Energy strategies towards hydrogen economy

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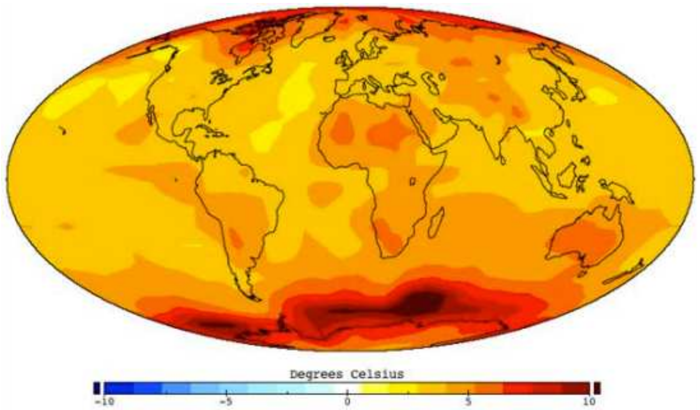
EU energy strategy

towards 2050

Future energy systems

- **Climate change**

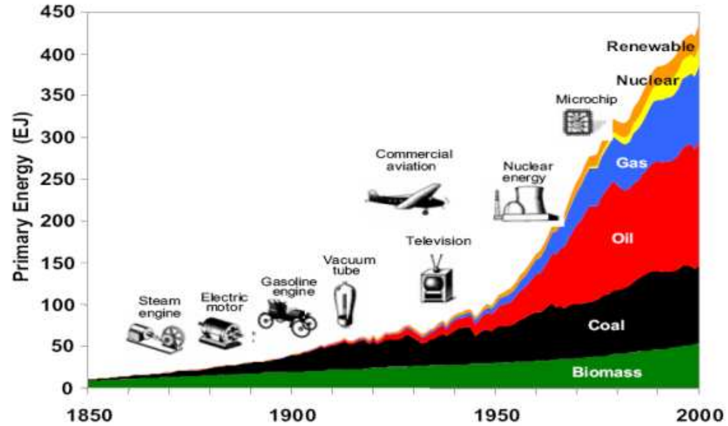


- **Third energy revolution**

- **Future energy economics**

EU energy objectives

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



Sustainable energy

… provision of energy that meets the needs of the present without compromising the ability of future generations to meet their needs …

Sustainable technologies

… technologies that promote sustainable energy include renewable energy sources as well as technologies designed to improve energy efficiency …

EU medium and long term targets

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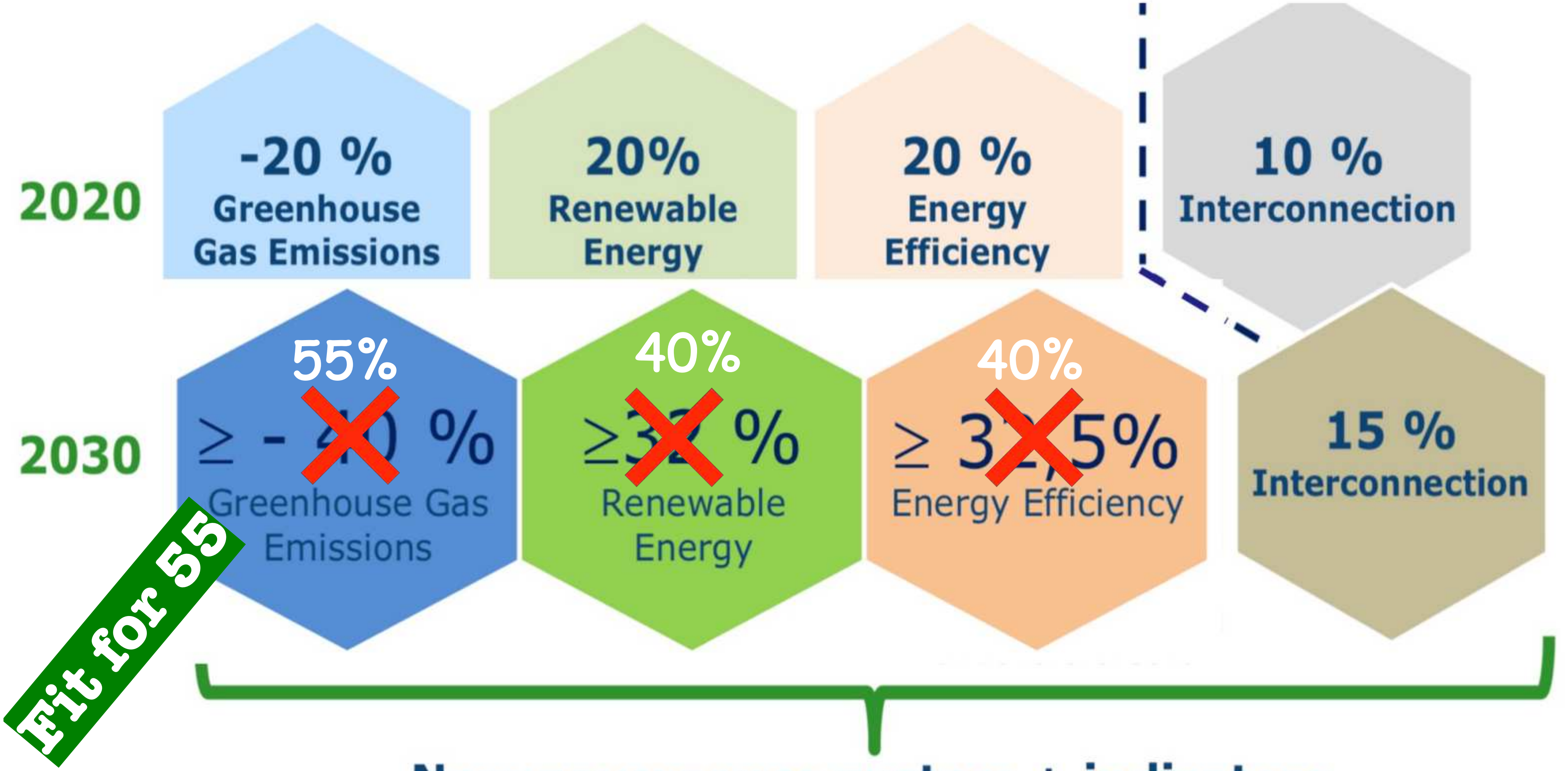
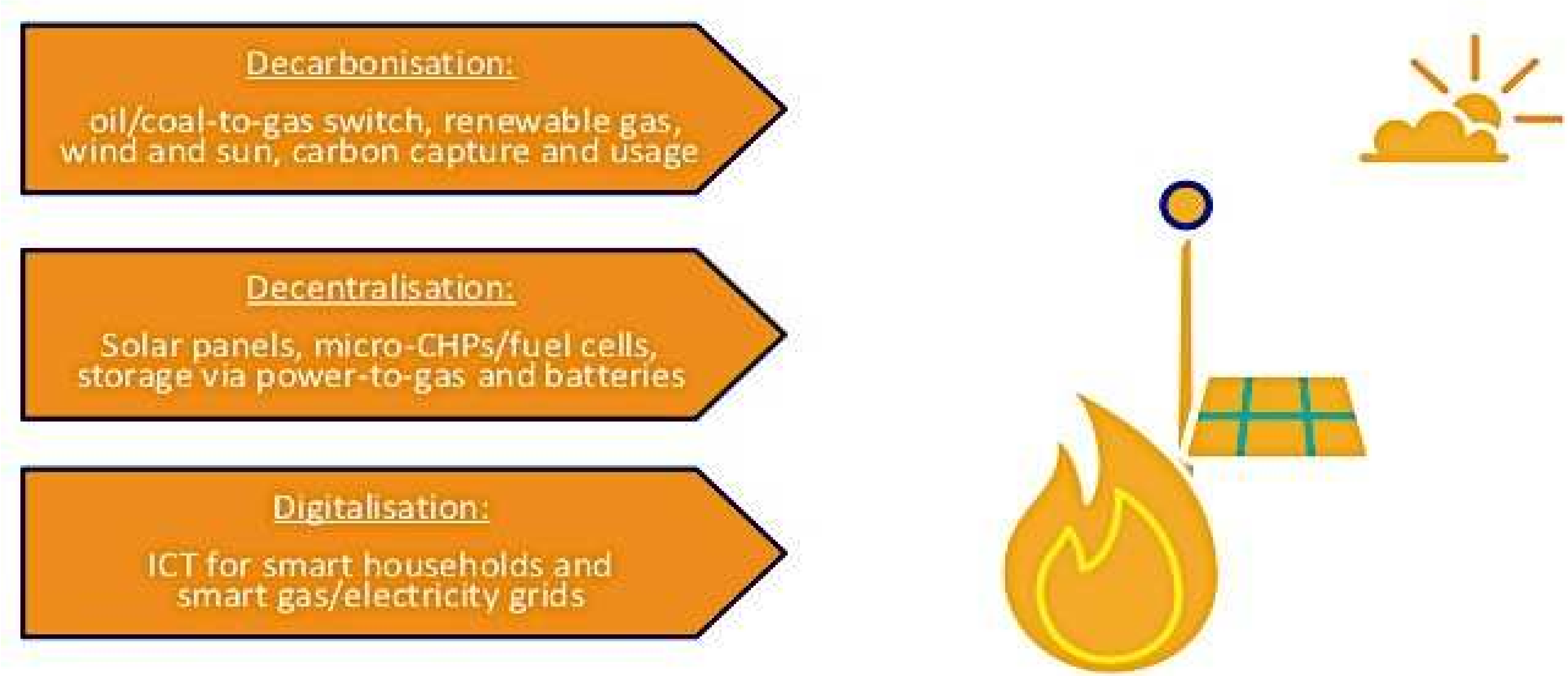


New governance system + indicators

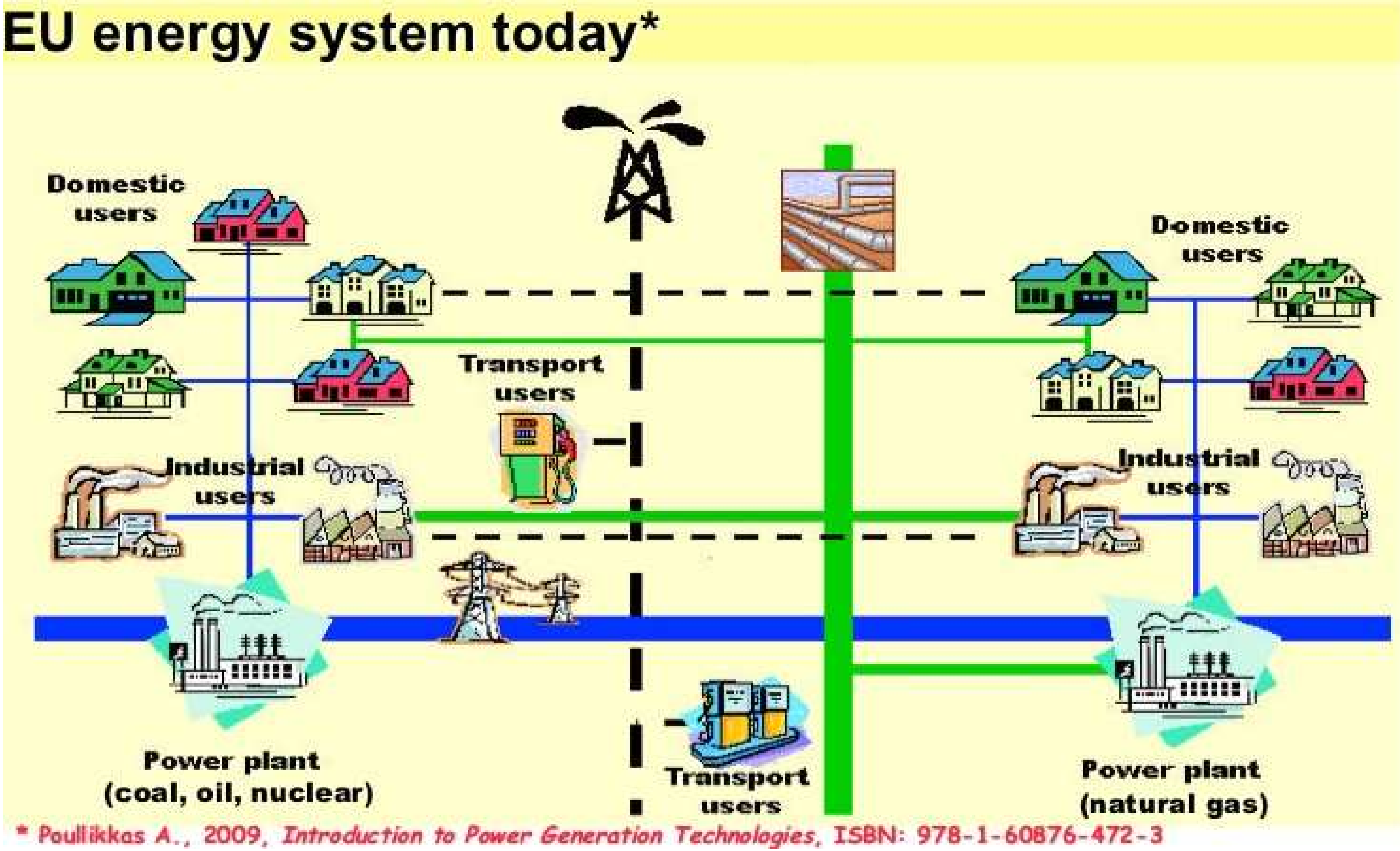
2050	**-80%**	**Greenhouse Gas Emissions**

Our energy future?

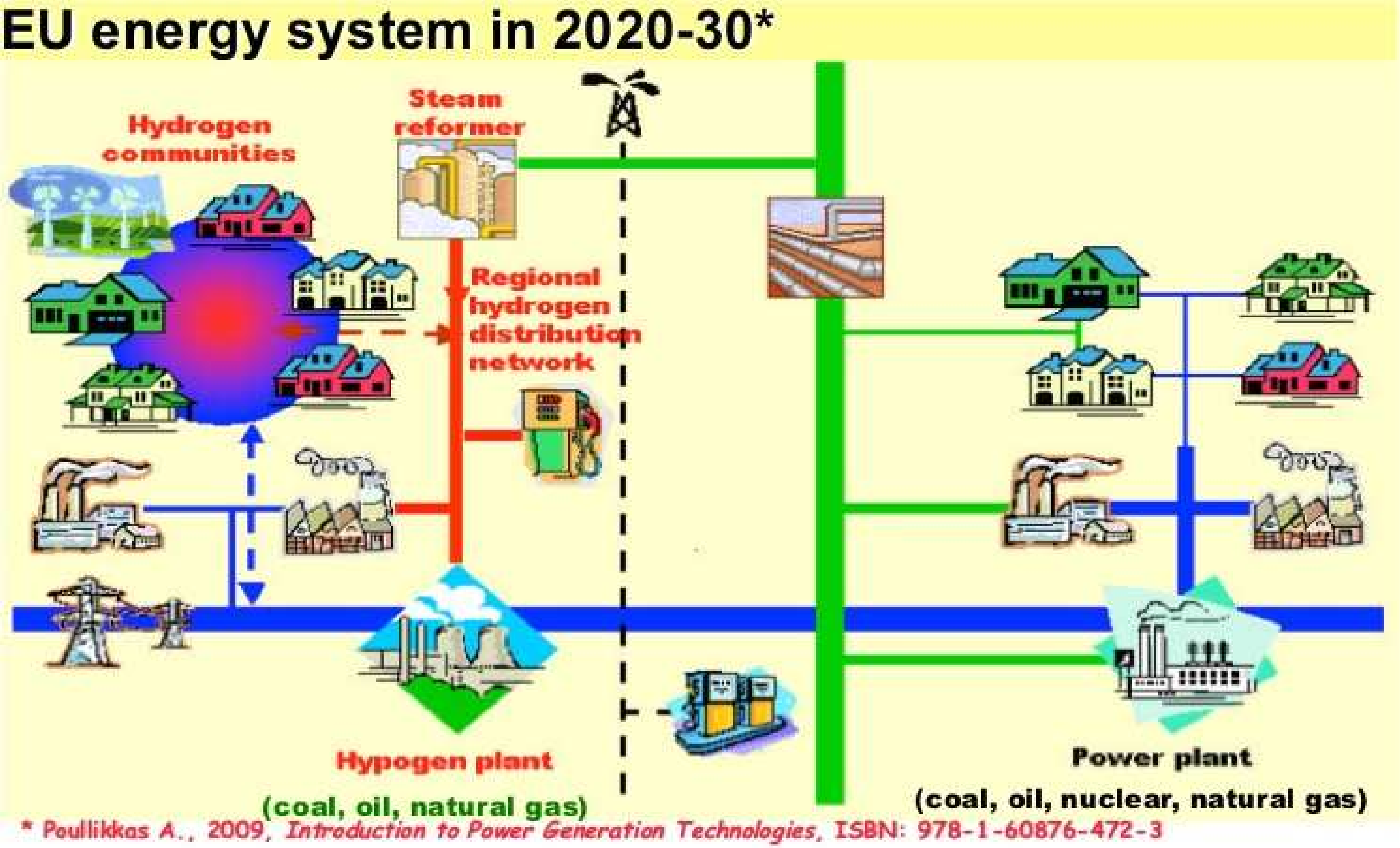


- **Extrapolating developments of the past does not forecast the future**
- **Gas, wind and sun – providing Europe with clean heat, electricity and transport**

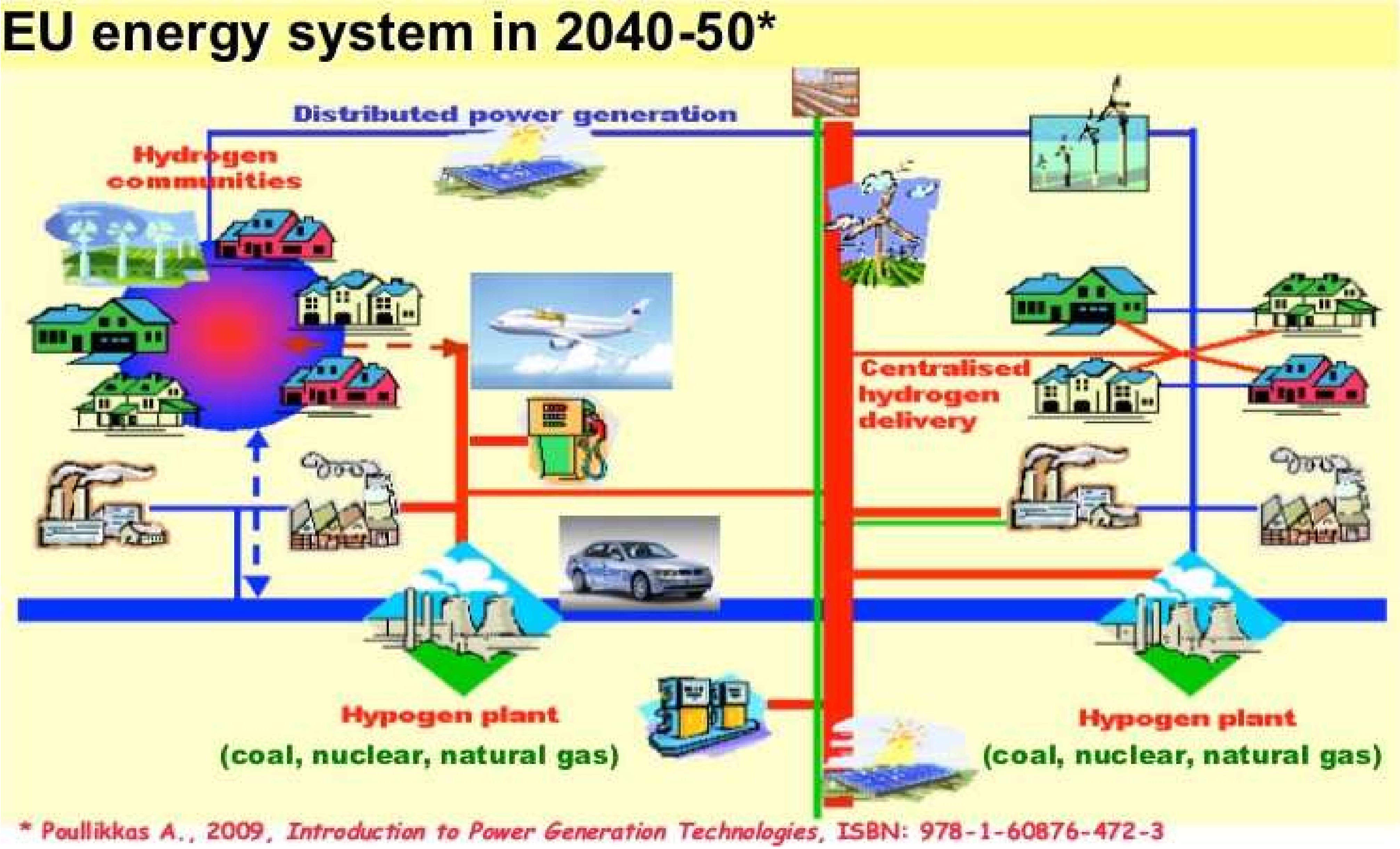
Current energy system



Future energy systems (optimistic scenario)

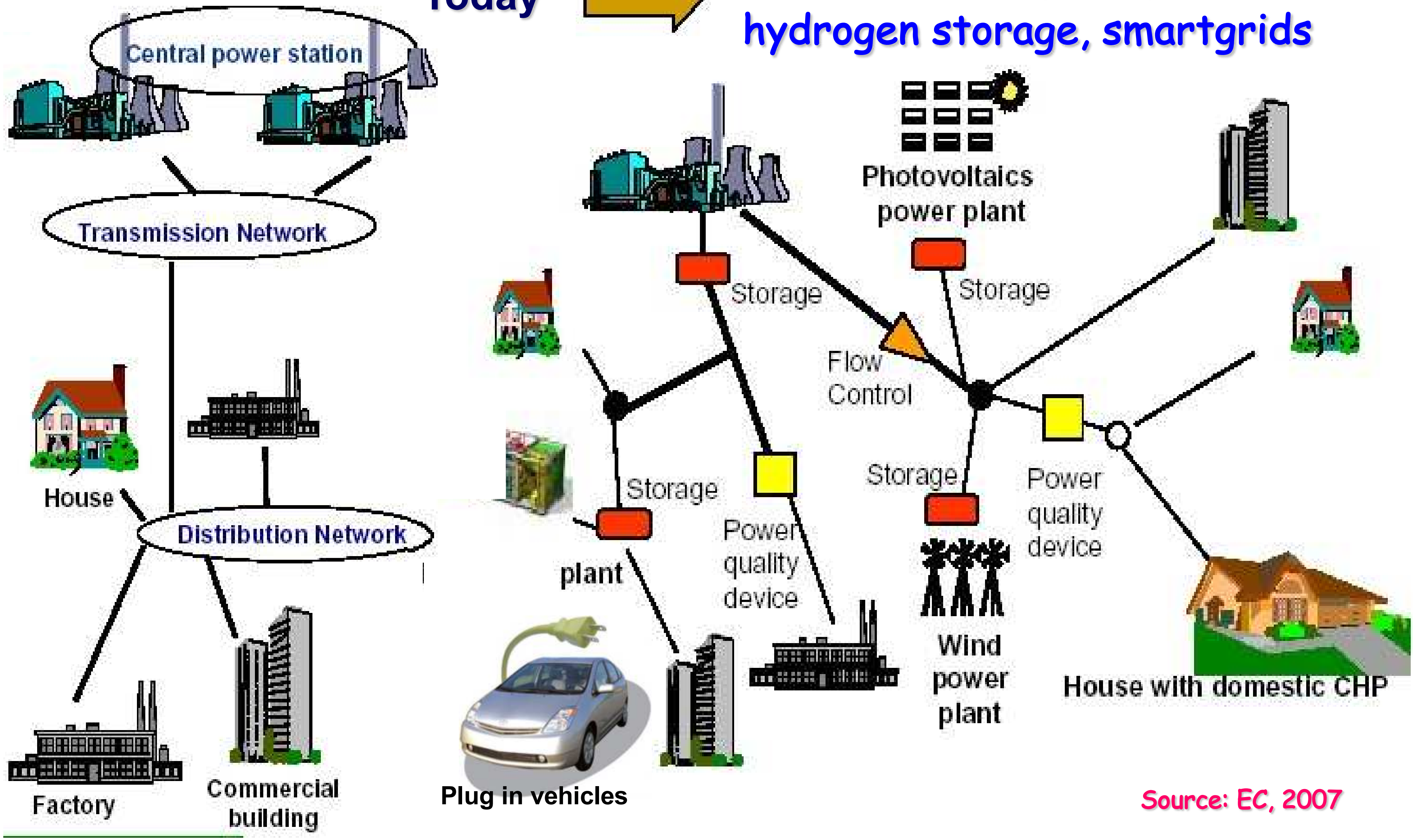


Future energy systems (optimistic scenario)



Future power systems

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



Source: EC, 2007

Future power system

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End goal – the smart future

The Super Smart Grid after 2050*
(may allow for 100% RES)

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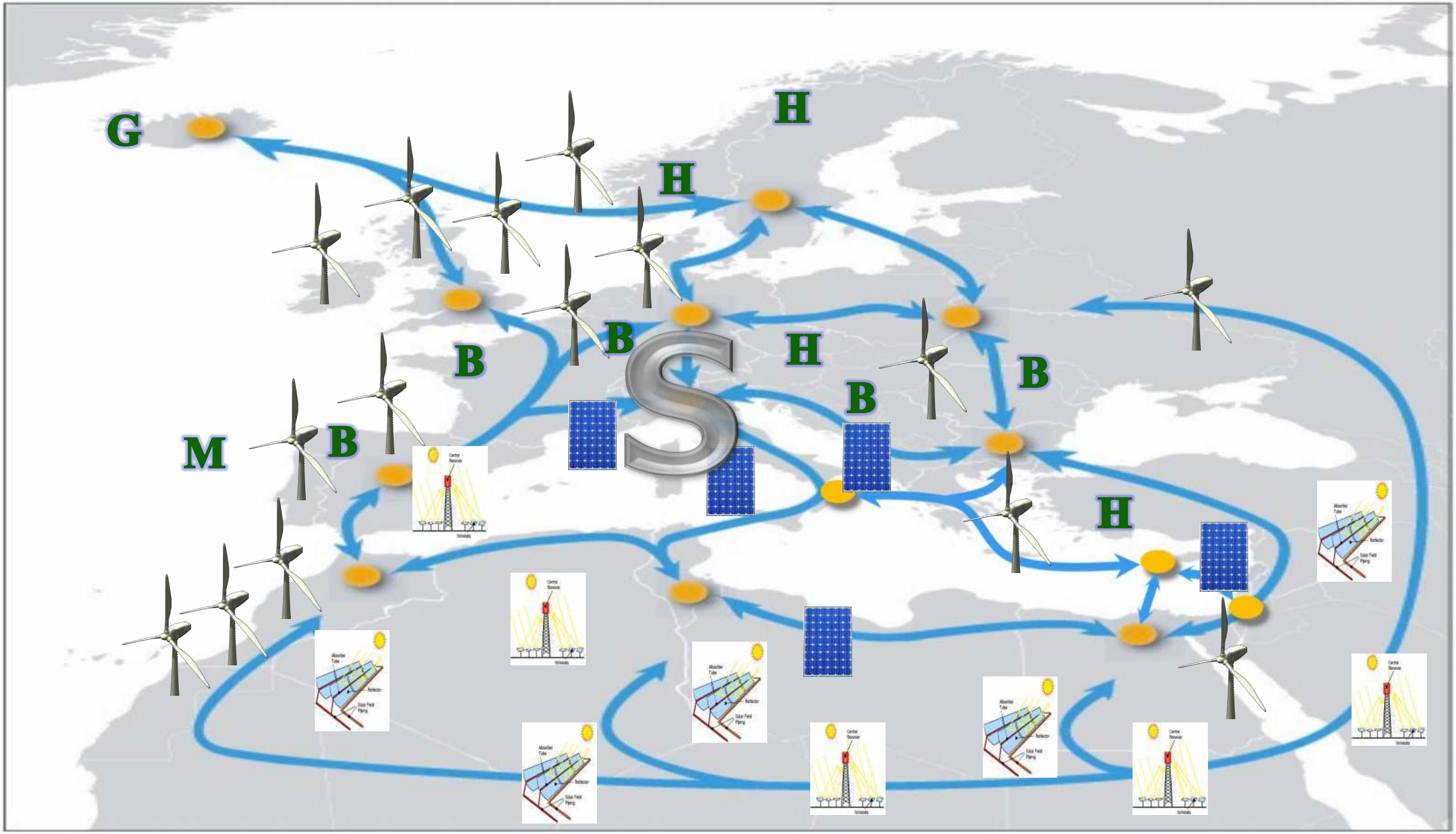
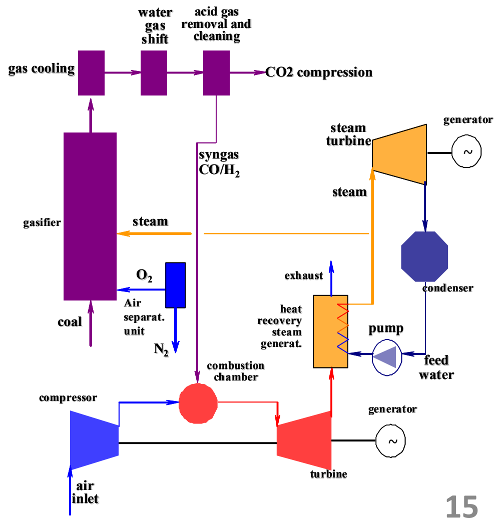


* Poullikkas A., 2013, *Sustainable Energy Development for Cyprus*, ISBN: 978-9963-7355-3-2

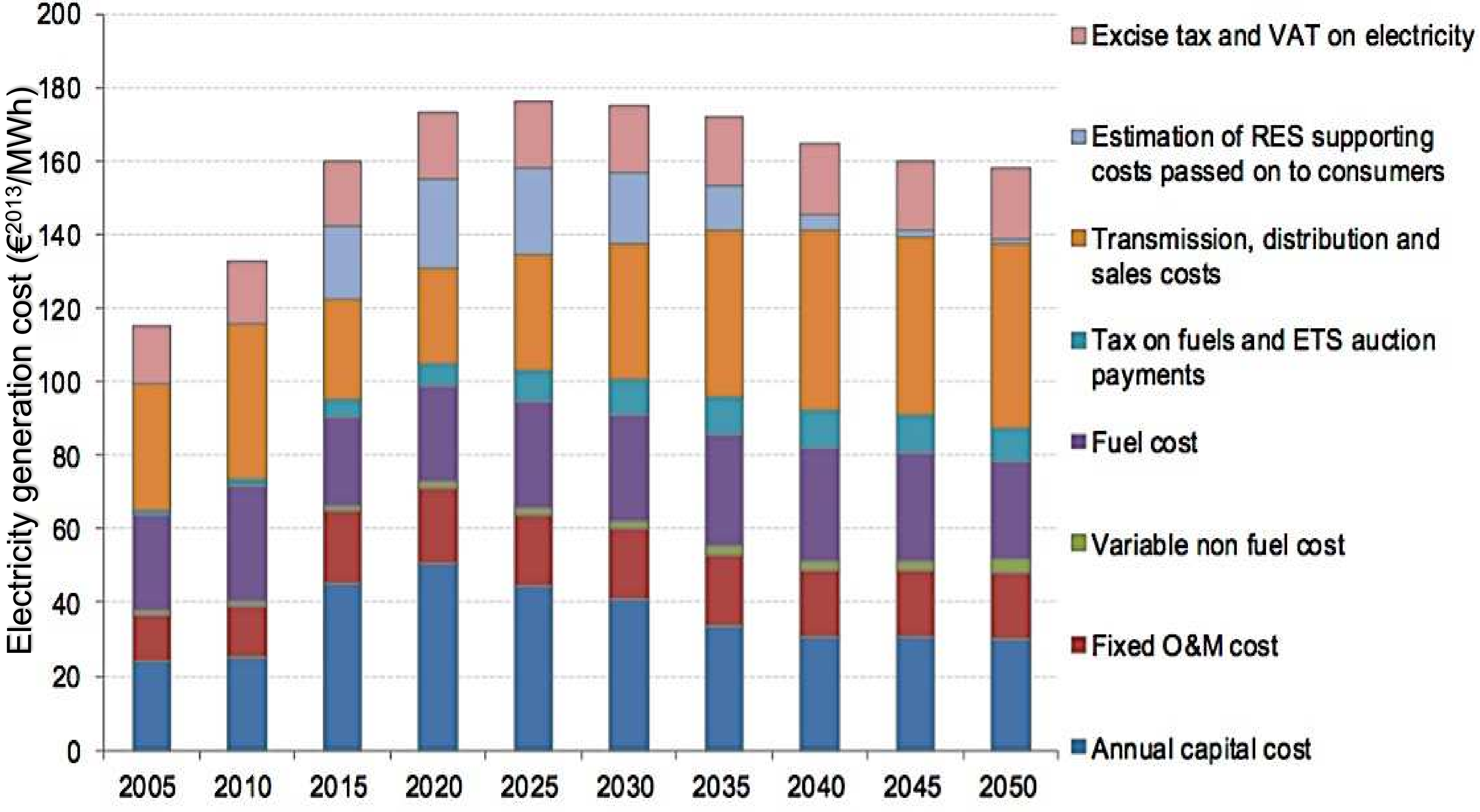
Long term EU energy strategy (2050)

- **A vision of carbon neutral 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**



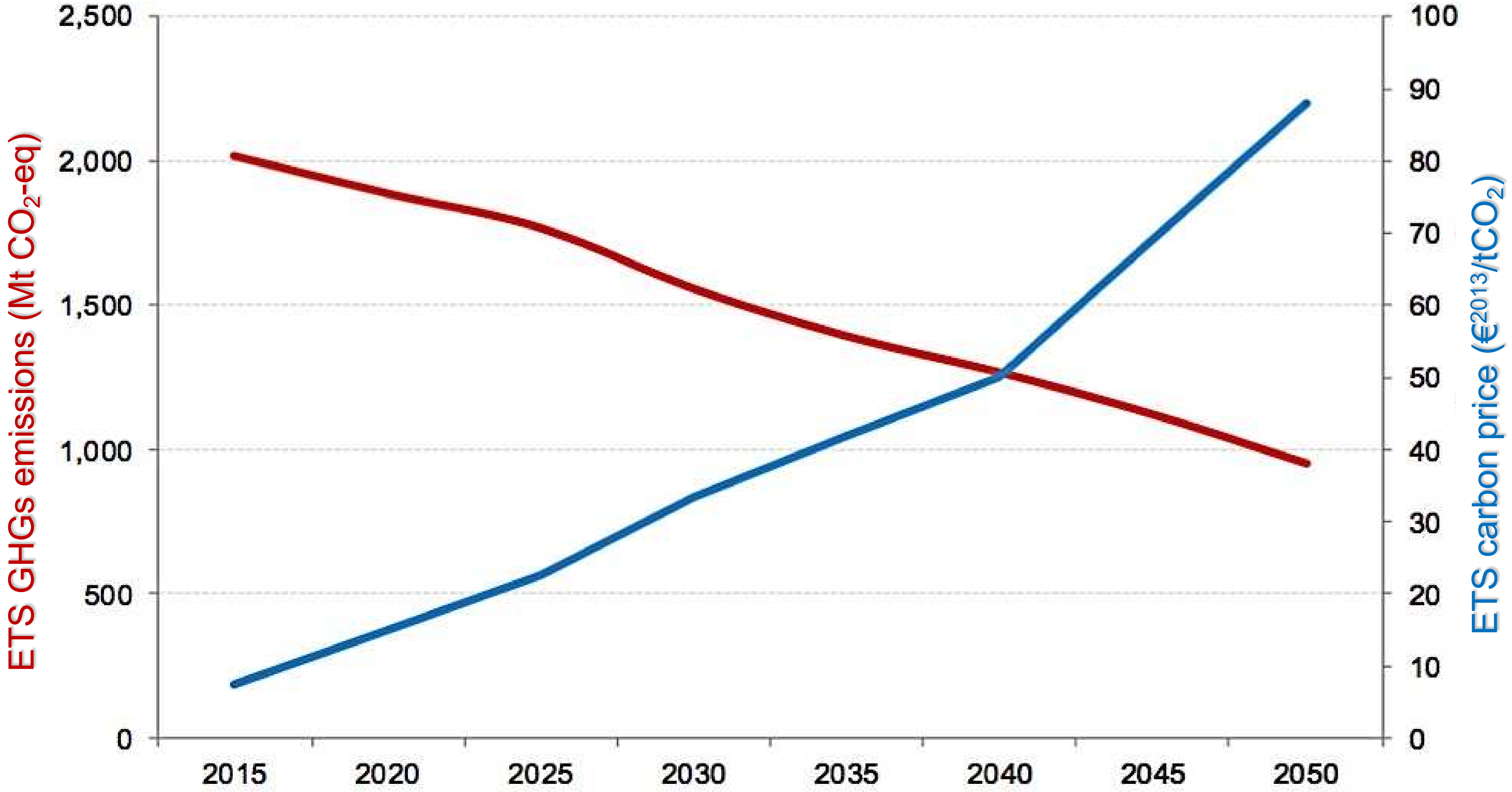
Development of new sustainable technologies and infrastructure

EU reference scenario 2016



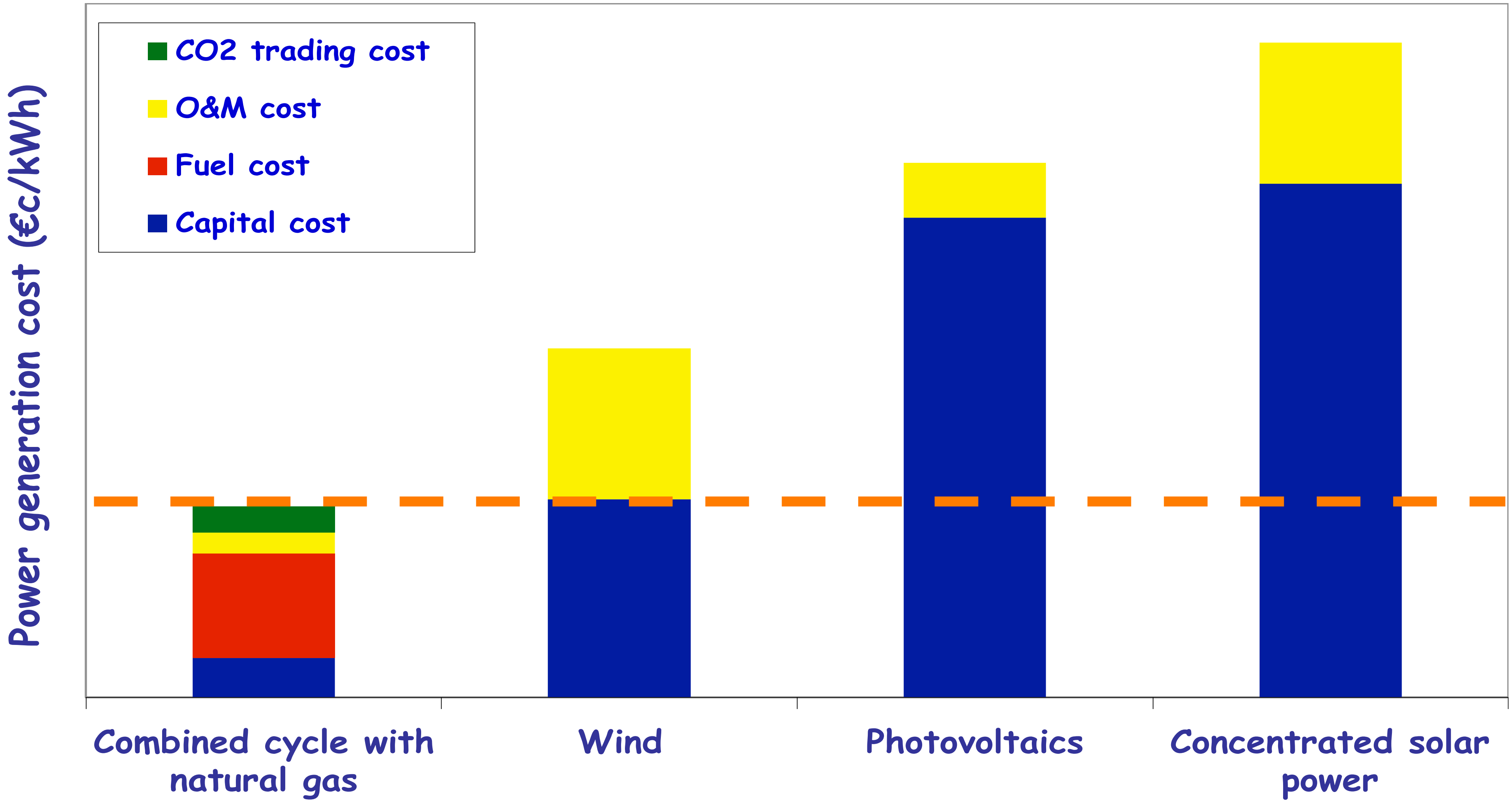
Source: PRIMES

EU reference scenario 2016



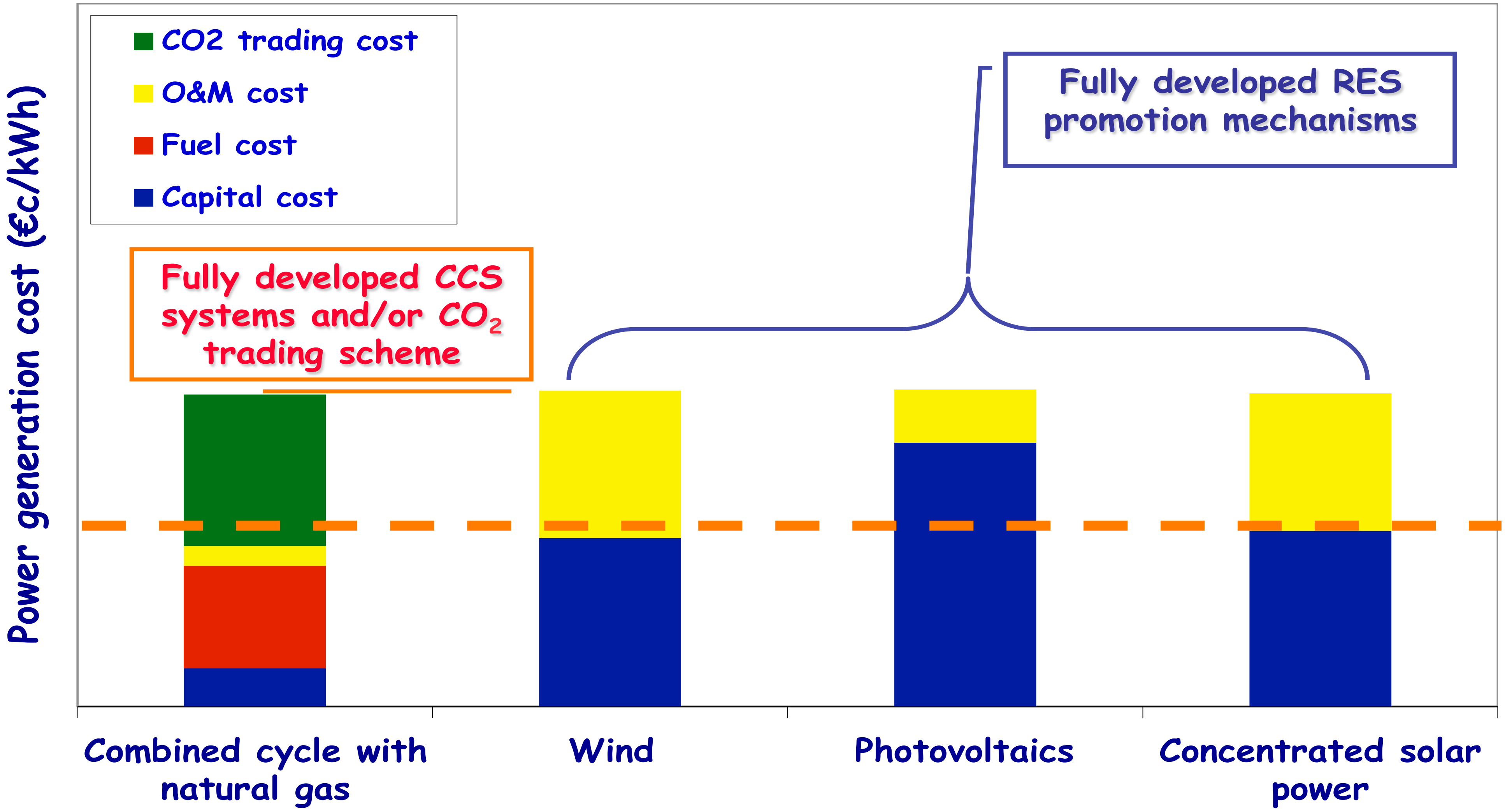
Source: PRIMES, GAINS

Power generation cost (year 2010)*



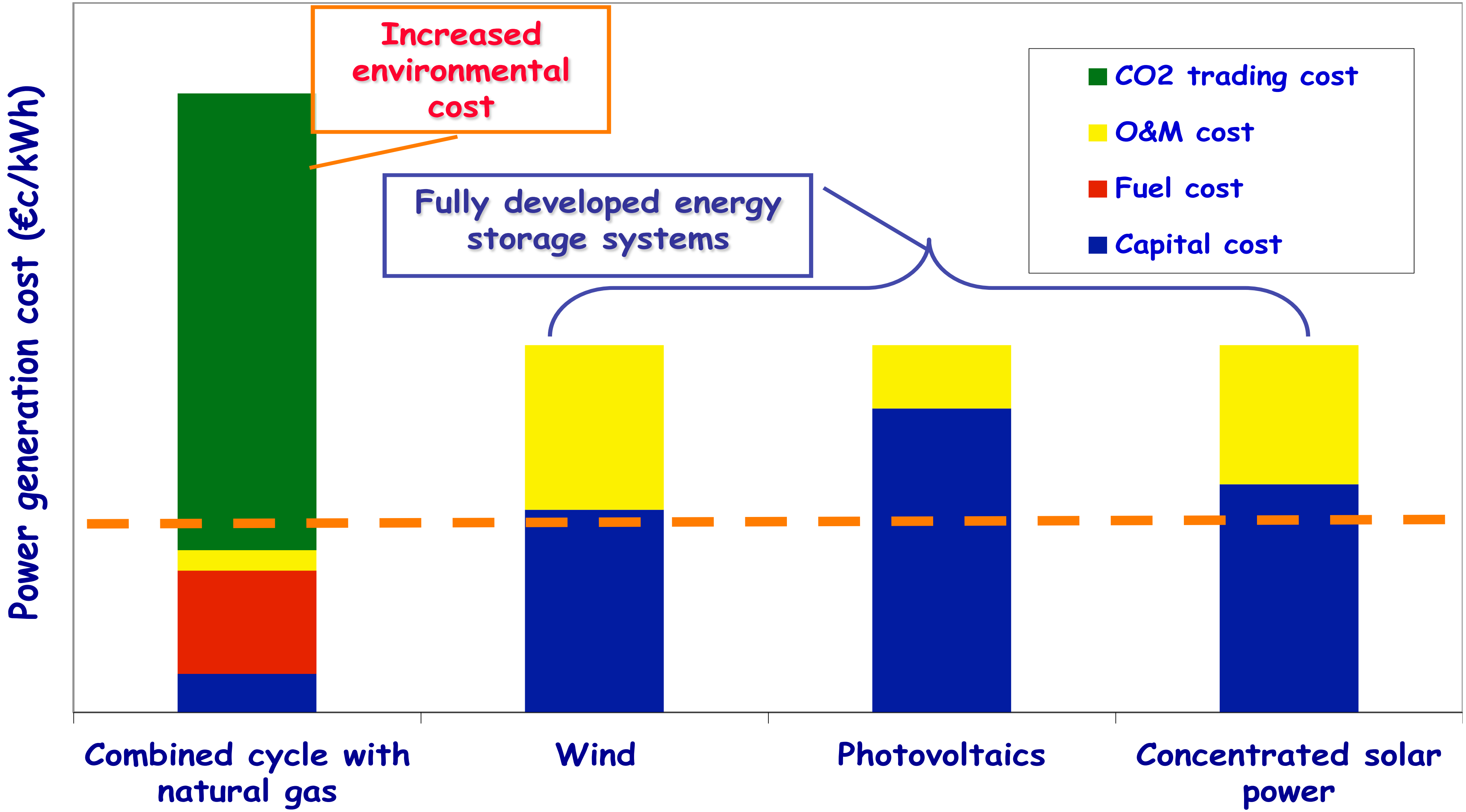
* Poullikkas A., 2010, "The cost of integration of renewable energy sources", *Accountancy*

Power generation cost (year 2020-30)*



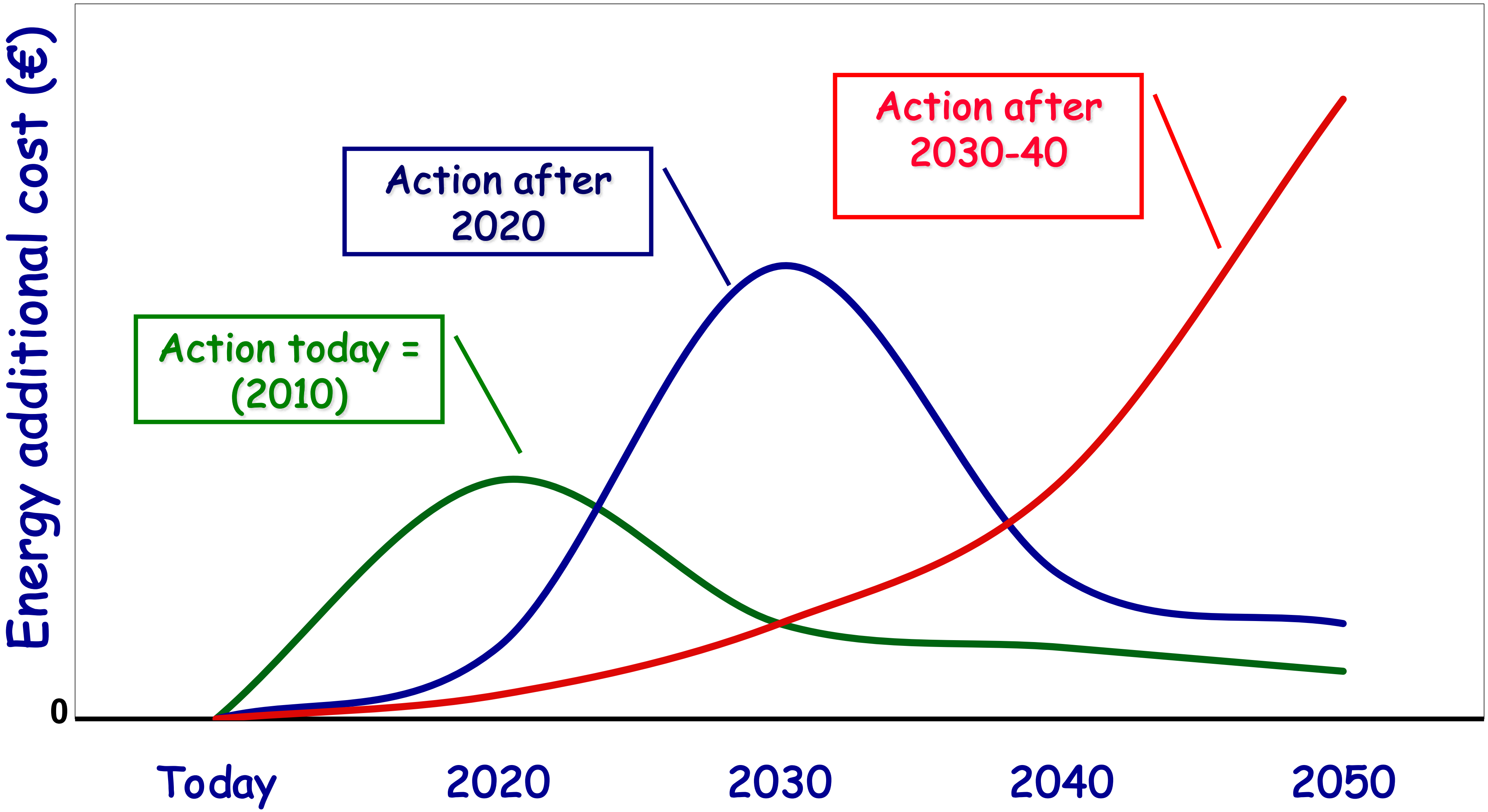
* Poullikkas A., 2010, "The cost of integration of renewable energy sources", *Accountancy*

Power generation cost (year 2040-50)*



* 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*

Challenges in electricity markets

Large scale integration of RES and storage

What is a power system?

- **Largest and most complex manmade system**
- **Electrical power is somewhat like the air we breath**
  - **We think about it only when it is missing**
- **PS should be operated with the goal of achieving:**
  - **Highest reliability standards**
  - **Lowest operation cost**
  - **Minimum environmental impacts**

Electricity market complexities*

- Energy market
- Power market (flow of energy)
- Ancillary services market
  - Reserve (spinning, cold, primary, etc.)
  - Voltage regulation
  - Frequency regulation, etc.

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

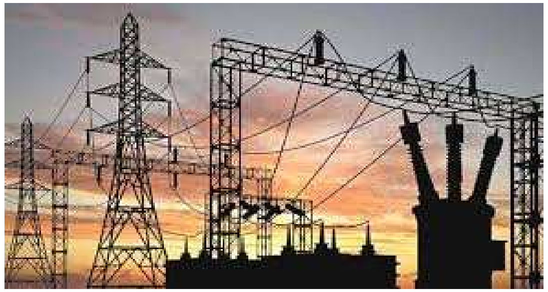
Electricity markets current issues

- **Protection of the environment**
  - Reduce primary emissions
  - Reduce greenhouse gas emissions
  - Develop alternative technologies
- **Electricity markets open to competition**
  - Increase in technologies efficiency
  - Reduce energy generation costs

Electricity market functions

- **Generation** (competition)

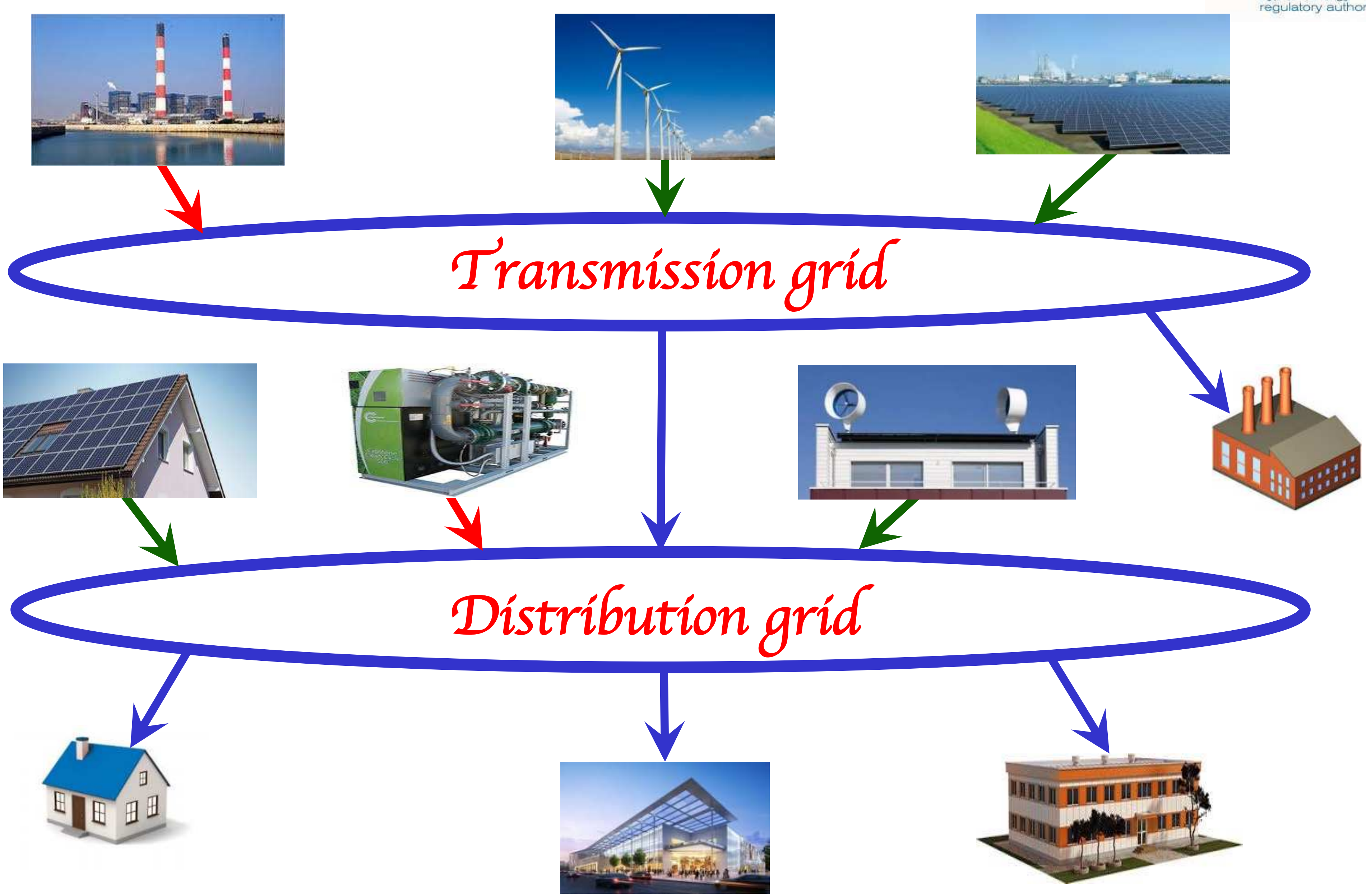
- **Transmission** (monopoly)



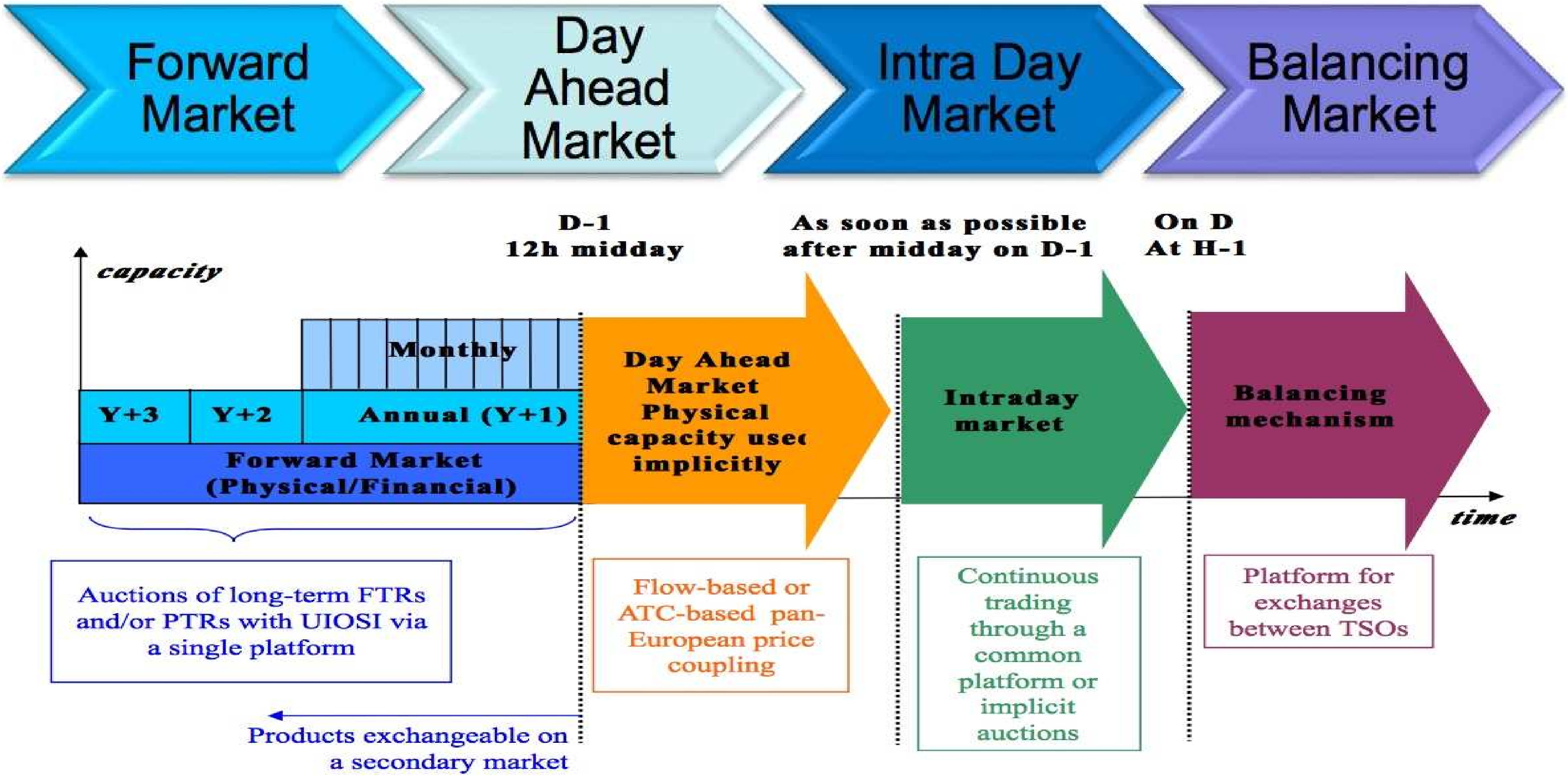
- **Distribution** (monopoly)

- **Supply** (competition)

Competition *vs* monopoly



EU electricity market target model



Integration of RES*: LCOE *vs* Reliability

* 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*

The fundamental requirement of electrical power supply

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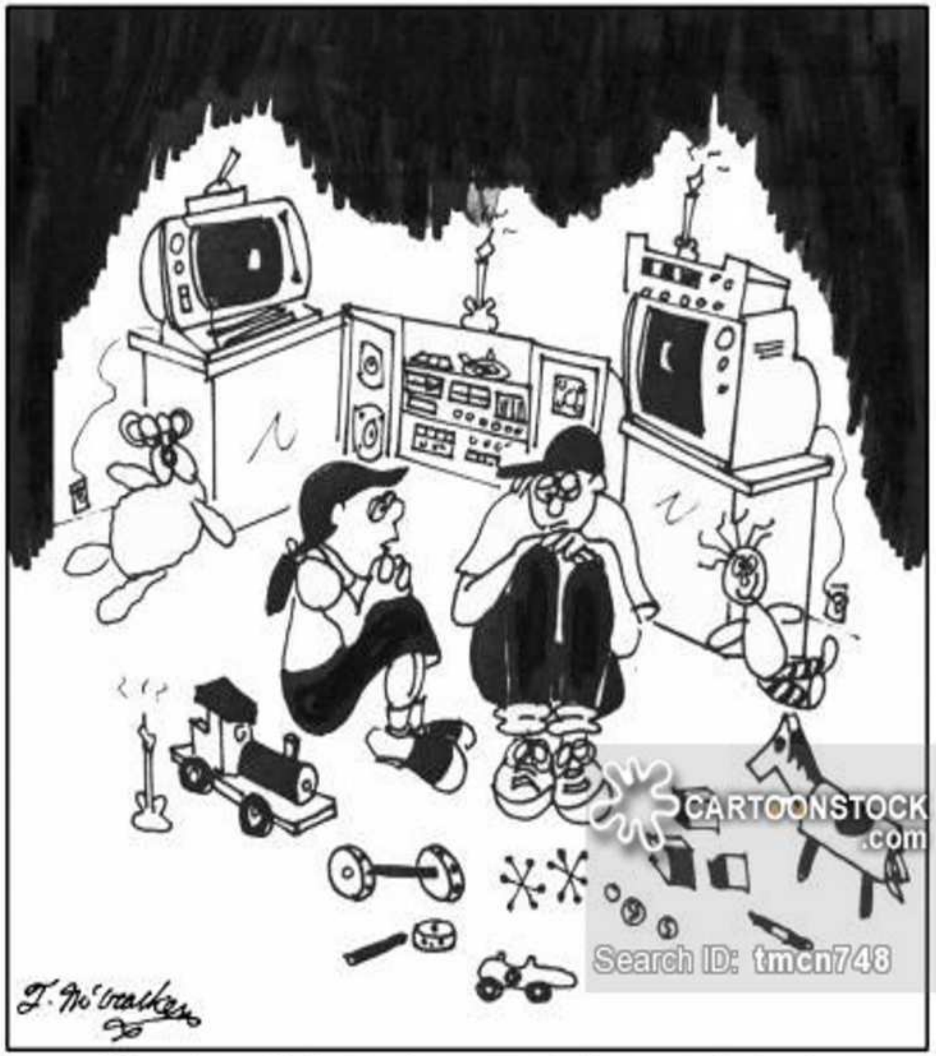
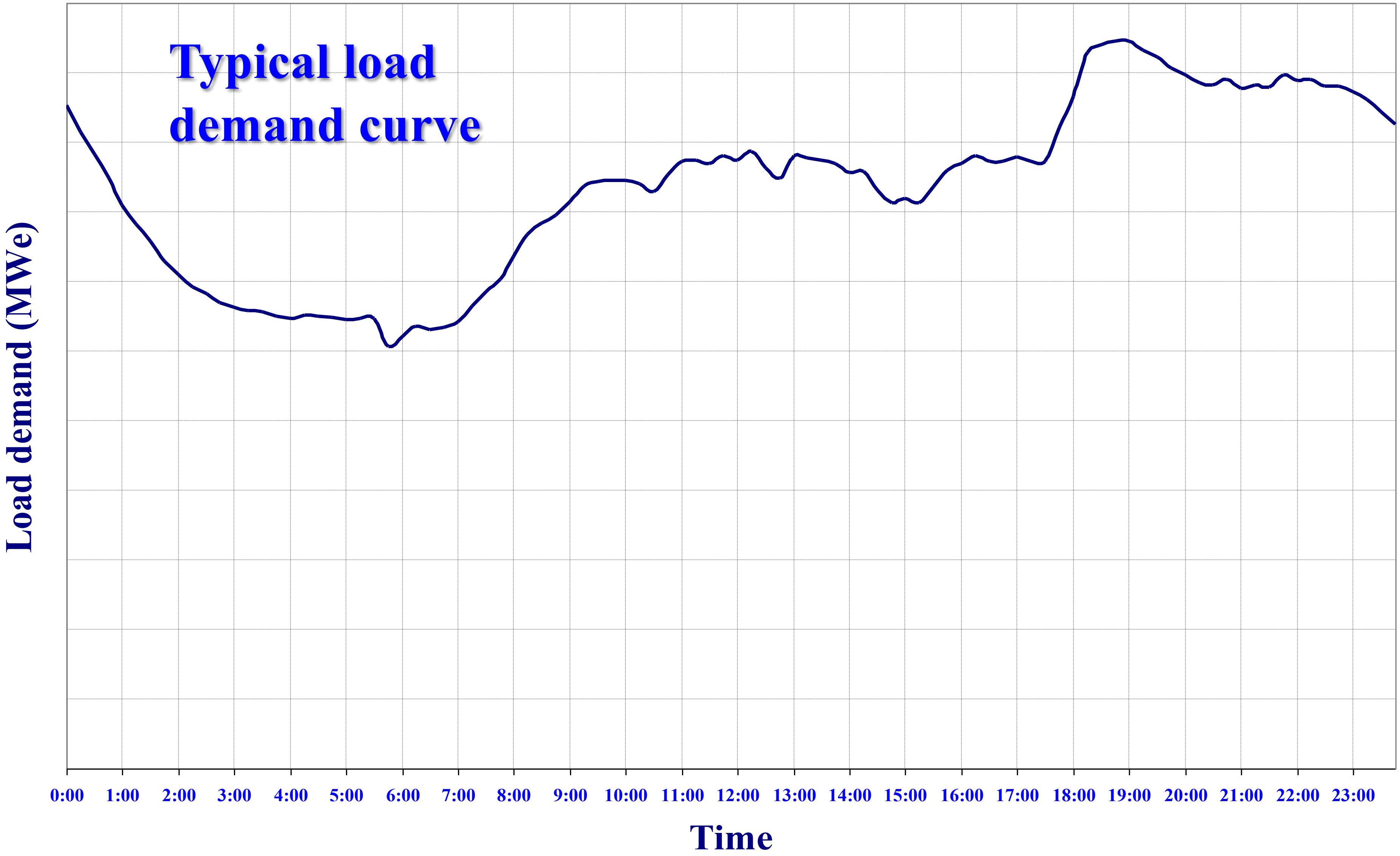
Get me what I want,

when I want it !!!

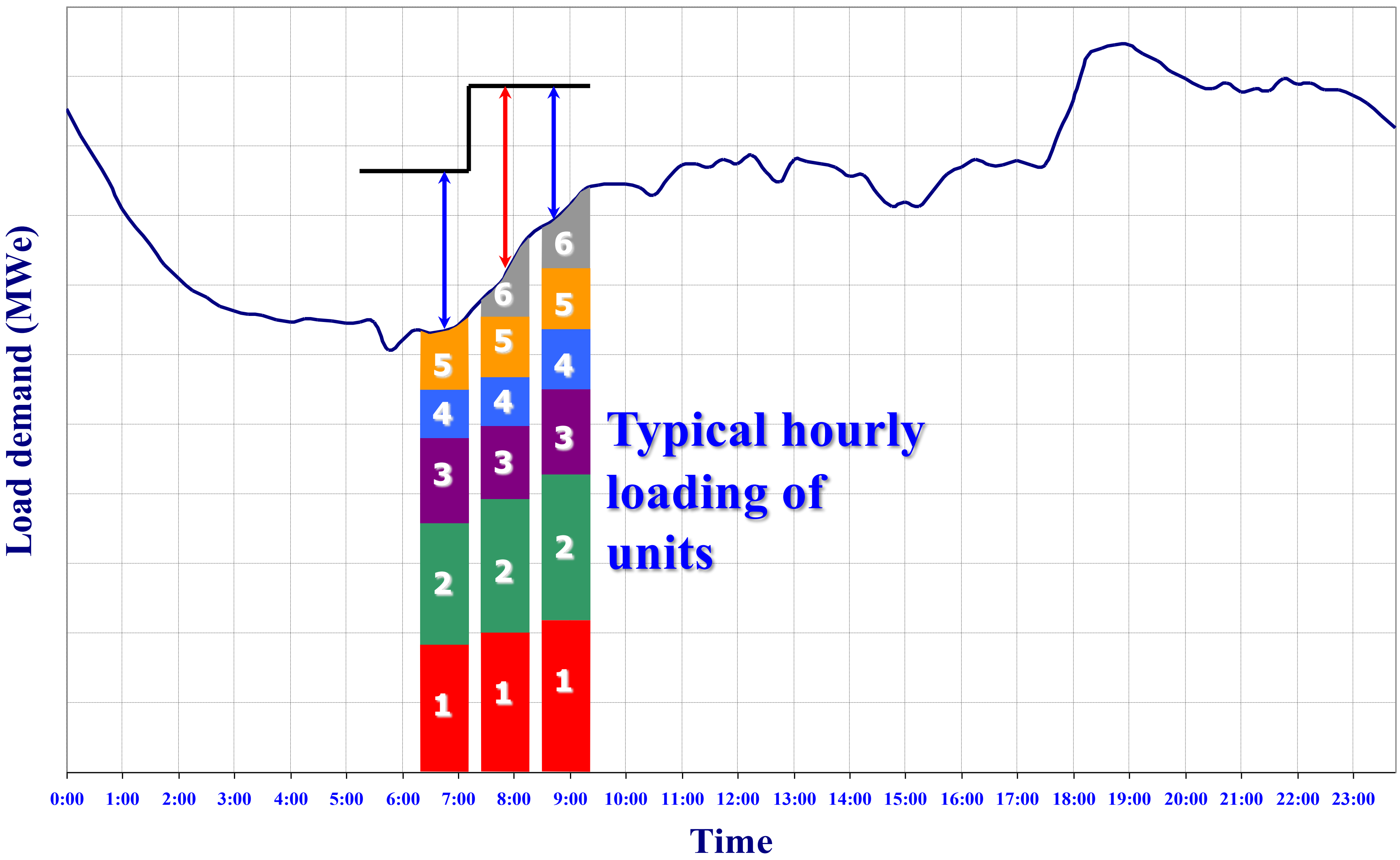


"Geeze. When the power's out there's nothing to play with around here."

PS operation and control



PS operation and control



Key operational parameters

- **Power balance: Generation must remain balanced with demand**
  - **Total generation (*t*) = Total demand (*t*) + Losses (*t*)**
- **System security**
  - **Equipment power flows must not exceed equipment ratings under normal or a single outage condition**

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

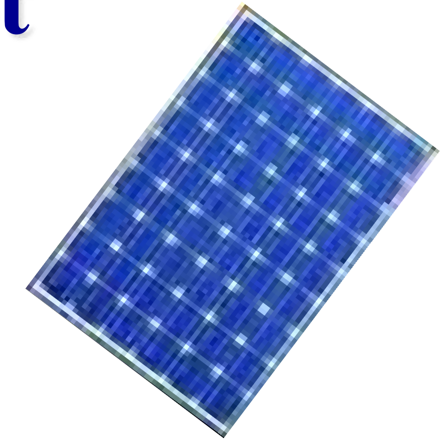
Power system reliability* (the 6 must)

- 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**

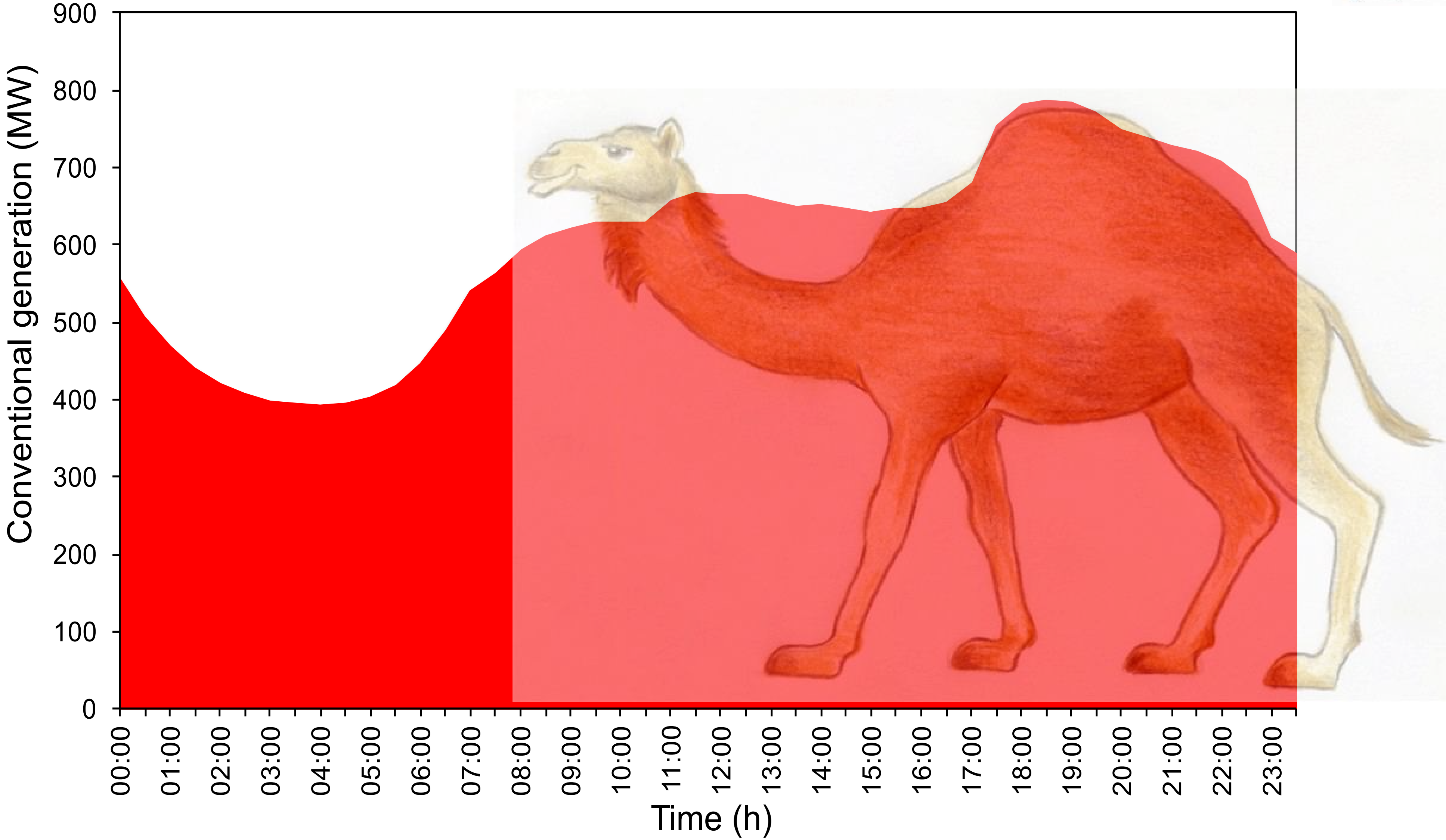


- **May be quite predictable**
- **Cannot be dispatched to meet the demand of a power system**

- **For dispatching need storage**

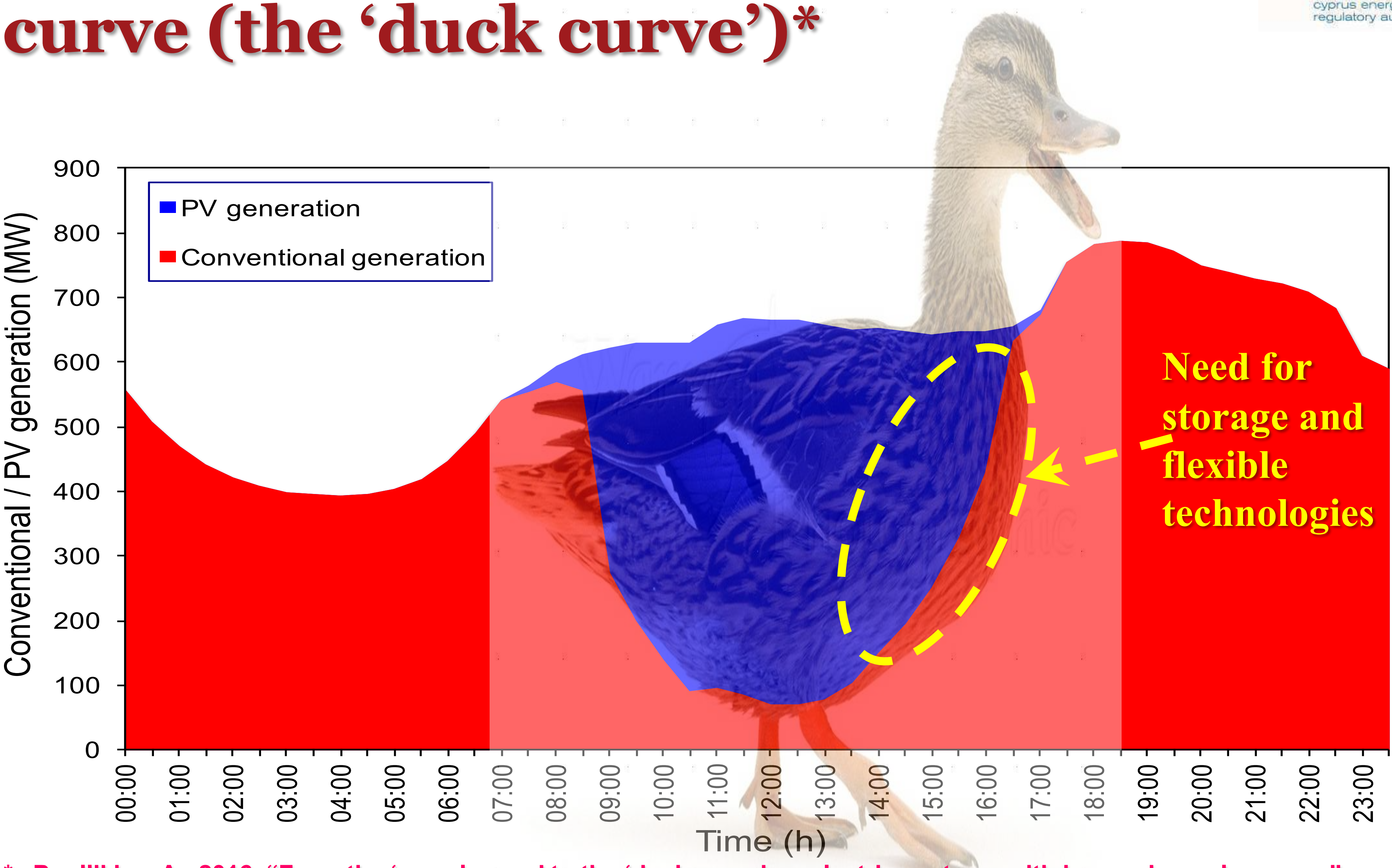
* Poullikkas A., 2013, *Renewable Energy: Economics, Emerging Technologies and Global Practices*, ISBN: 978-1-62618-231-8

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*

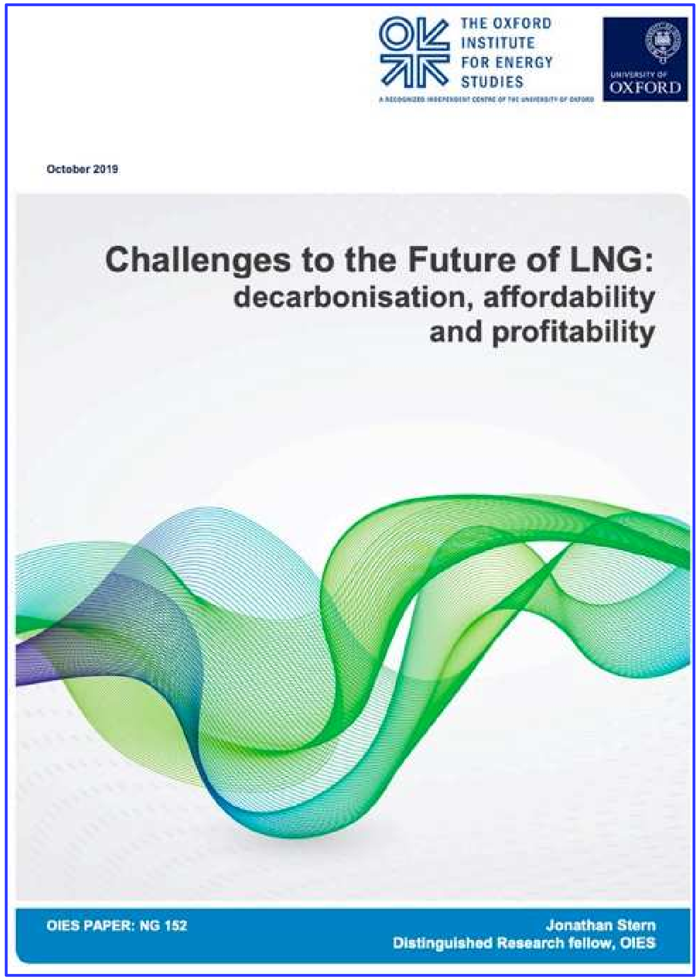
Effect of PV generation on load curve (the ‘duck curve’)*



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

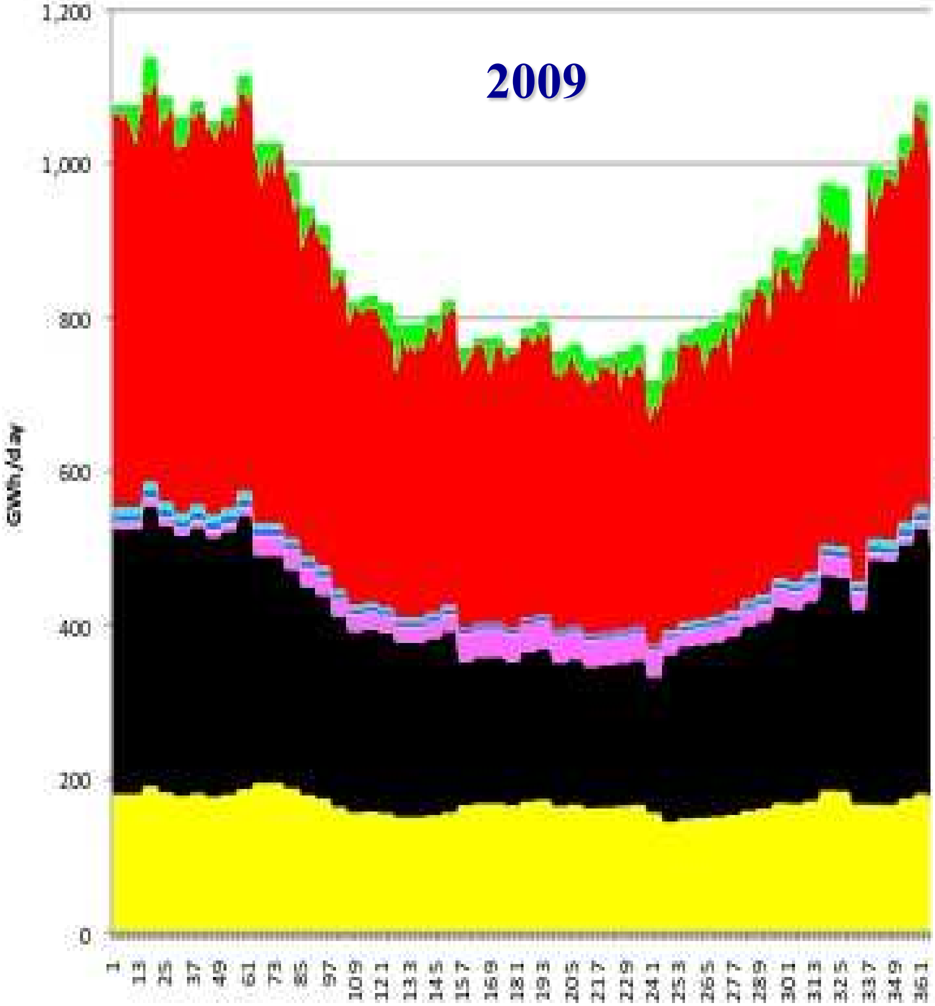
Use of natural gas as a transition or bridge fuel*

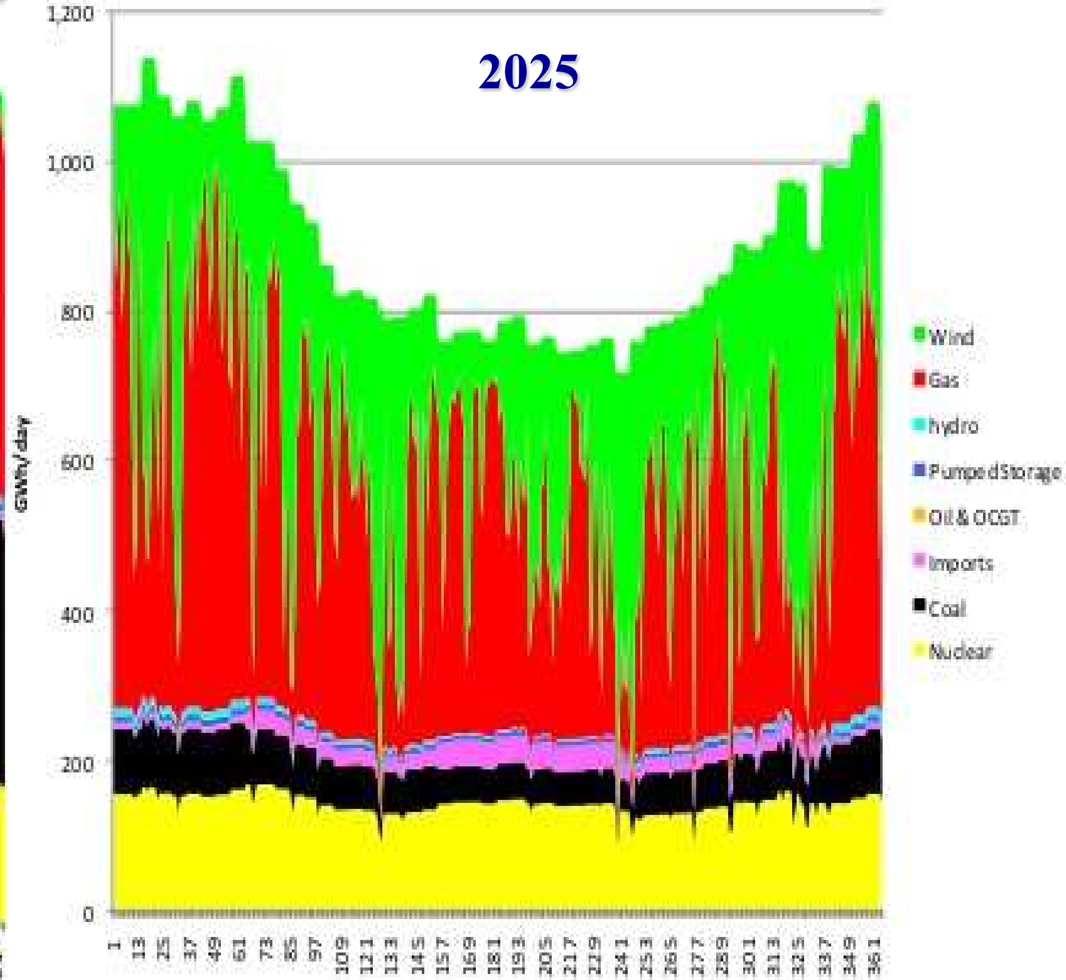
- **switching from coal to gas**
- **using gas and storage to back up intermittent renewables**
- **the quickest, easiest and lowest cost decarbonization path**



* Sterm J., 2019, *Challenges to the future of LNG: decarbonisation, affordability and profitability*, The Oxford Institute For Energy Studies

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



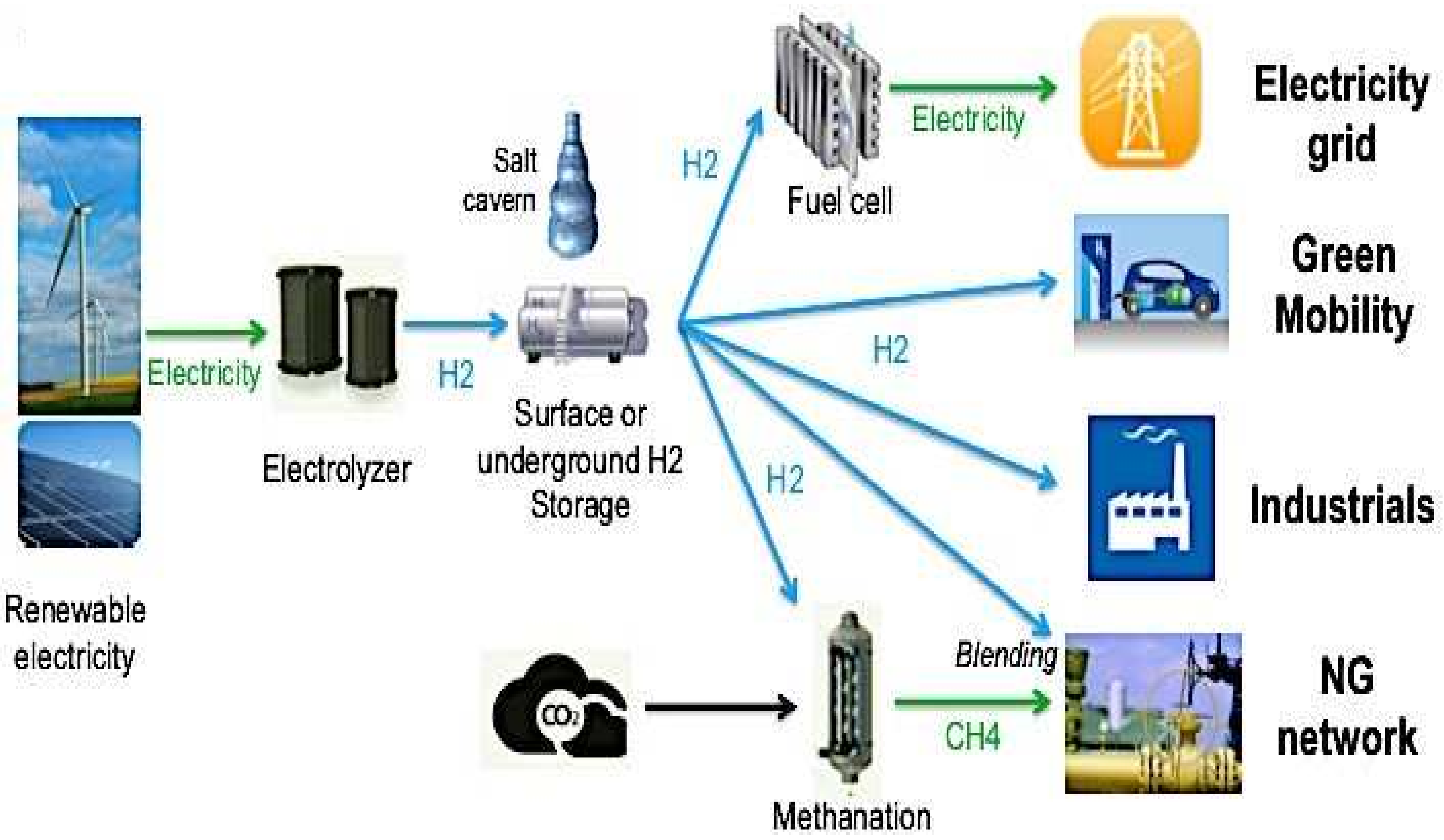


* H.V. Rogers, 2011, *The Impact of Import Dependence and Wind Generation on UK Gas Demand and Security of Supply to 2025*, The Oxford Institute For Energy Studies

The role of Hydrogen in Energy Transition

Long-term scenarios

Hydrogen : an efficient vector in a decarbonized energy mix



Long term scenarios in Europe

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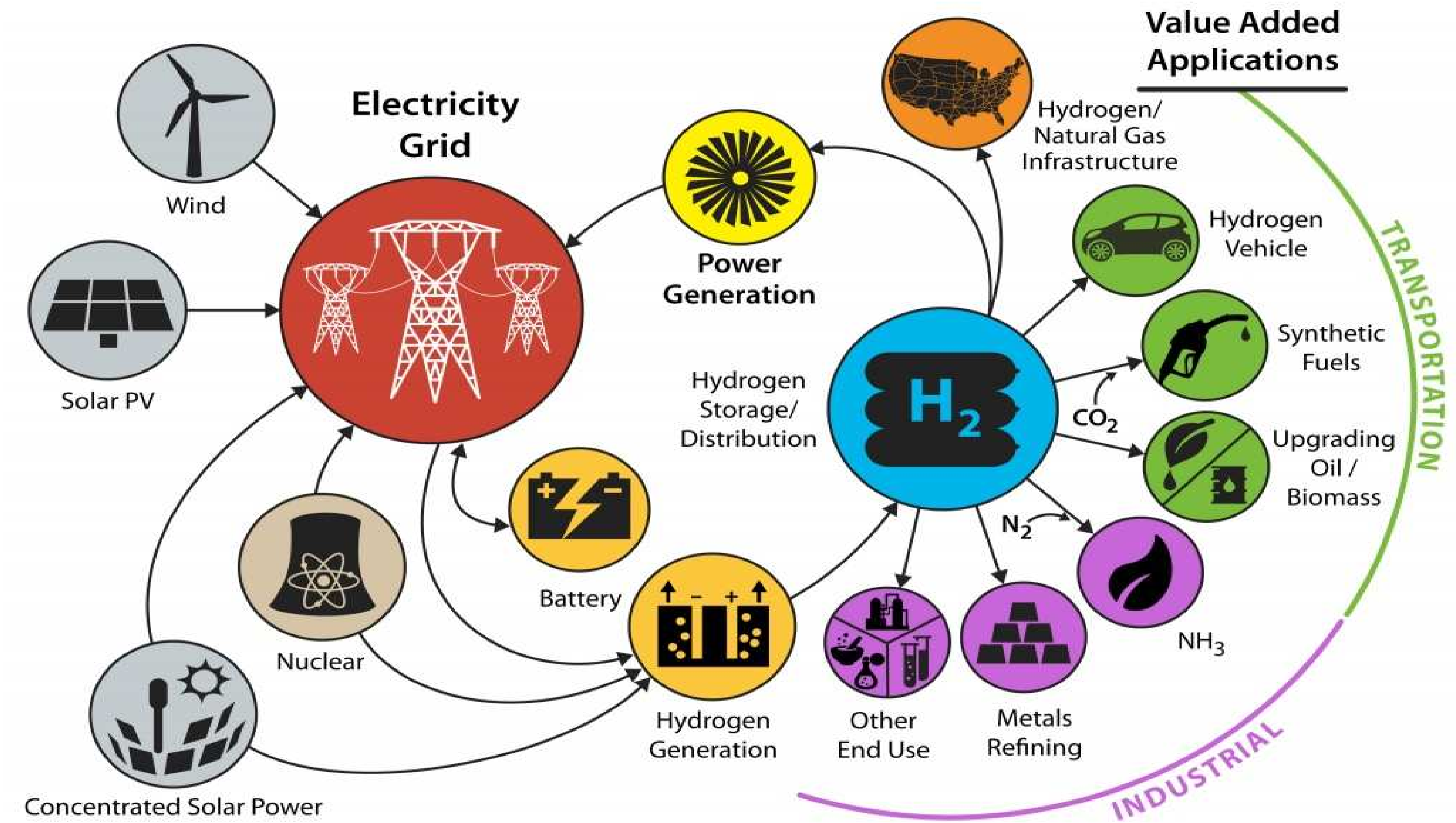
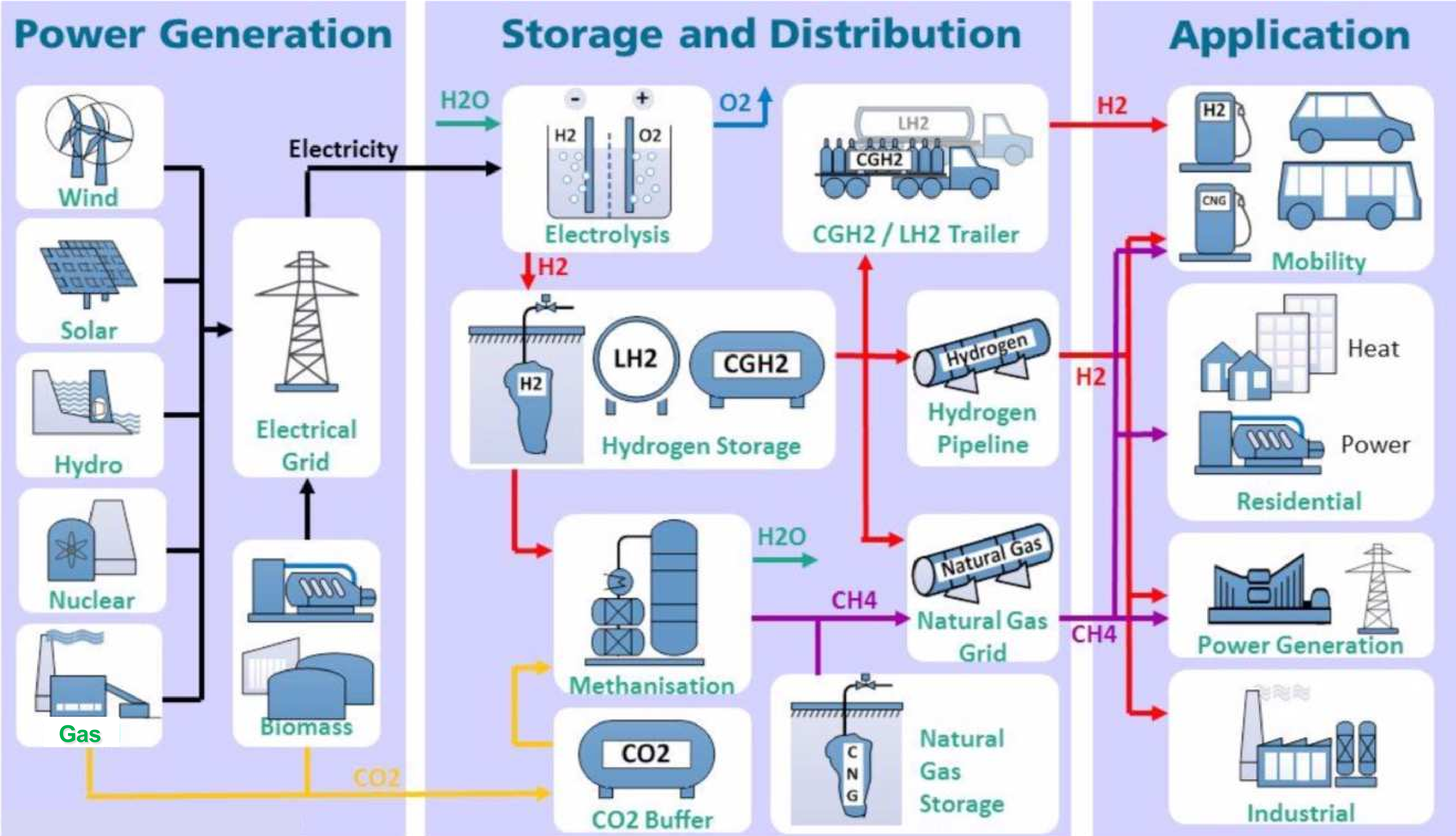
Moving from Carbon economy to Hydrogen economy



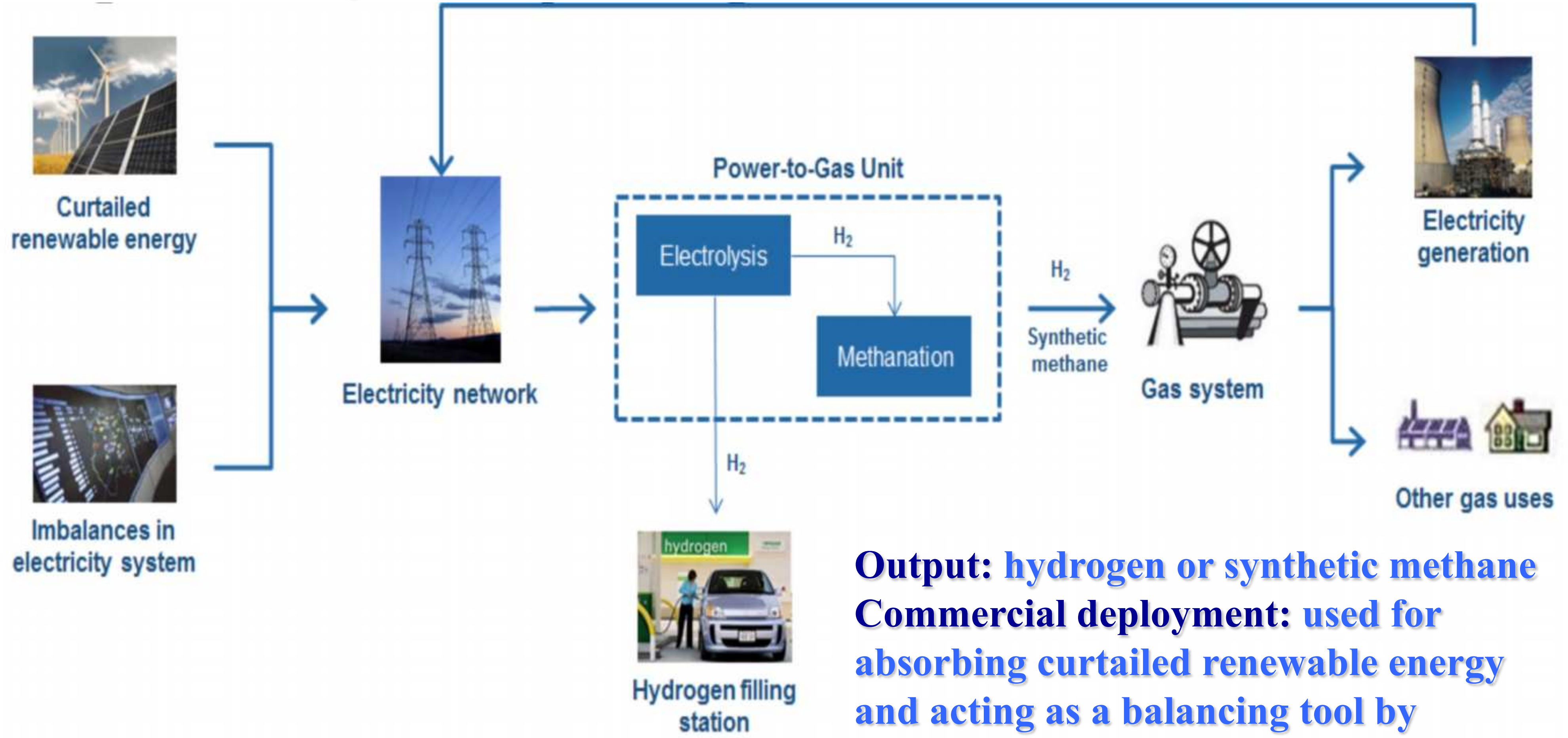
Potential role of hydrogen in the energy transition



Source: EU, 2019

Power-to-Gas (P2G)*

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



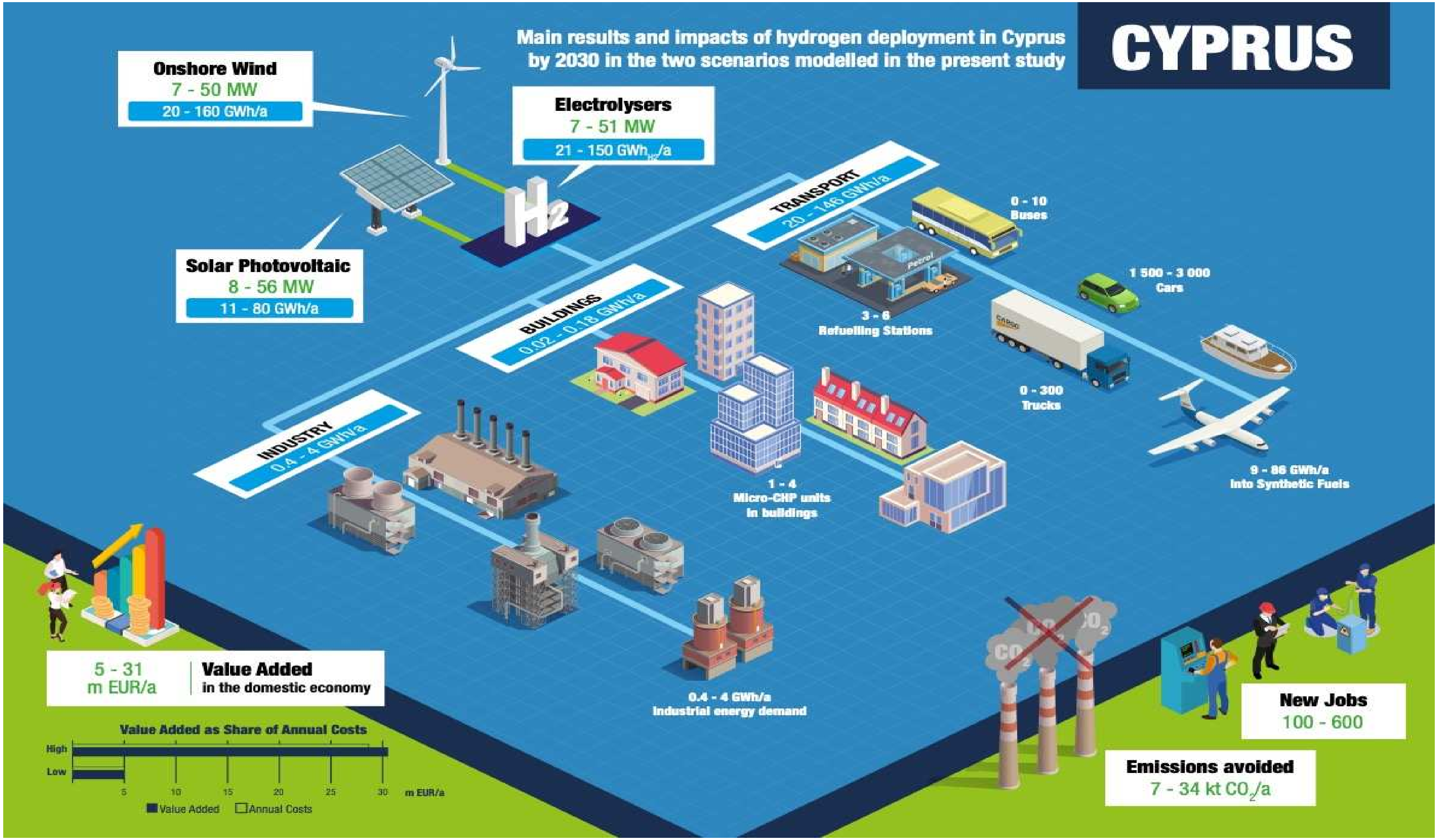
Output: hydrogen or synthetic methane
Commercial deployment: used for absorbing curtailed renewable energy and acting as a balancing tool by electricity TSOs

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

Saudi Arabia $5bn Helios H2 project

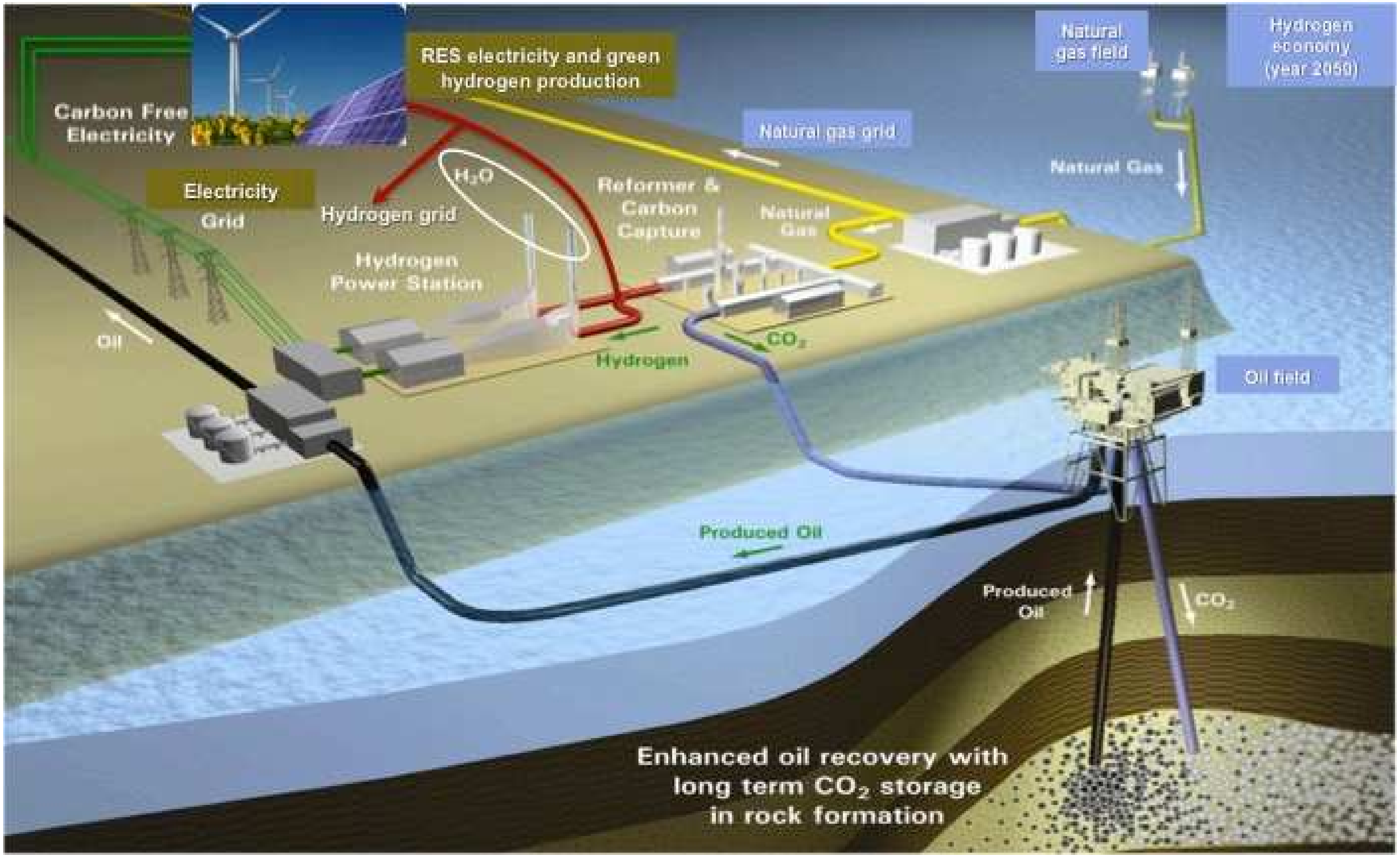
- Desert area = Belgium
- 4GW of Wind and PVs
- Production of 650t/day of H_2
- Reduce of H_2 production from 5US$/kg to 1.5US$/kg
- Long-term: Saudi Arabia to become H_2 exporter

Introduction of H2 in Cyprus's by 2030*



* FCH, EU, 2020

Towards hydrogen economy in 2050*



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

Development of optimization algorithms

Advanced simulation tools for large scale integration of RES and storage

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 including storage**

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

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

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

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

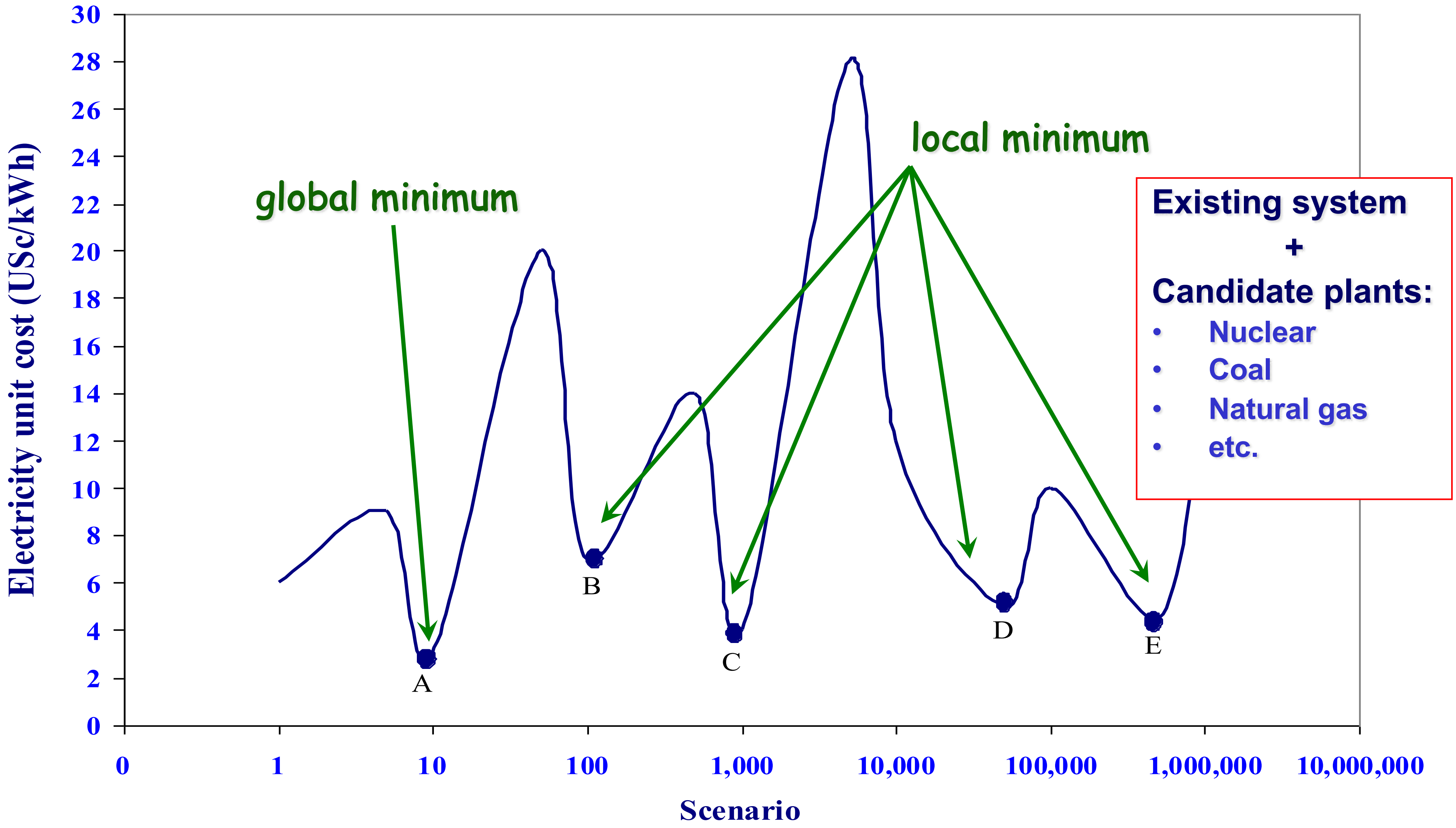
$$R_{S(t)} \le \sum_i r_{s(i,t)} I_{(i,t)} \qquad r_{s(i,t)} = \min\left[10MSR_i, P_{g,\max(i)} - P_{(i,t)}\right]$$

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

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

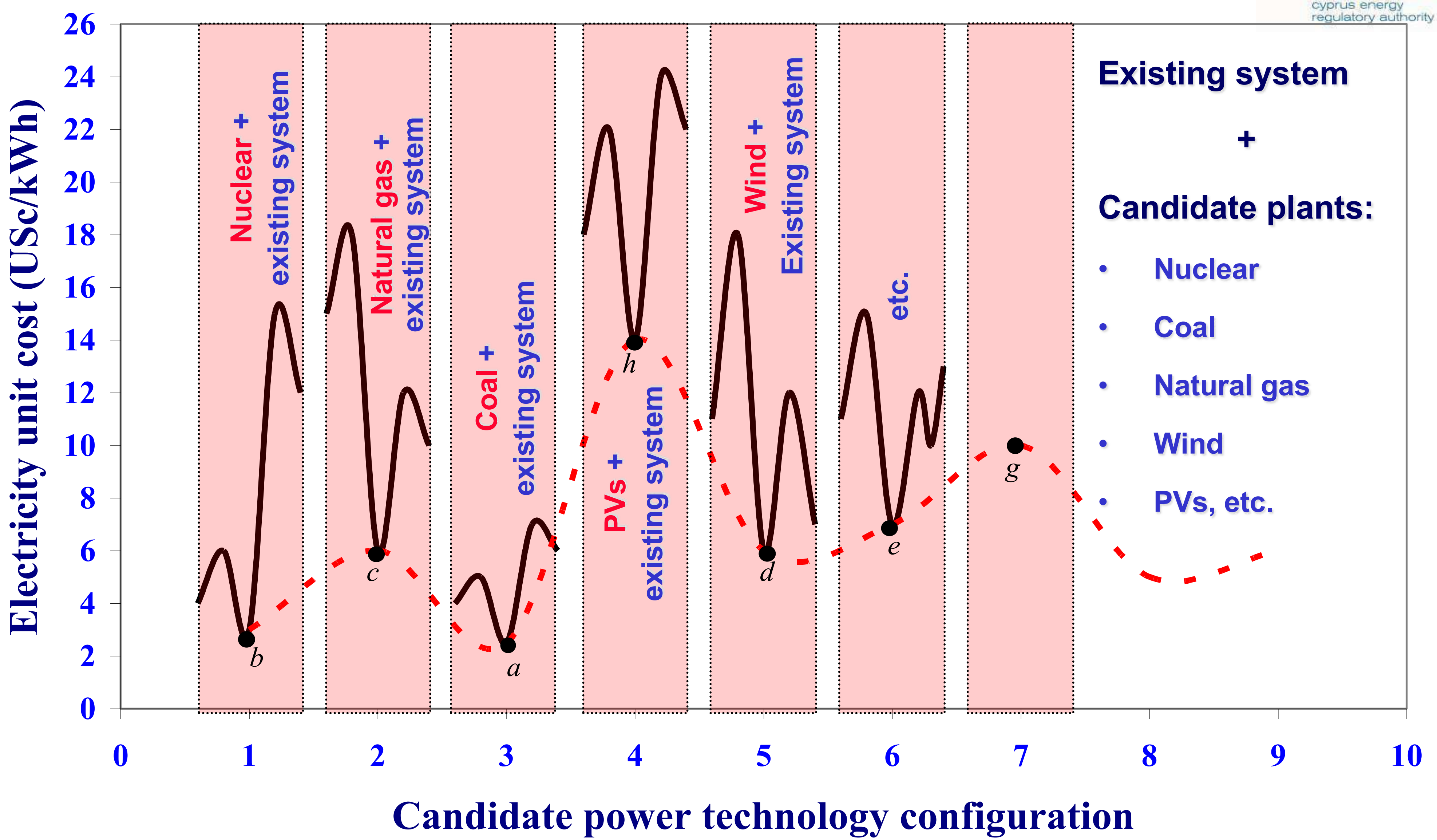
* Poullikkas A., 2009, "A decouple optimization method for power technology selection in competitive markets", *Energy Sources*

Typical shape of objective function*



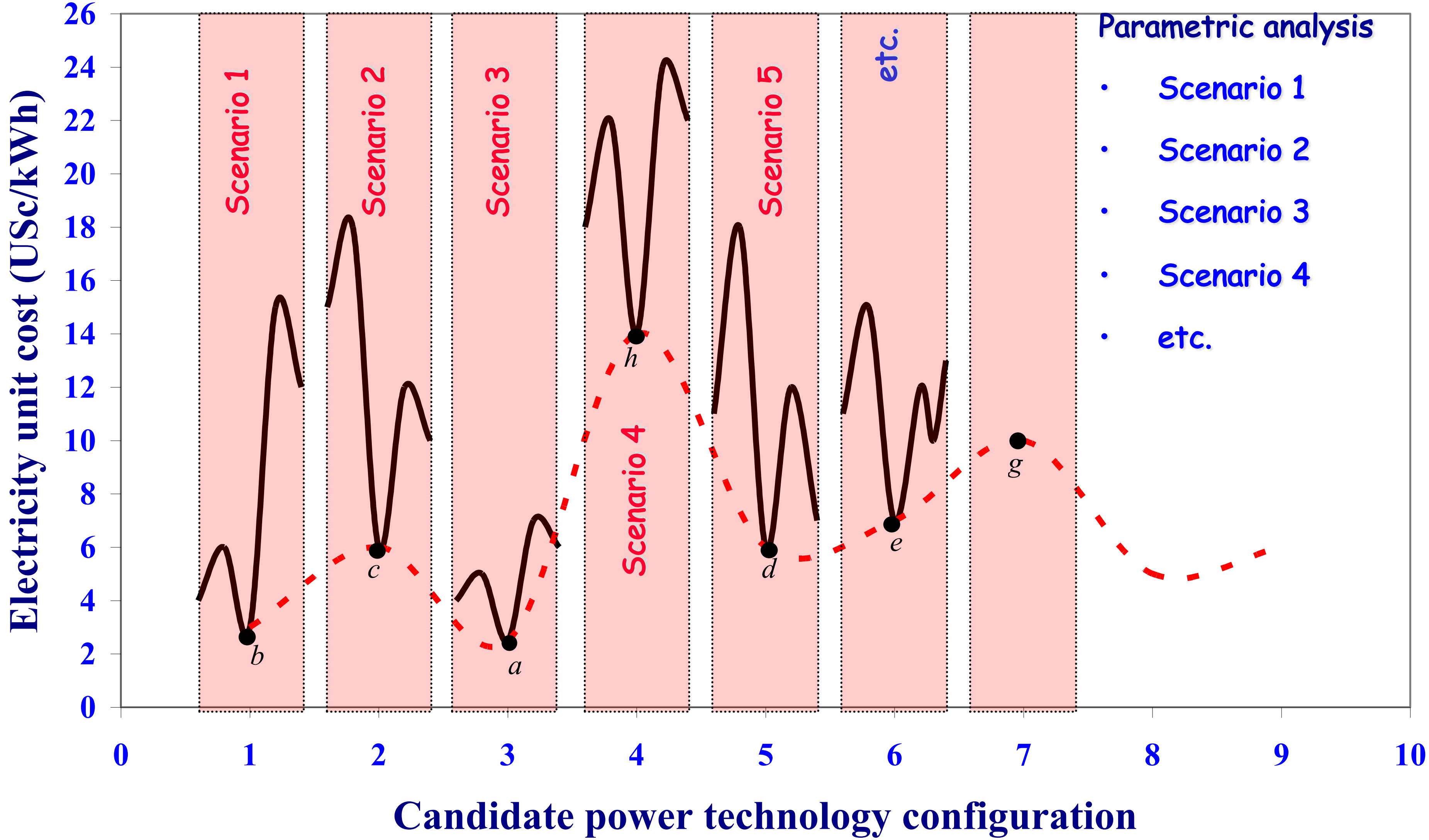
* Poullikkas A., 2009, "A decouple optimization method for power technology selection in competitive markets", *Energy Sources*

Decouple optimization technique*



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

Decouple optimization technique*



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

Minimisation procedure*

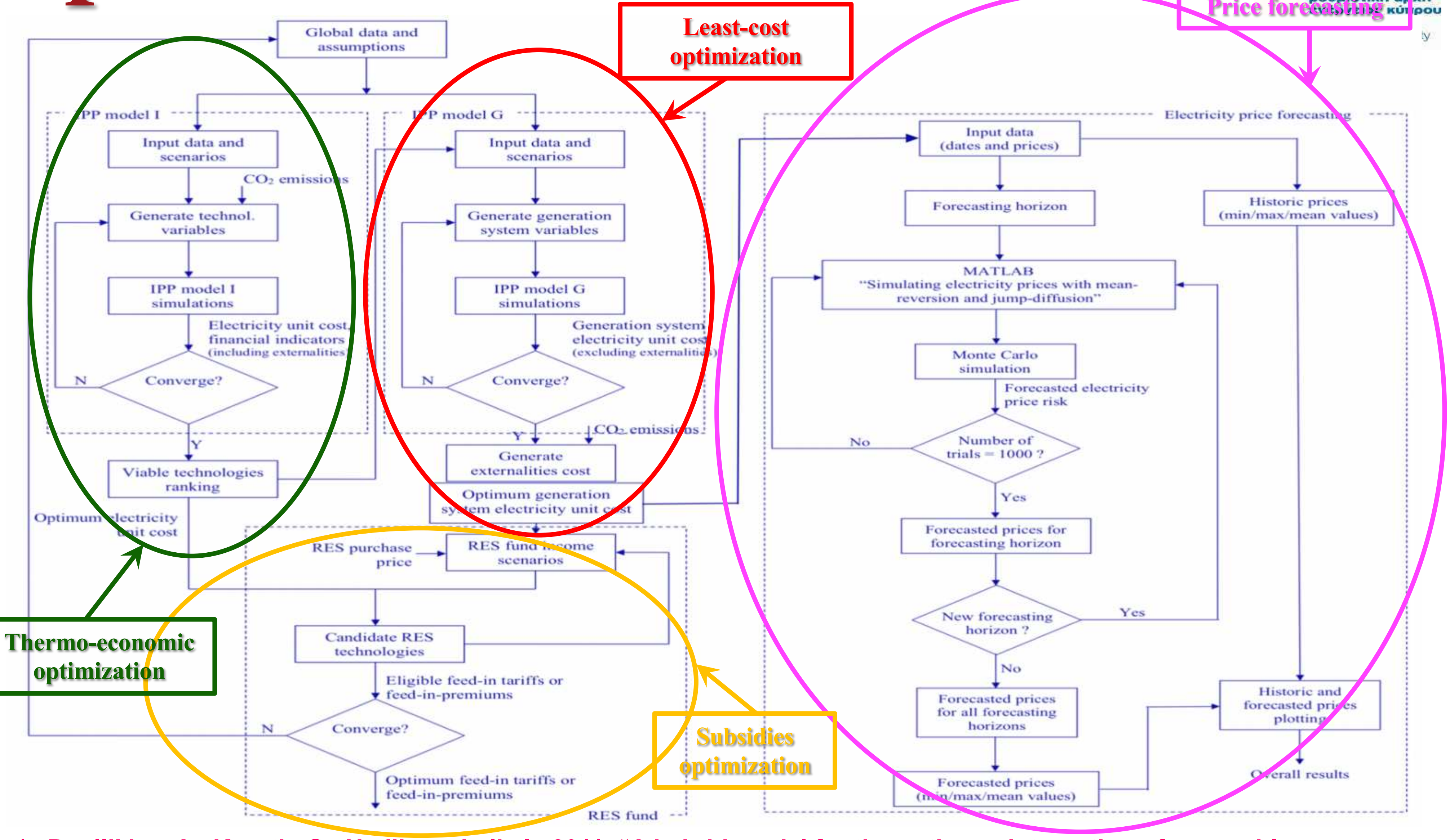
Set of equations*

$$\min c = \min \frac{\partial}{\partial k} \begin{bmatrix} \left(\dfrac{A_1 + A_2 + A_3 + A_4}{A_5} \right)_1 \\ \left(\dfrac{A_1 + A_2 + A_3 + A_4}{A_5} \right)_2 \\ \left(\dfrac{A_1 + A_2 + A_3 + A_4}{A_5} \right)_3 \\ \left(\dfrac{A_1 + A_2 + A_3 + A_4}{A_5} \right)_4 \\ \cdots \\ \left(\dfrac{A_1 + A_2 + A_3 + A_4}{A_5} \right)_k \end{bmatrix}$$

- Row 1 ← Candidate technology 1 + existing system
- Row 2 ← Candidate technology 2 + existing system
- Row 3 ← Candidate technology 3 + existing system
- Row 4 ← Candidate technology 4 + existing system
- Row k ← Candidate technology k + existing system

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

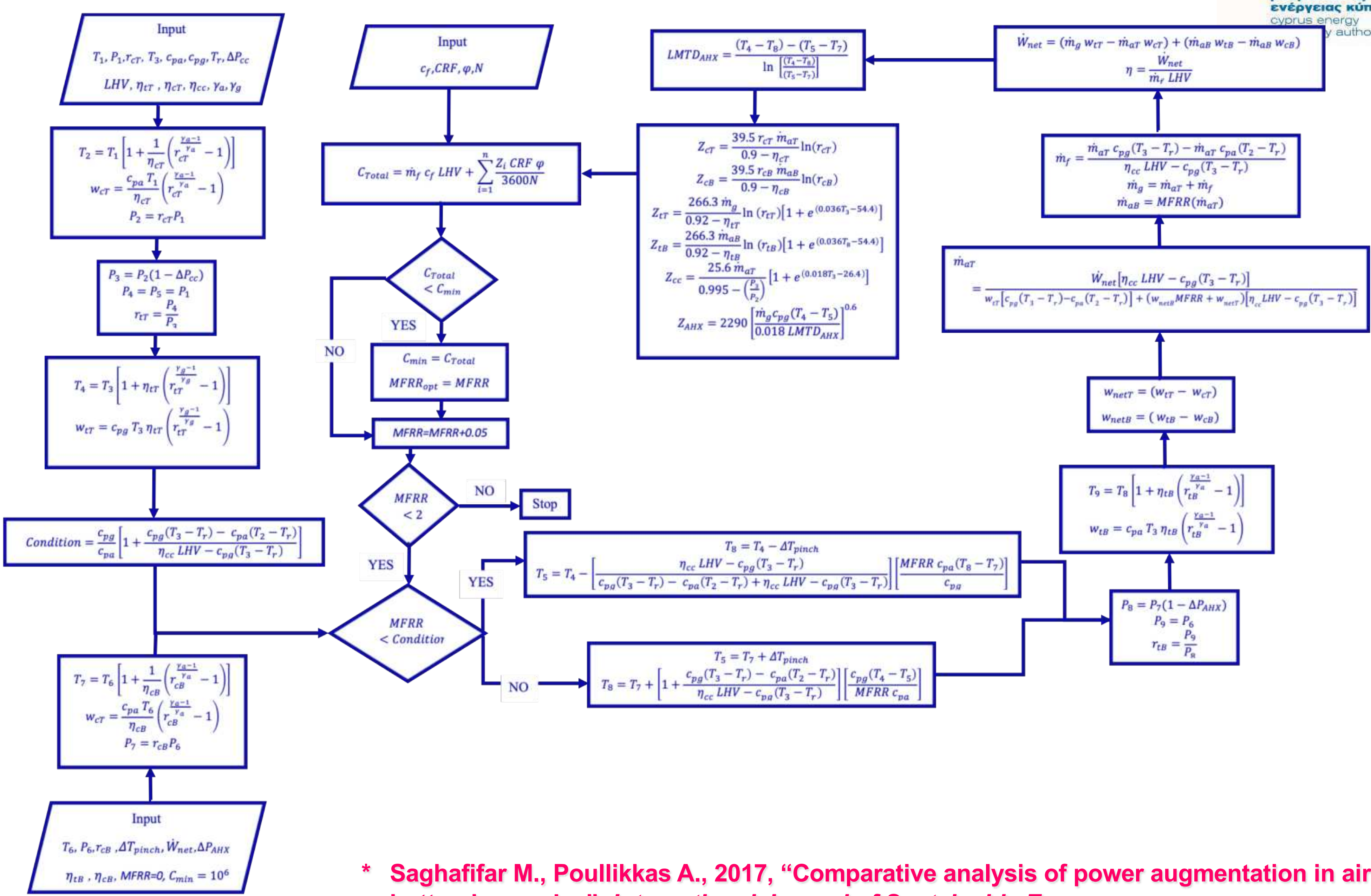
Optimization model*,**



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

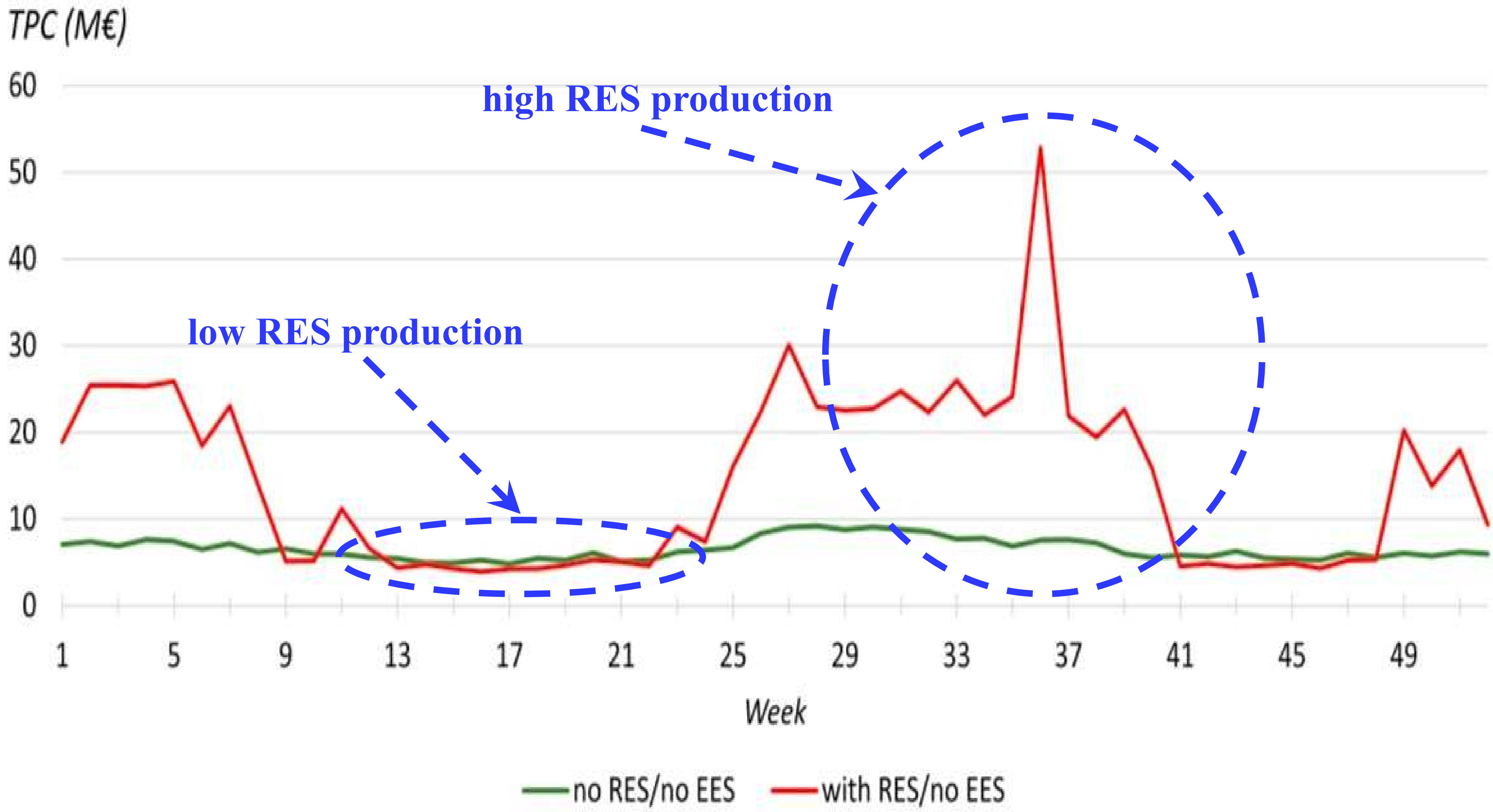
** Poullikkas A., 2018, "An adaptive longterm electricity price risk modelling using Monte Carlo simulation", *Journal of Power Technologies*

Example of thermo-economic optimization*



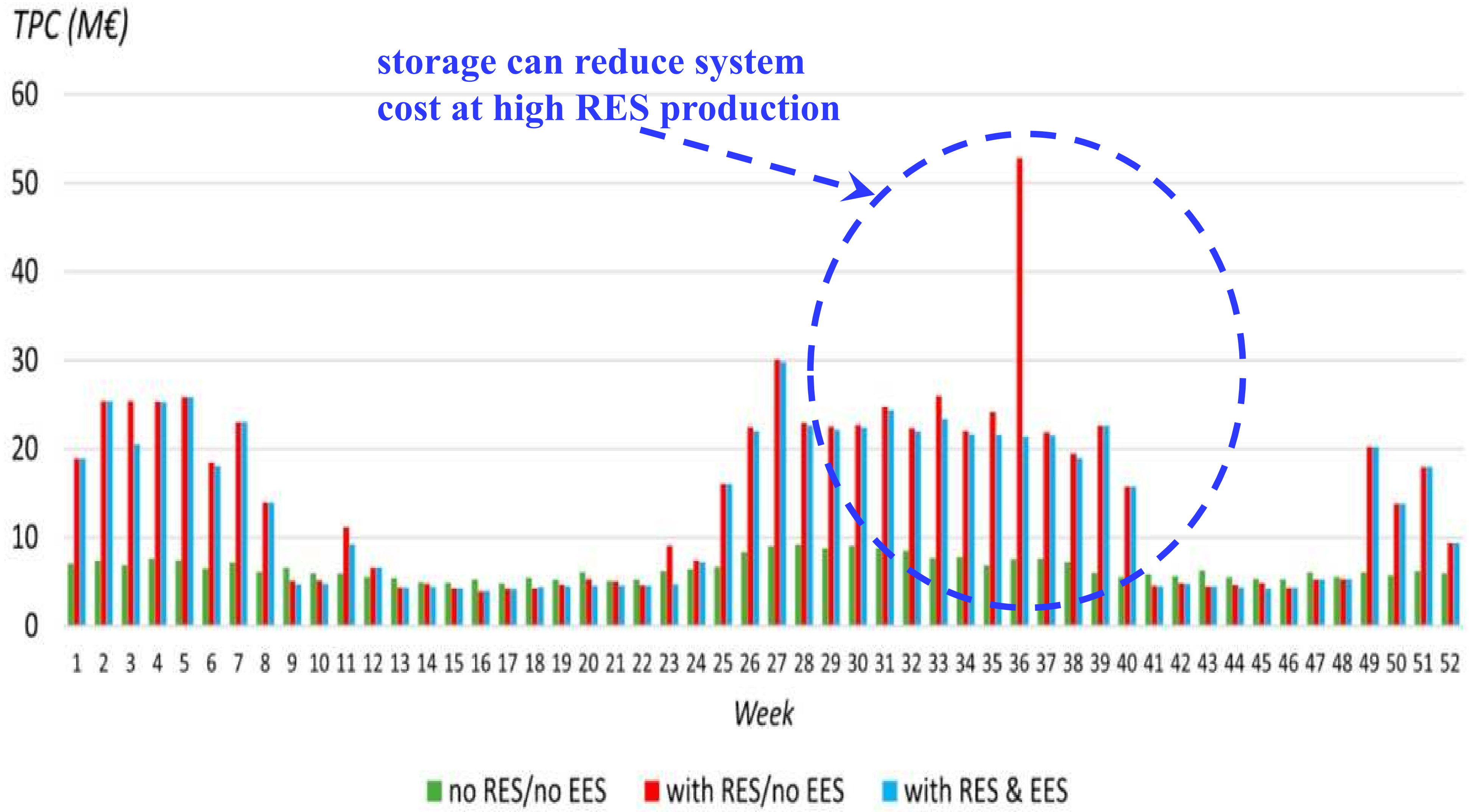
* Saghafifar M., Poullikkas A., 2017, "Comparative analysis of power augmentation in air bottoming cycles", *International Journal of Sustainable Energy*.

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*

Long-term energy strategy for Cyprus

Regional cooperation towards hydrogen economy

Characteristics of isolated electricity systems*

- **High fuel costs**
  - ~ **use of oil derivatives**
- **Economies of scale cannot be adequately exploited**
  - ~ **generation units cannot exceed a certain size since the loss of a unit would mean the loss of a high percentage of the entire system**
- **Need to maintain high reserve capacity to ensure power system reliability**

The smaller the electrical system size, the more the expenses will be

*** Poullikkas A., 2015, *Sustainable Energy Policy for Cyprus*, ISBN: 978-9963-7355-6-3**

Energy transition for non-interconnected islands*

Need to:

- Reduce cost of security of supply
- Achieve market integration
- Increase socio-economic welfare benefits

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

The solution*

- **Increase system flexibility**
  - ~ integrate RES into electricity market
  - ~ use natural gas, storage and RES for power generation
  - ~ promote e-mobility (V2G technology - bidirectional flow of electricity between the electric car and the grid)

- **Establish electricity interconnections**
  - ~ with EU internal electricity market (the island of Cyprus is the only non-interconnected Member State)

- **Production of hydrogen** (energy carrier)
  - ~ from RES and natural gas

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

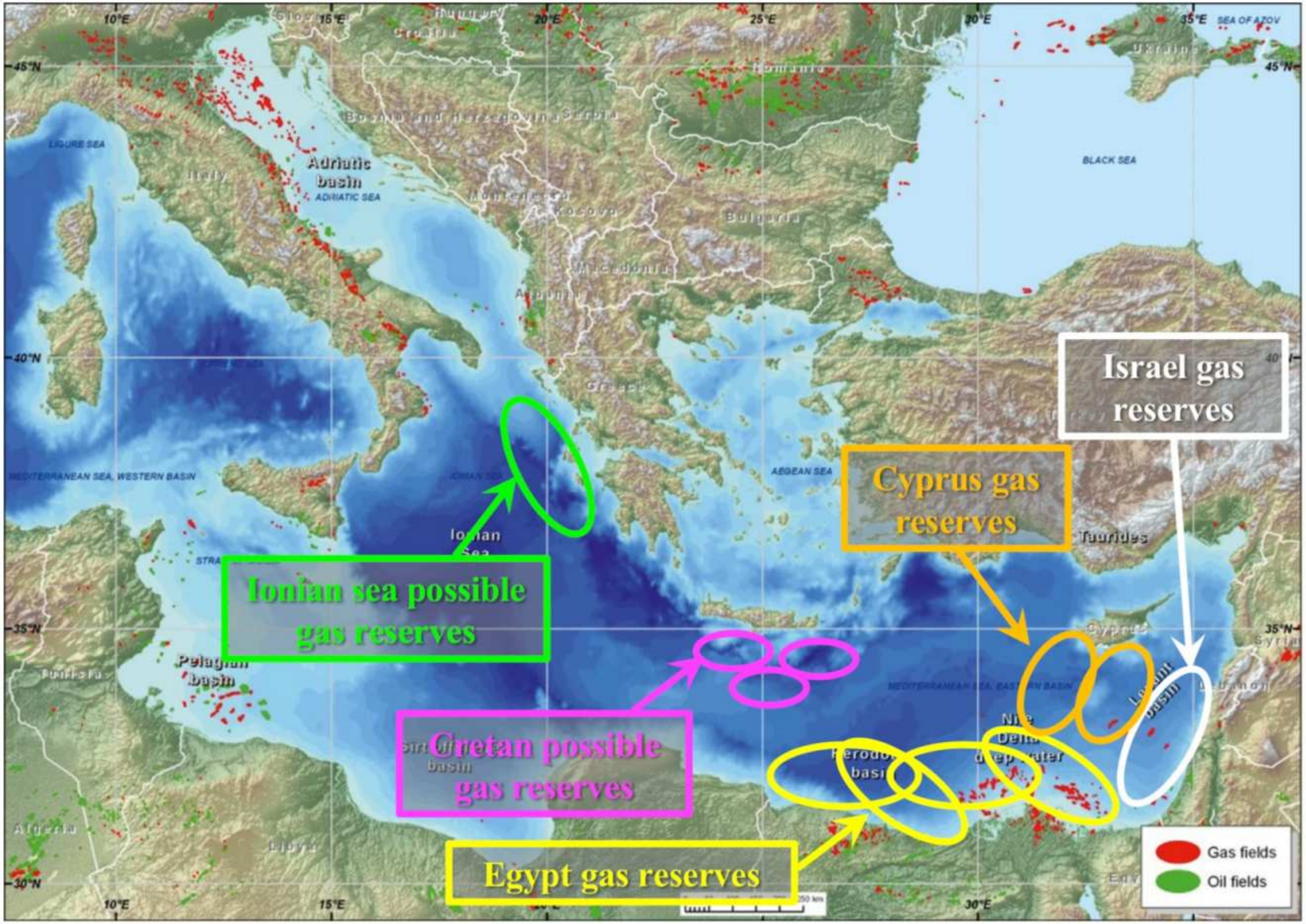
Main goal

The sustainable satisfaction of Cyprus' future energy needs with safety and reliability

Regional primary energy sources

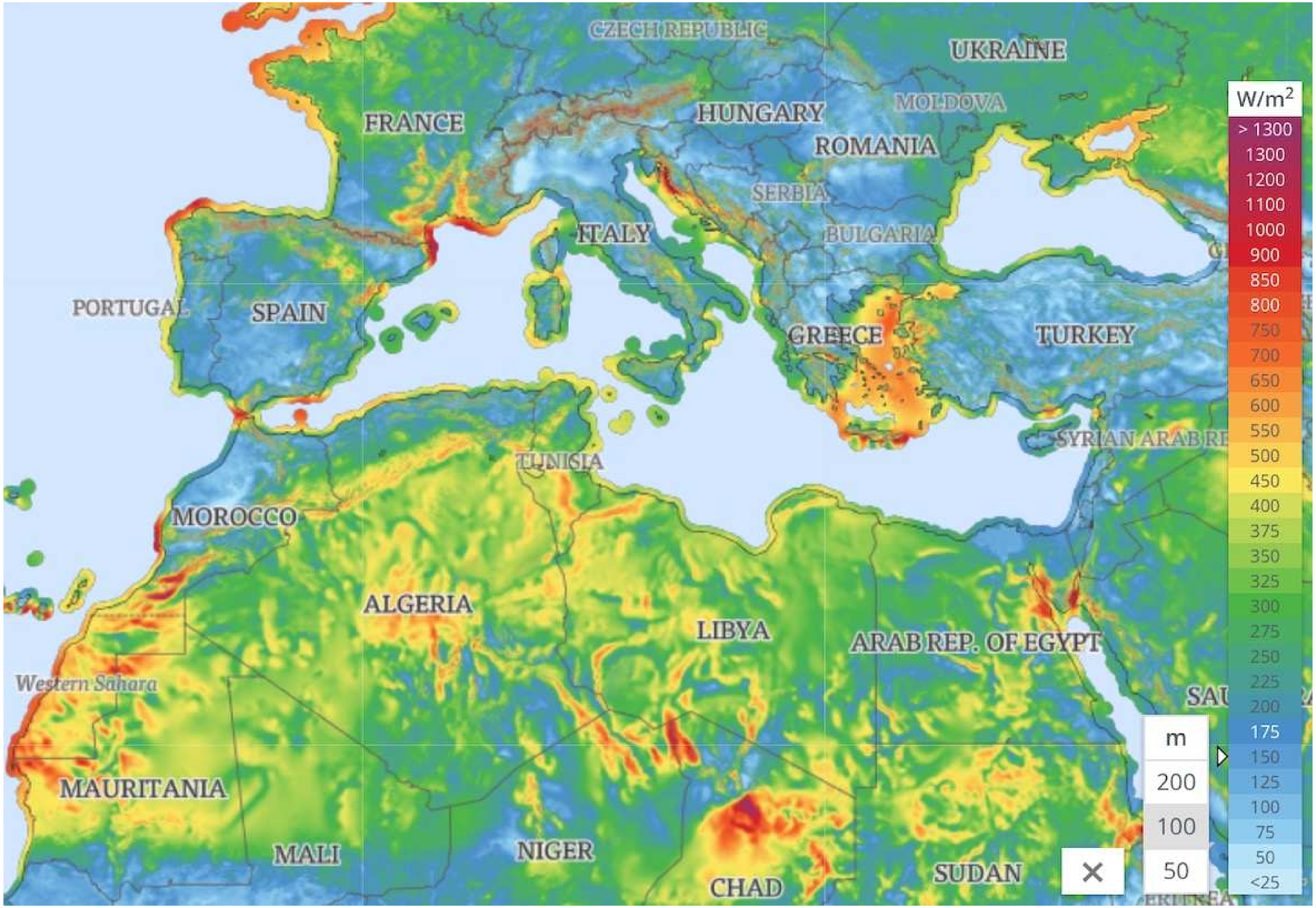
Indigenous energy sources

Gas reserves in SE Mediterranean region*



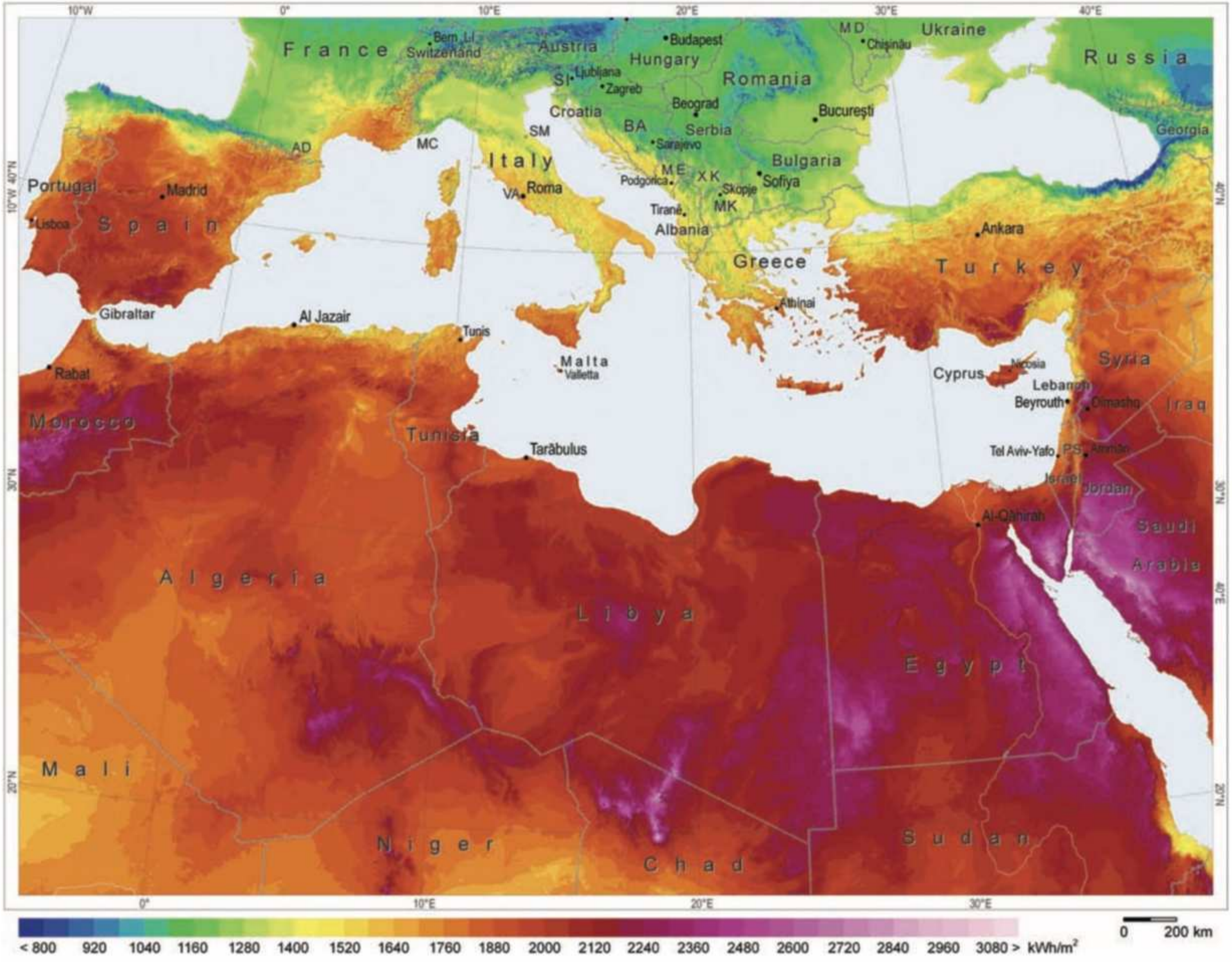
*** A. Belopolsky, *et al.*, 2012, "New and emerging plays in the Eastern Mediterranean", *Petroleum Geoscience***

Wind potential in SE Mediterranean region*



* The Global Wind Atlas (https://globalwindatlas)

Solar potential in SE Mediterranean region*



* Easac & Pihl, Erik. (2011). Concentrating Solar Power: Its potential contribution to a sustainable energy future

Main indigenous energy sources in SE Mediterranean region

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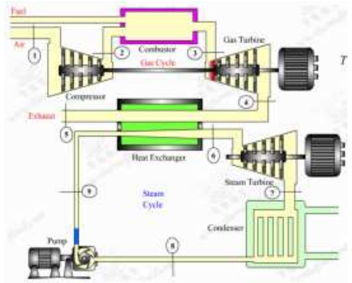
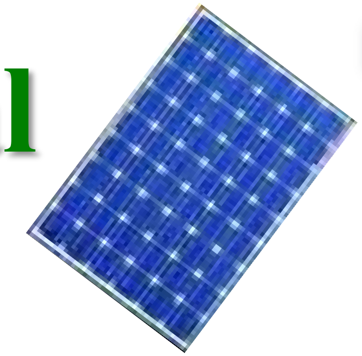
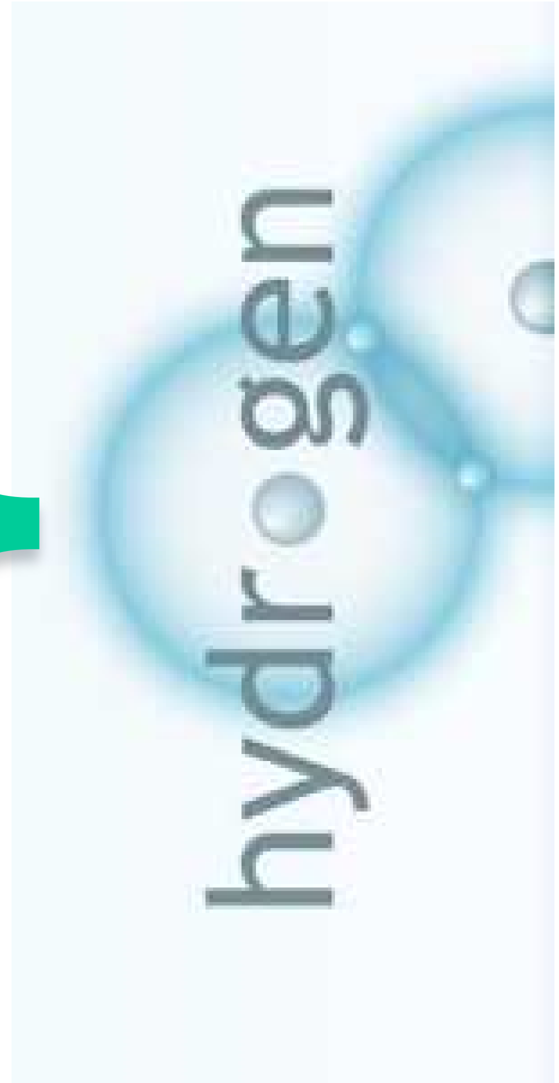
- **Natural gas**



- **Wind potential**

- **Solar potential**





Target-setting for Cyprus' transition to hydrogen economy*

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Target	Year		
	2030	2040	2050
Greenhouse gases	-30%	-75%	-100%
Renewable energy sources	30%	75%	100%
Electrical interconnections	50%	65%	80%

Cyprus could set a long-term goal of reducing greenhouse gas emissions by 100% by 2050 !

* Poullikkas A., 2020, *Long-term Sustainable Energy Strategy: Cyprus' Energy Transition to Hydrogen Economy*, ISBN: 978-9925-7710-0-4

Energy transition by 2050

Cyprus' energy system:

- smart and digitised
- flexible
- decentralised
- electrically interconnected
- interconnected gas and/or hydrogen pipelines

Integration:

- hydrogen in all energy sectors
- renewable energy sources
- storage energy systems
- electric mobility

Transition of Cyprus from the current carbon economy to hydrogen economy by the year 2050

Development of regional energy strategy ?

- **Horizon up to 2060**
- **Development of strategic plan for SE Med region:**
  - ~ **Electrical interconnections**
  - ~ **Pipeline interconnections (or virtual pipelines)**
  - ~ **Integration of sustainable technologies and storage**
  - ~ **Use of hydrogen after 2030**
  - ~ **Hydrogen production**
    - **From natural gas**
    - **From renewables**

- **Energy exporters to EU**