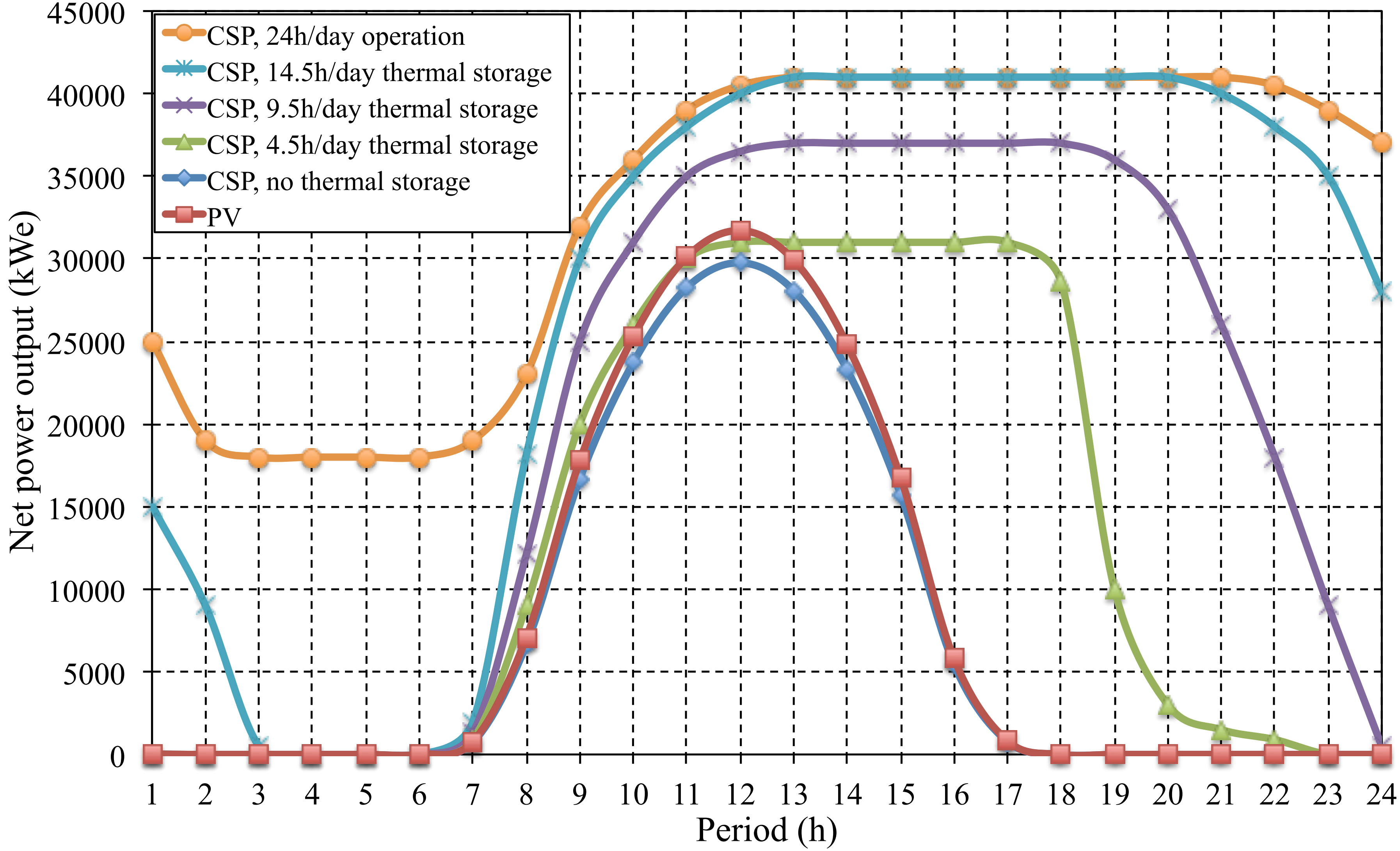


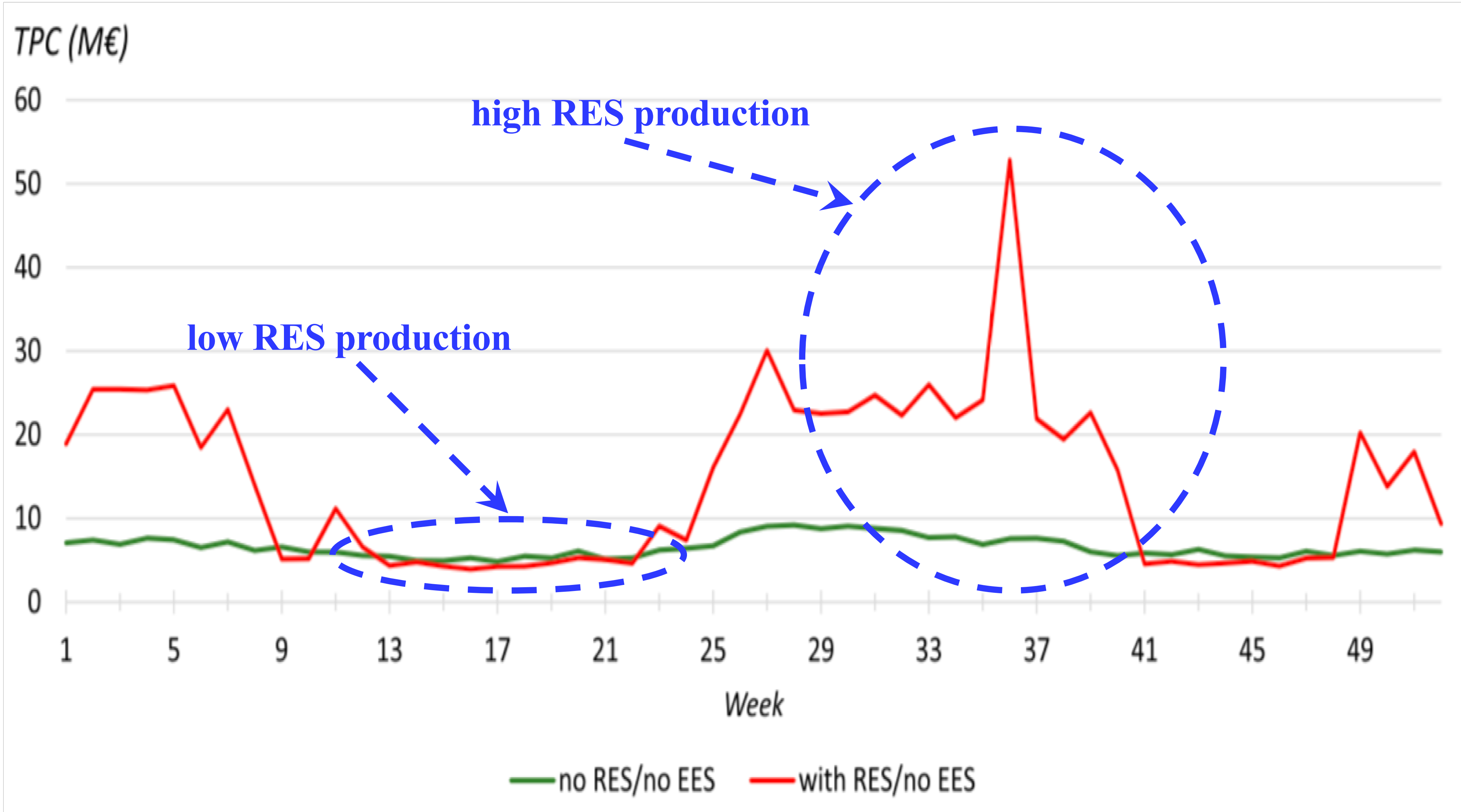
* **Poullikkas A., Gadalla M., 2013, "Assessment of solar electricity production in United Arab Emirates",** ***International Journal of Sustainable Energy***

Typical net power output profile during winter*



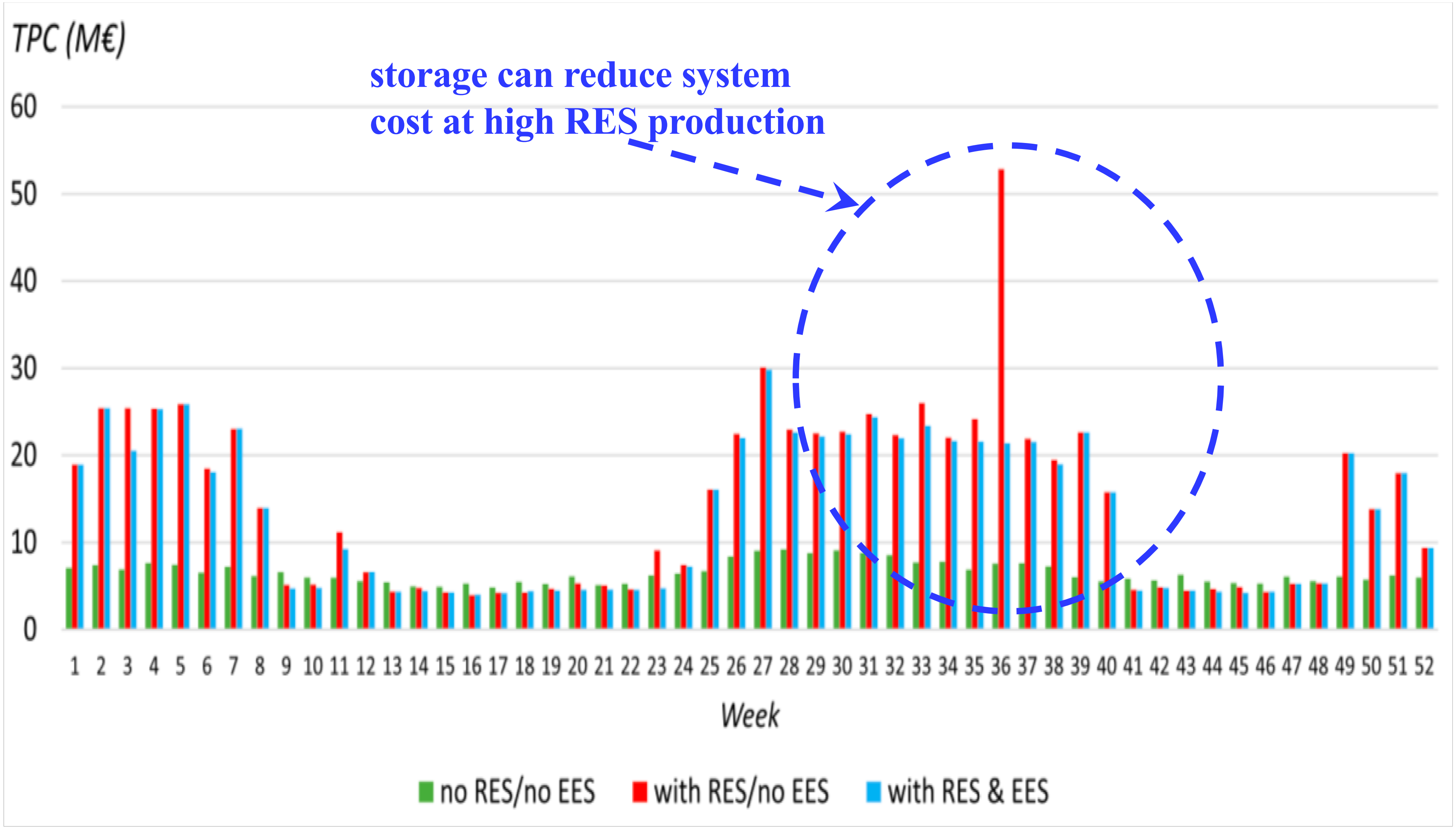
* **Poullikkas A., Gadalla M., 2013, "Assessment of solar electricity production in United Arab Emirates", *International Journal of Sustainable Energy***

Cost of reserves with RES production*



* **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*