Plenary Talk

Large Scale Integration of Renewable Energy Systems into Electricity Markets

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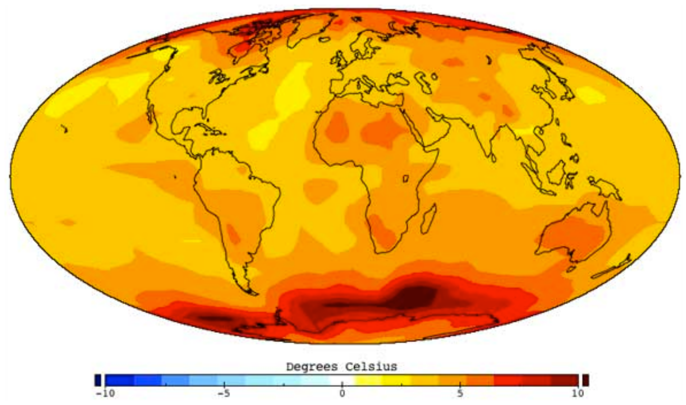
  - RES integration
  - NG and storage
- **Modeling for optimum large scale integration of RES**
  - Simulation of RES operation
  - Integration of storage

EU energy strategy

2020, 2030, 2050

Future energy systems

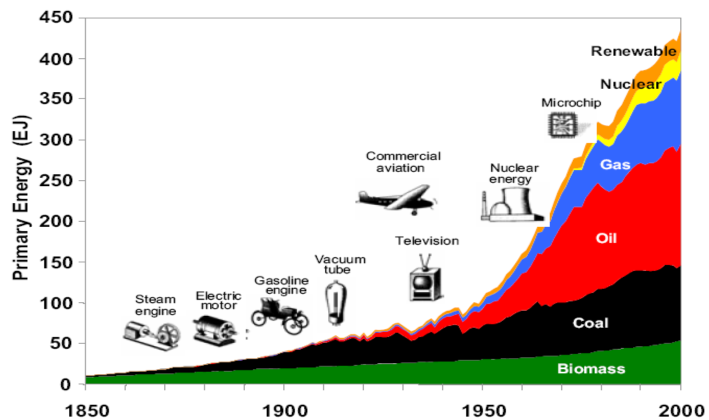
- **Climate change**



- **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

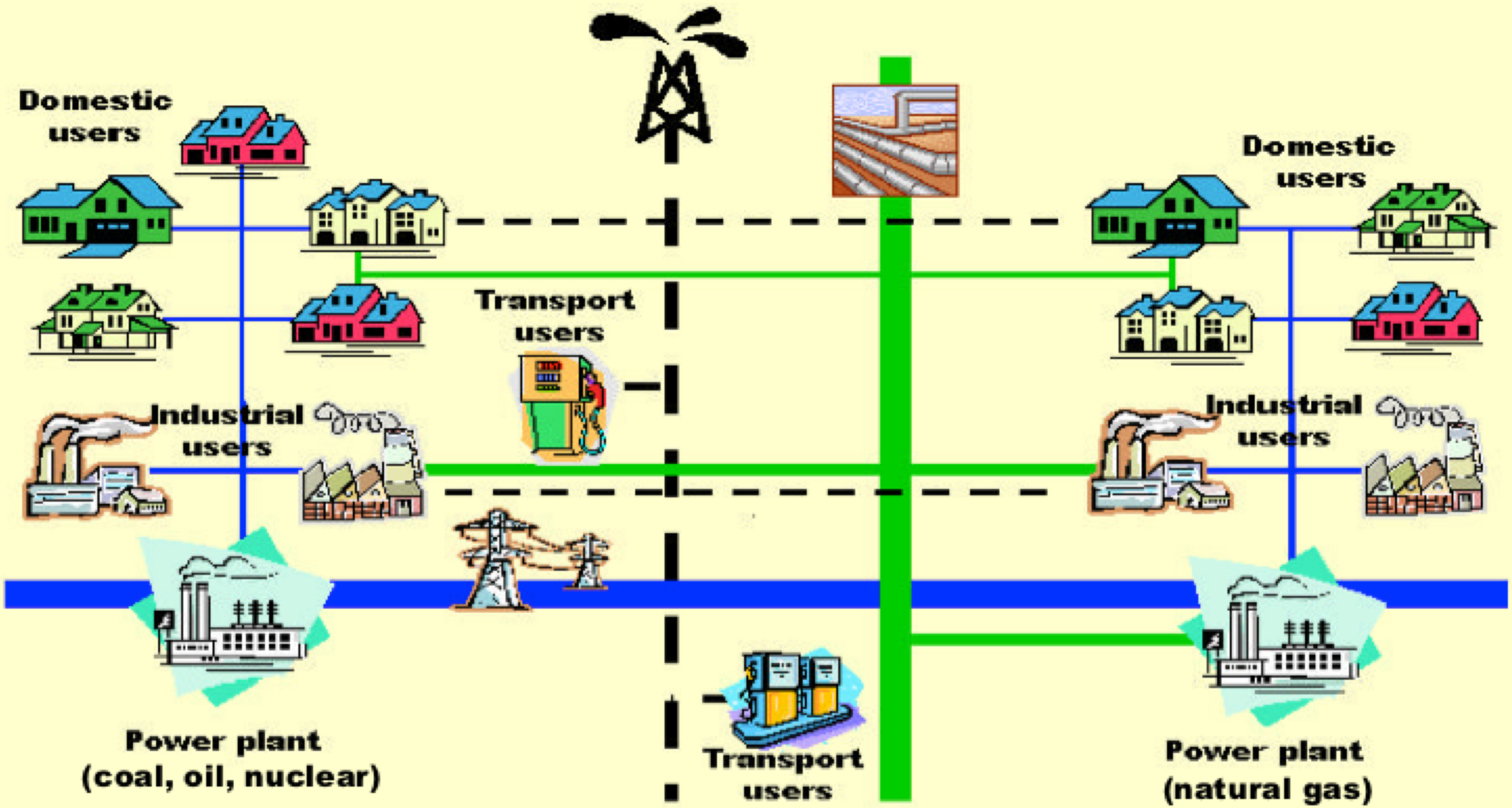
2020	-20 % Greenhouse Gas Emissions	20% Renewable Energy	20 % Energy Efficiency	10 % Interconnection
2030	≥ - 40 % Greenhouse Gas Emissions	≥32 % Renewable Energy	≥ 32,5% Energy Efficiency	15 % Interconnection

New governance system + indicators

2050 -80% Greenhouse Gas Emissions

Current energy system

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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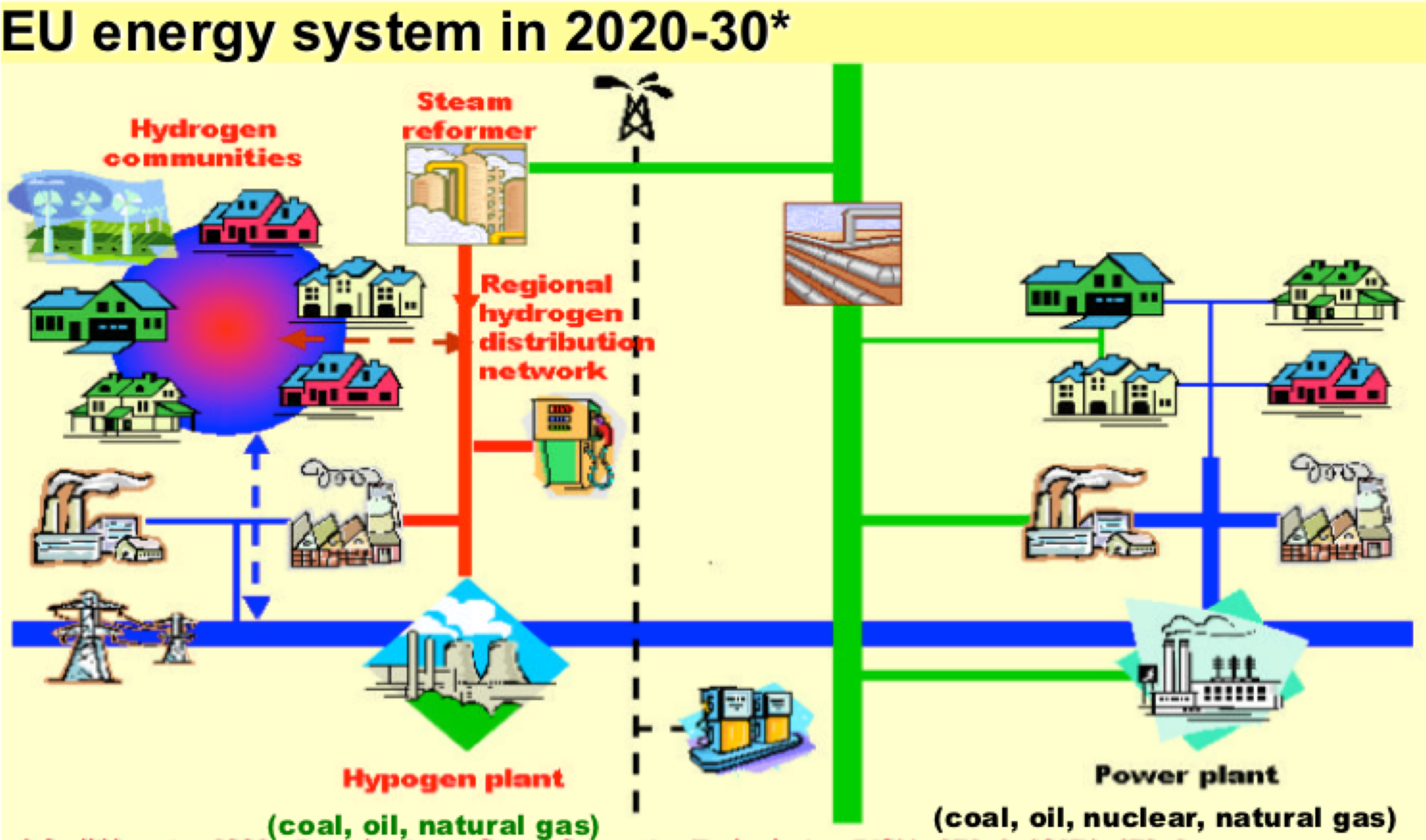
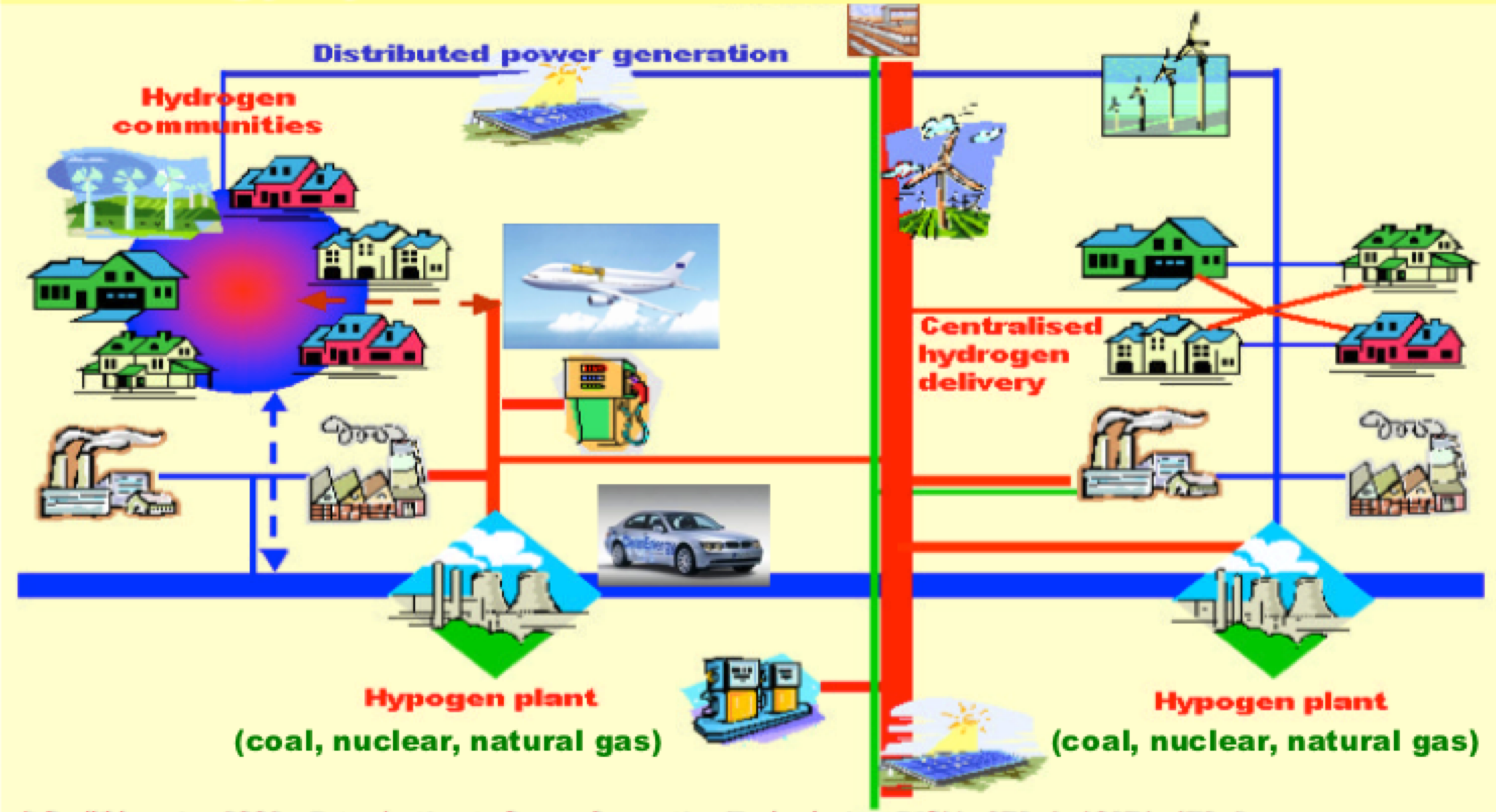


* Poullikkas A., 2009, *Introduction to Power Generation Technologies*, ISBN: 978-1-60876-472-3

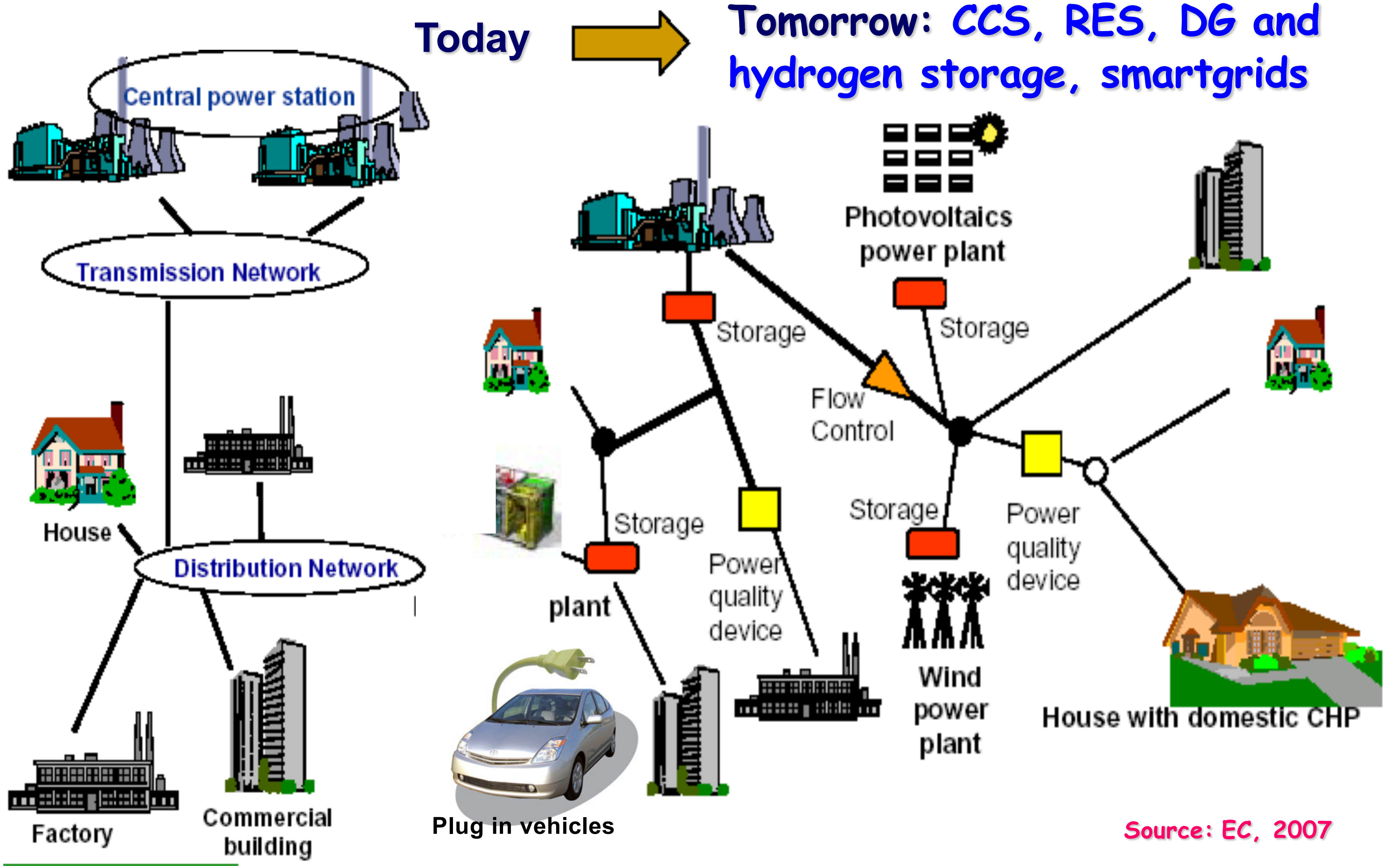
Future energy systems (optimistic scenario)

EU energy system in 2040-50*

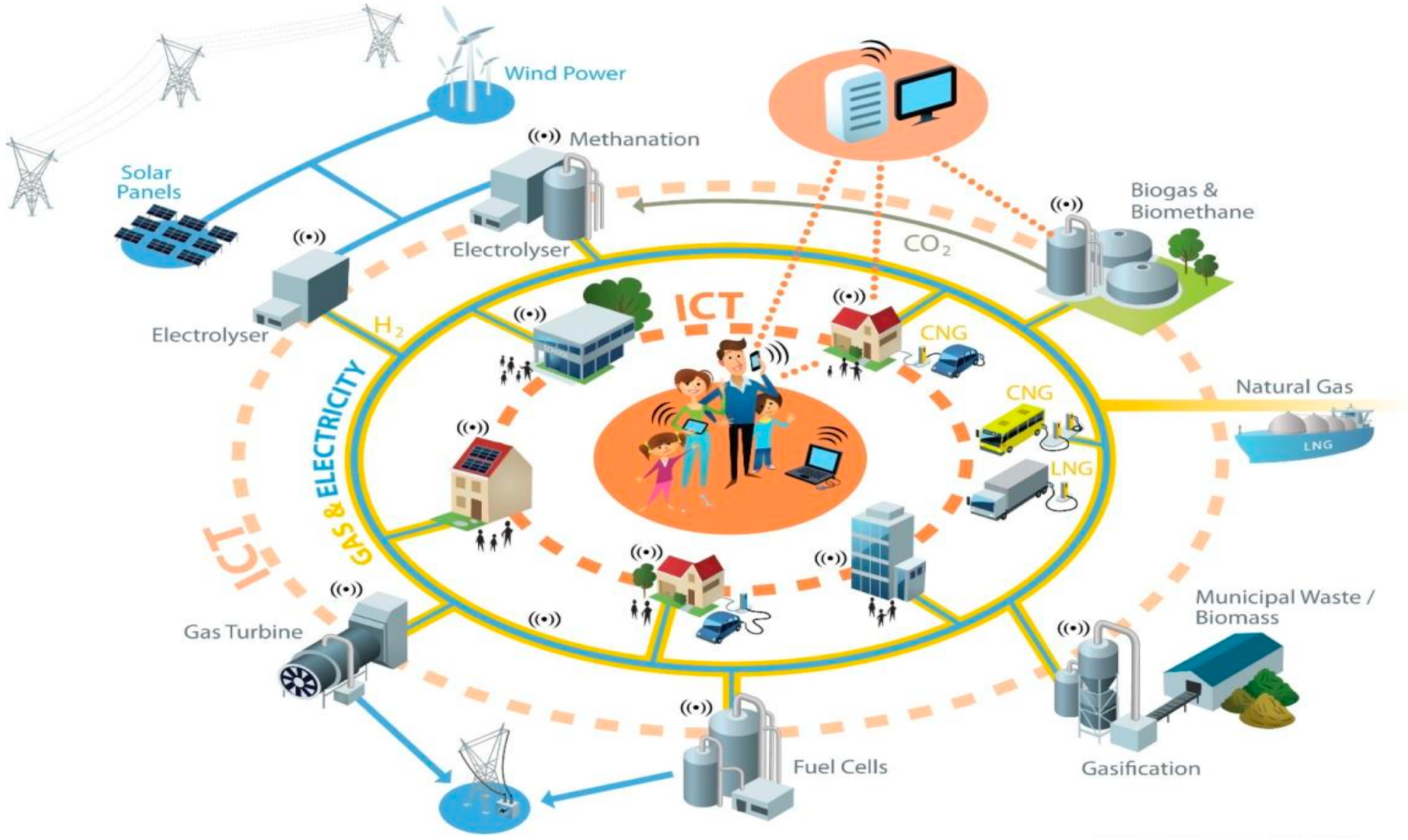


* Poullikkas A., 2009, *Introduction to Power Generation Technologies*, ISBN: 978-1-60876-472-3

Future power systems



End goal – the smart future



The Super Smart Grid after 2050*

(may allow for 100% RES)

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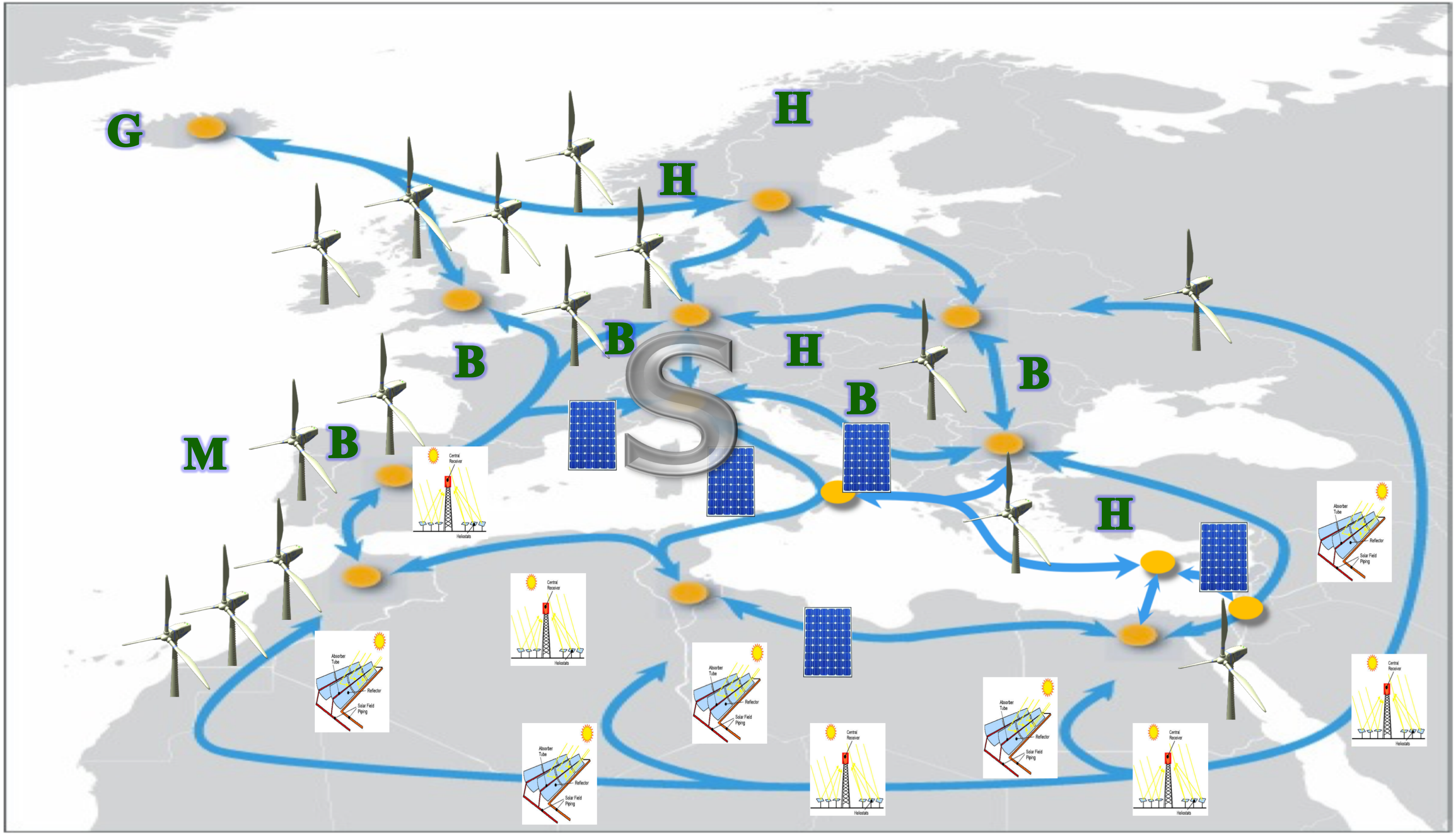

* Poullikkas A., 2013, *Sustainable Energy Development for Cyprus*, ISBN: 978-9963-7355-3-2

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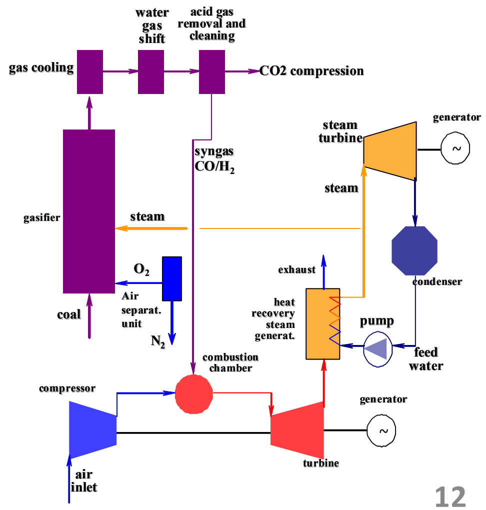
Long term EU energy strategy (2050)

- 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

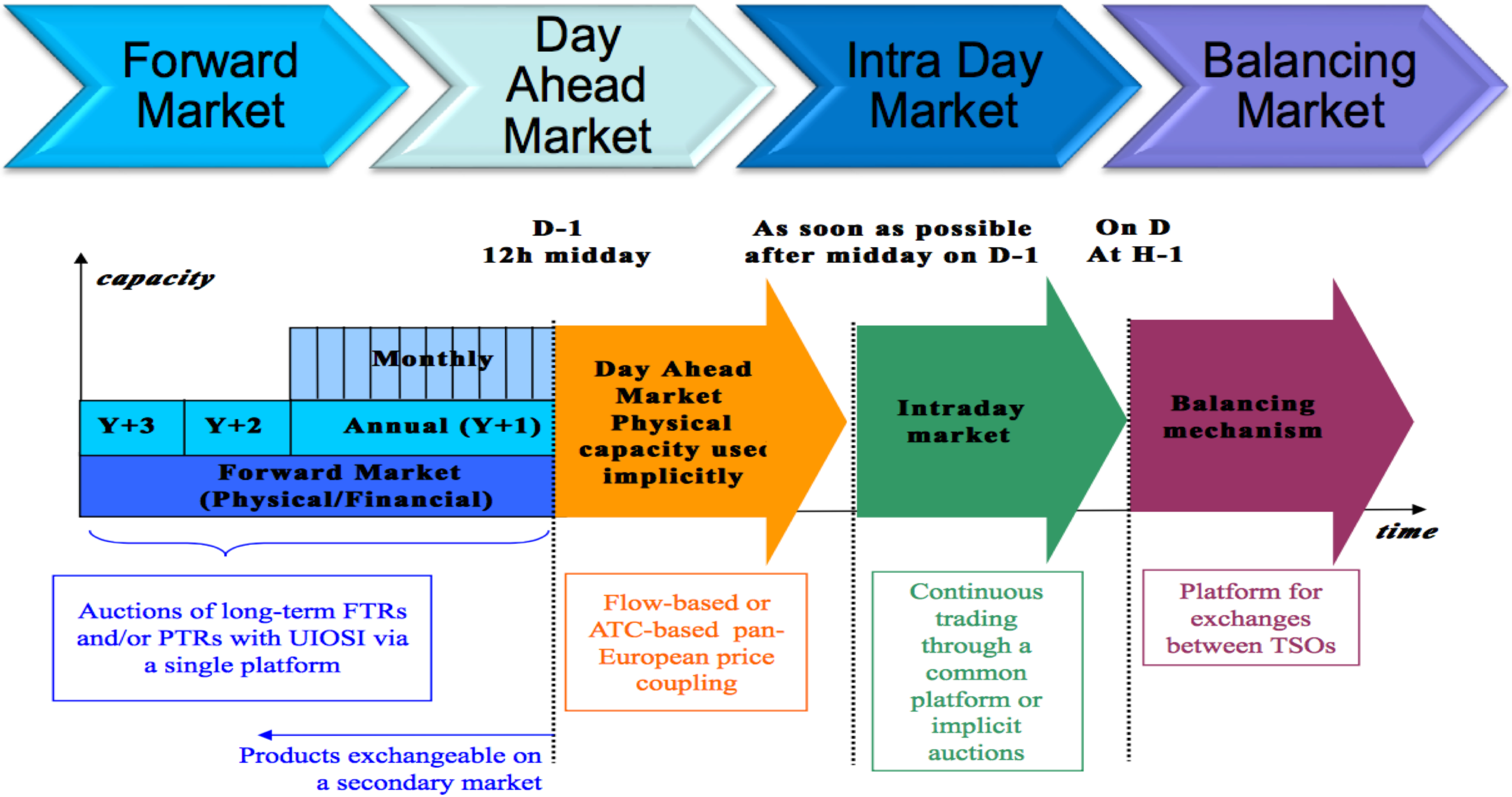


Need to develop advanced simulation tools, new sustainable technologies and infrastructure !!

Challenges in electricity markets

RES integration

EU electricity market target model



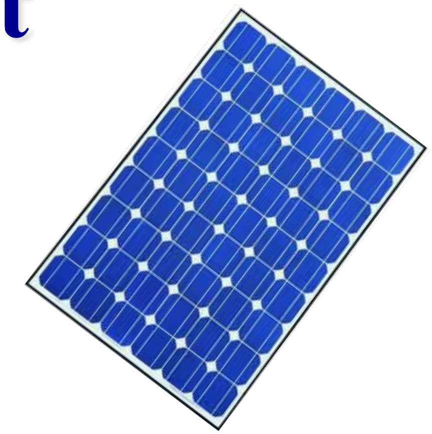
Integration of RES: LCOE *vs* Reliability

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

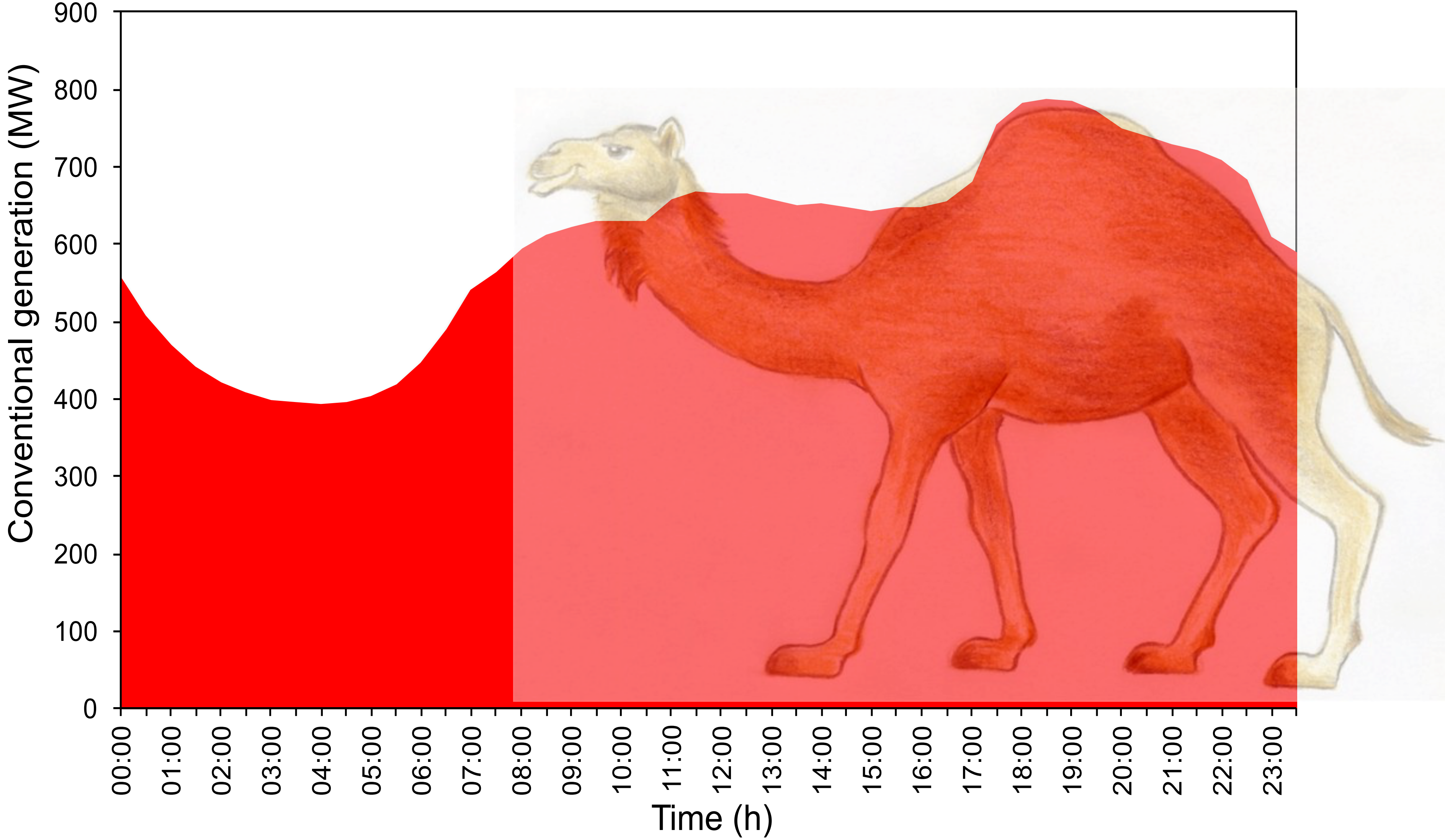
Intermittent energy source*



- **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**

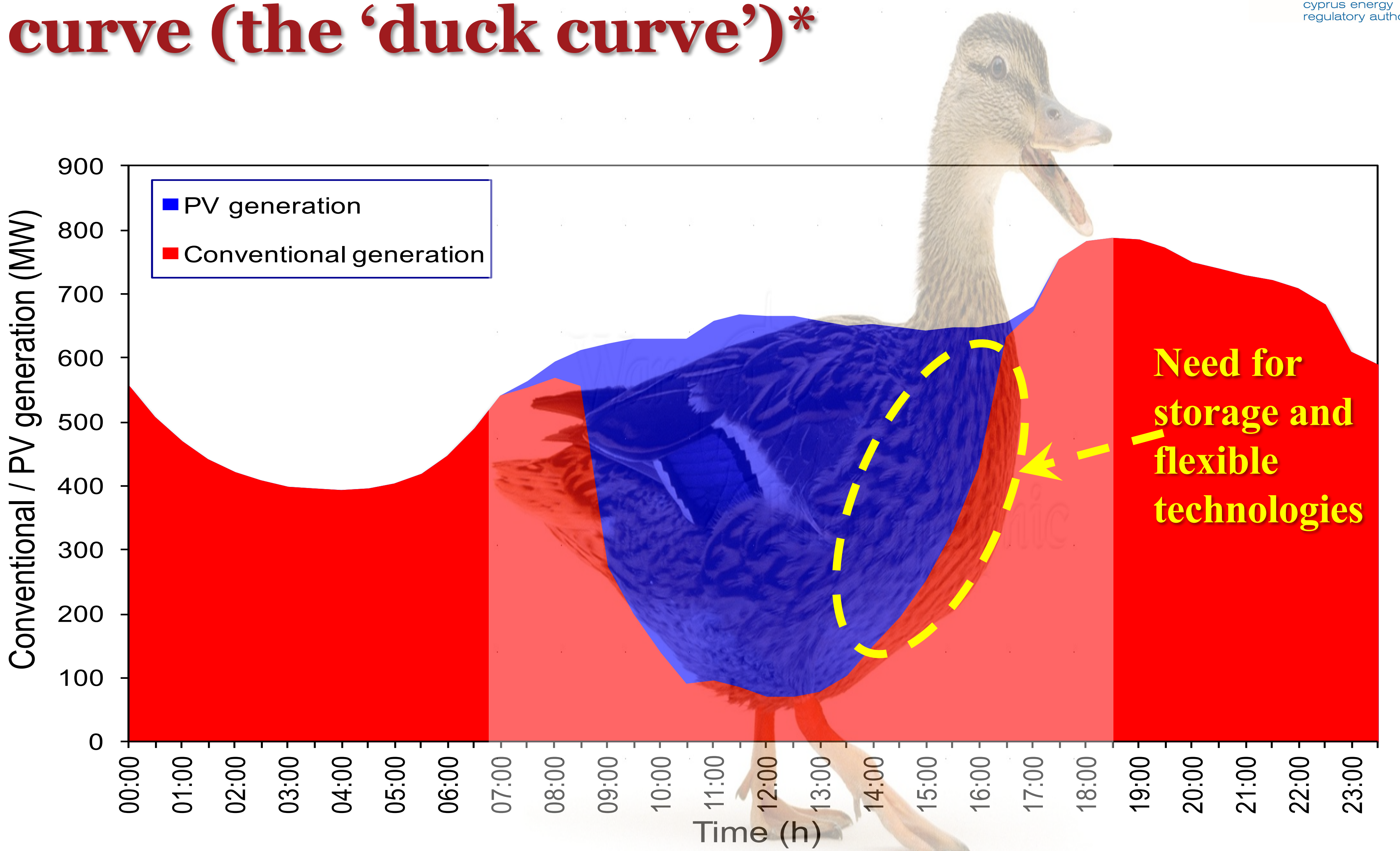
* Poullikkas A., 2013, *Renewable Energy: Economics, Emerging Technologies and Global Practices*, ISBN: 978-1-62618-231-8

Daily load curve (the 'camel curve')*



* **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*)

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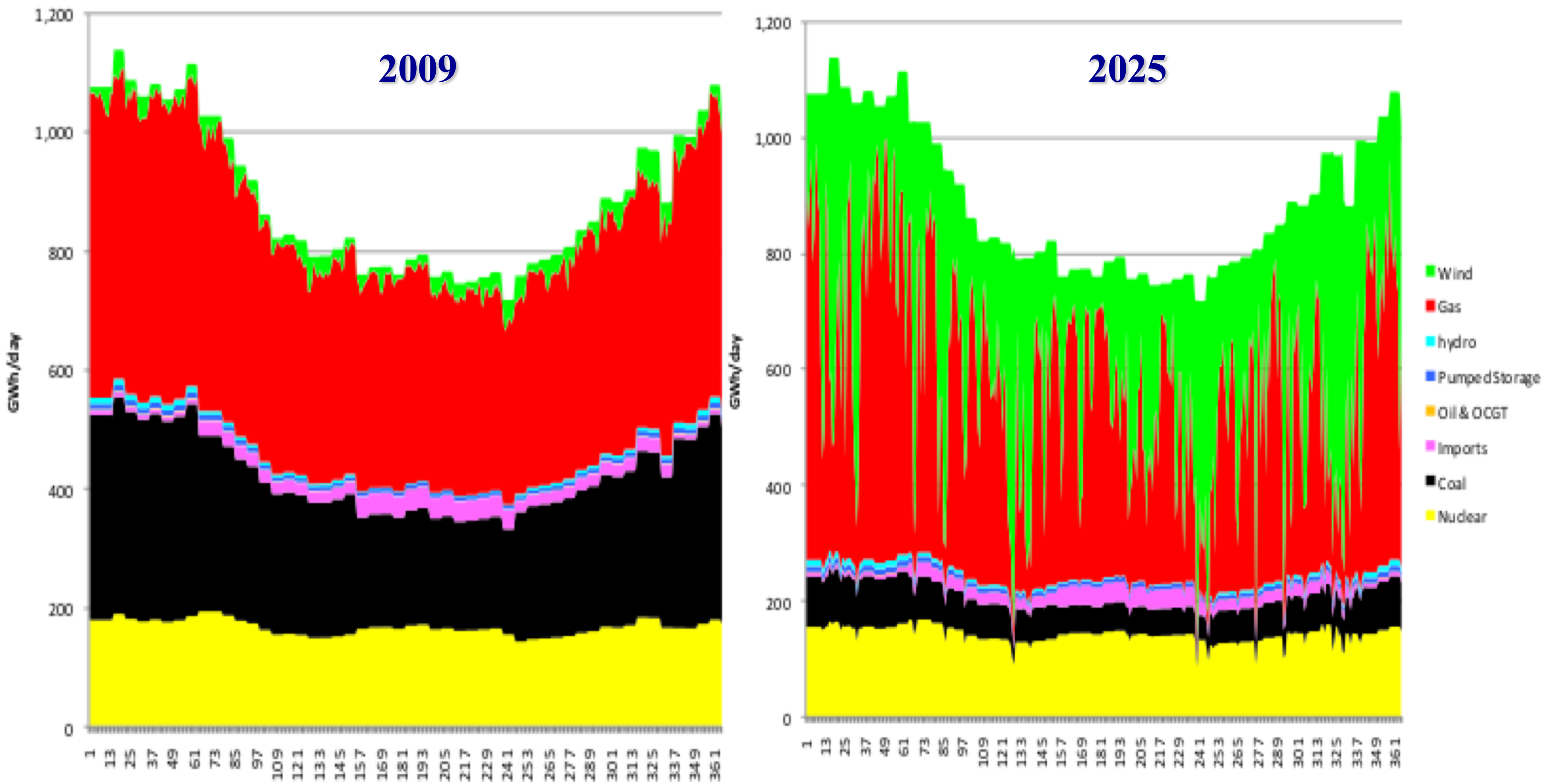


* H.V. Rogers, 2011, *The Impact of Import Dependence and Wind Generation on UK Gas Demand and Security of Supply to 2025*, The Oxford Institute For Energy Studies

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

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

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

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

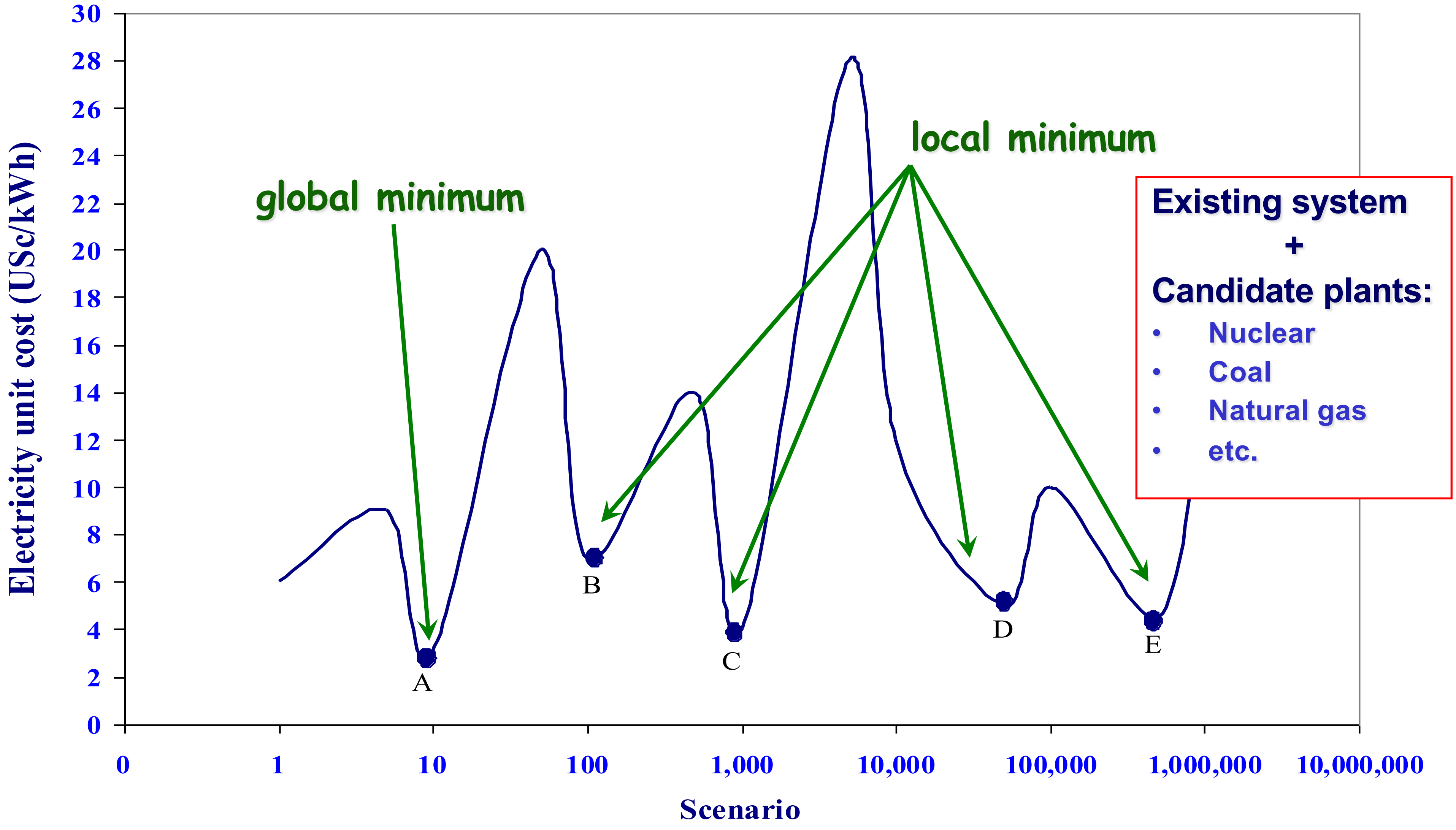
$$R_{S(t)} \leq \sum_i r_{s(i,t)} I_{(i,t)} \qquad r_{s(i,t)} = \min\left[10MSR_i, P_{g,\max(i)} - P_{(i,t)}\right]$$

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

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

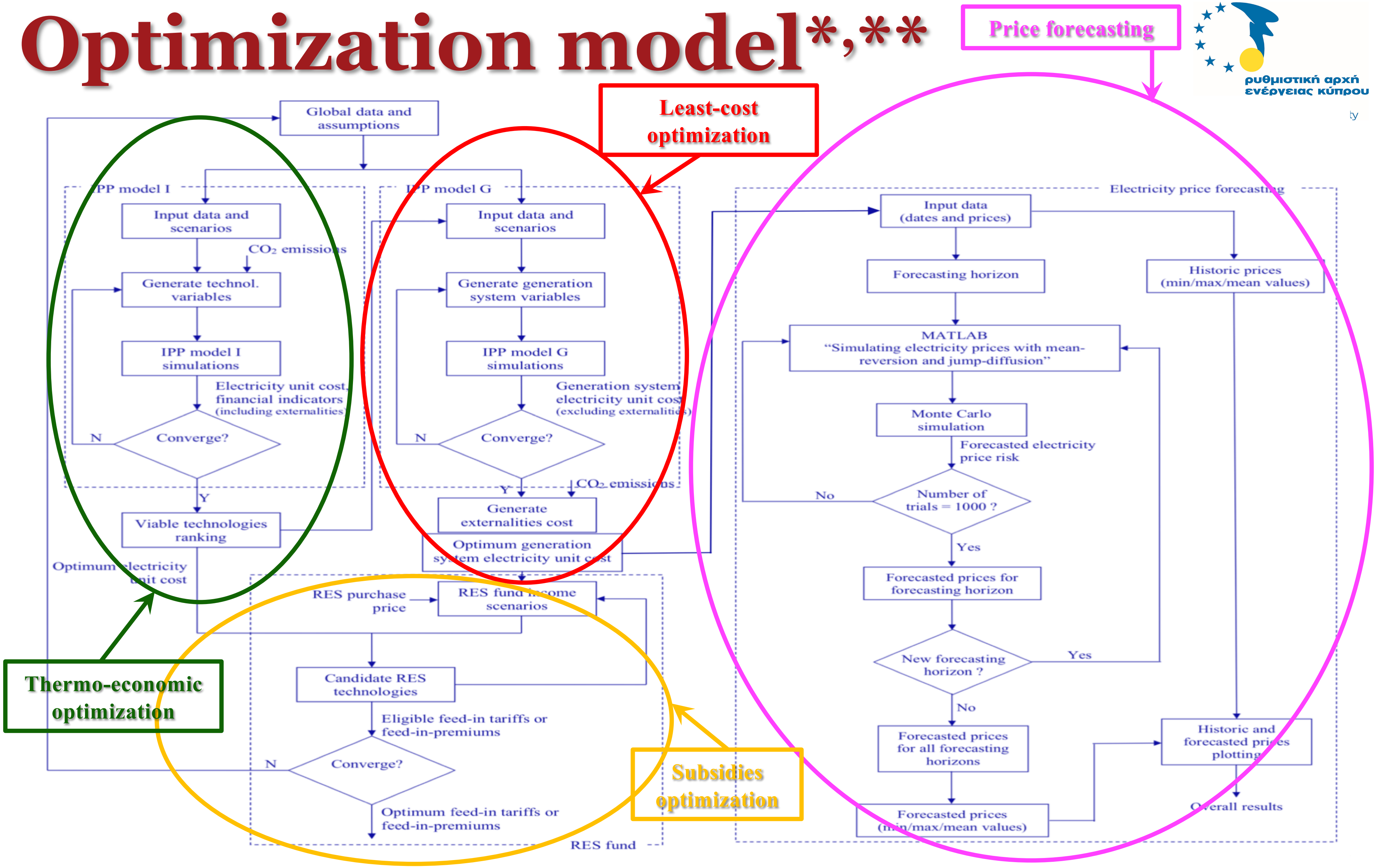
* Poullikkas A., 2009, "A decouple optimization method for power technology selection in competitive markets", *Energy Sources*

Typical shape of objective function*



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

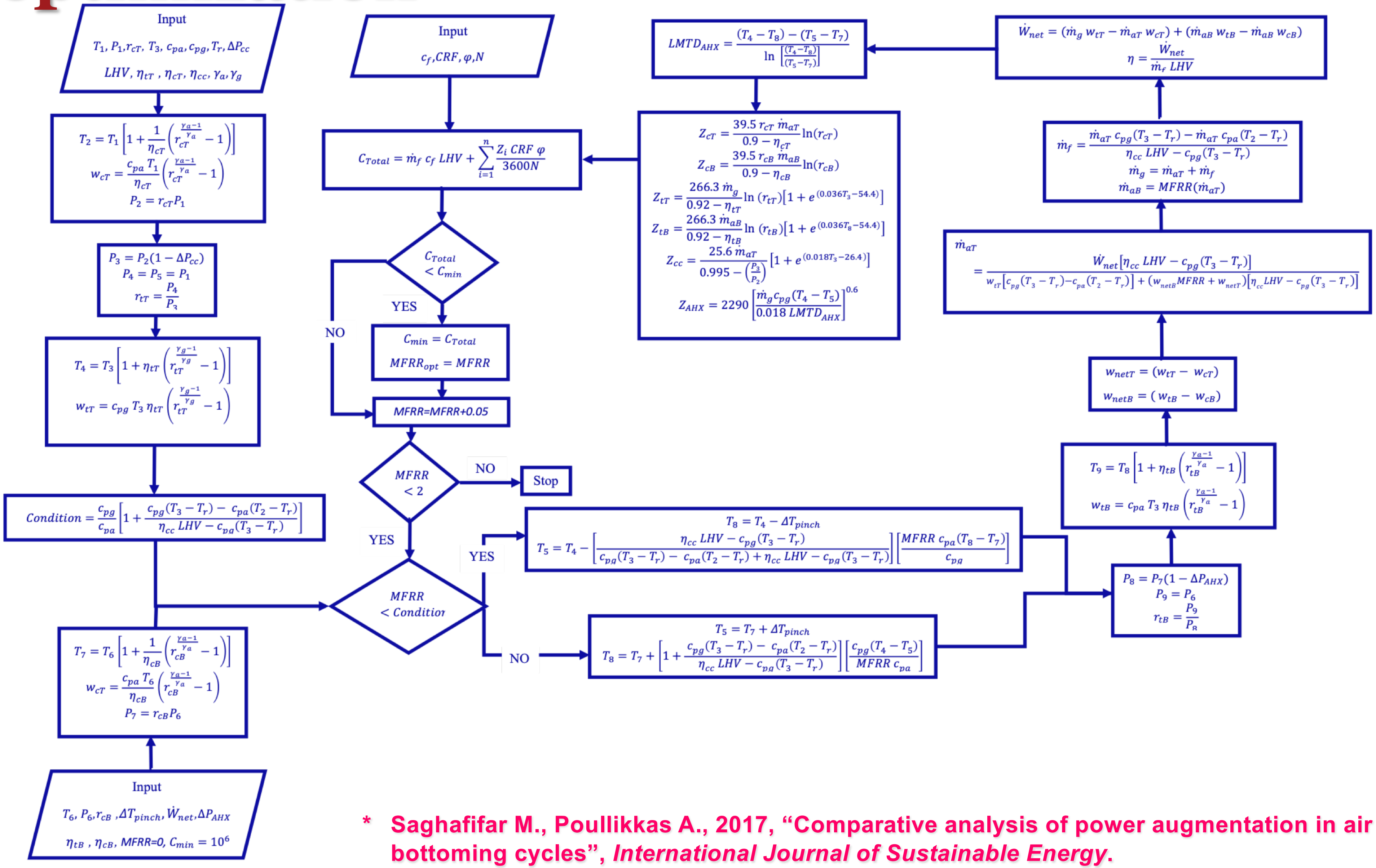
Optimization model*,**



* 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 ($) Variable O&M ($)

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

Electricity unit cost ($c/kWh)

Energy (kWh)

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

Development of sustainable technologies

Design, development and testing

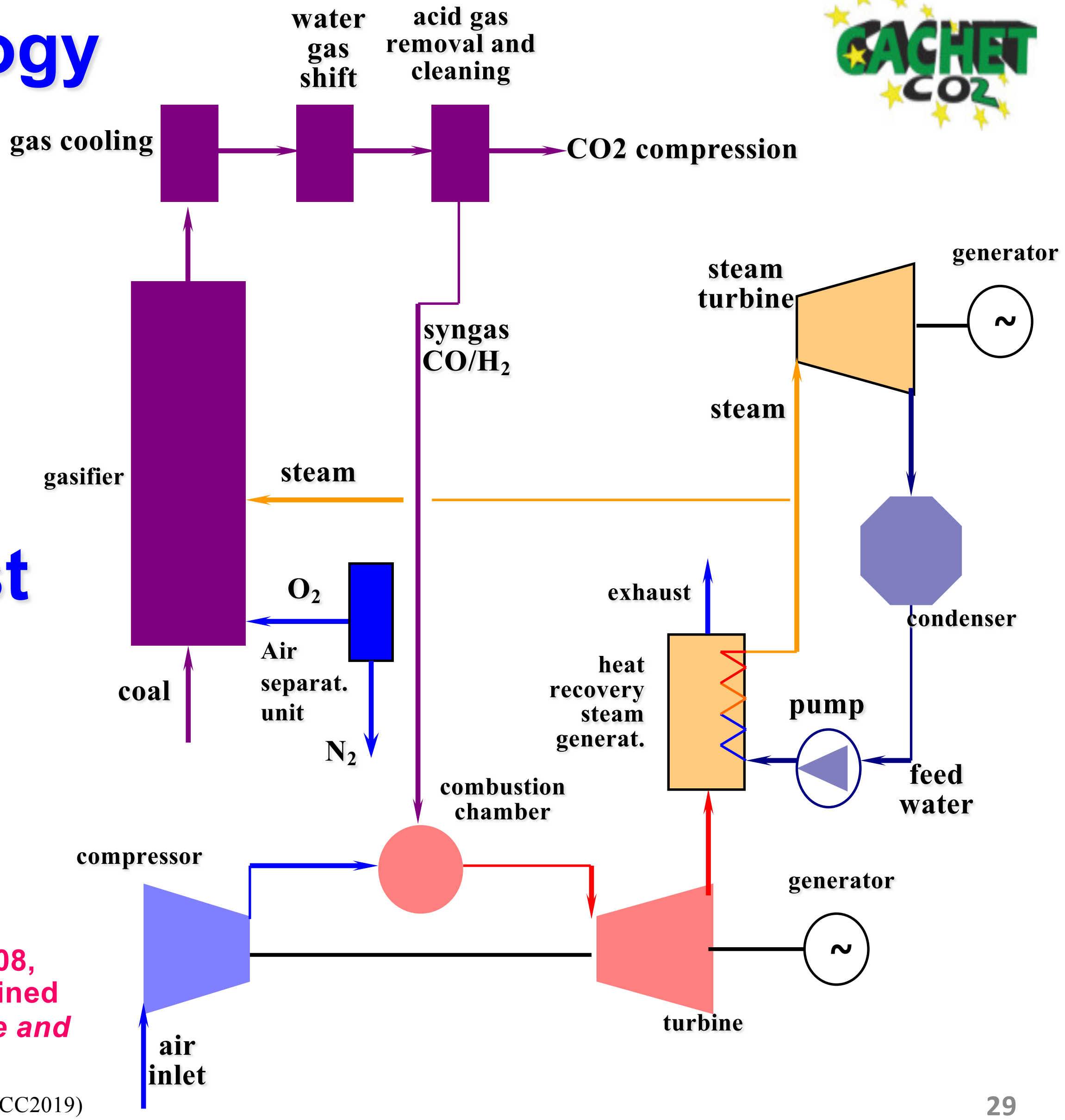
IGCC technology with CCS*

- **Emerging technology**
- **Efficiency**

  34 %

- **Electricity unit cost**

  7.30 US$c/kWh



* Christou C., Hadjipaschalis I., Poullikkas A., 2008, "Assessment of Integrated Gasification Combined Cycle technology competitiveness", *Renewable and Sustainable Energy Reviews*

Natural gas combined cycle with pre CCS*

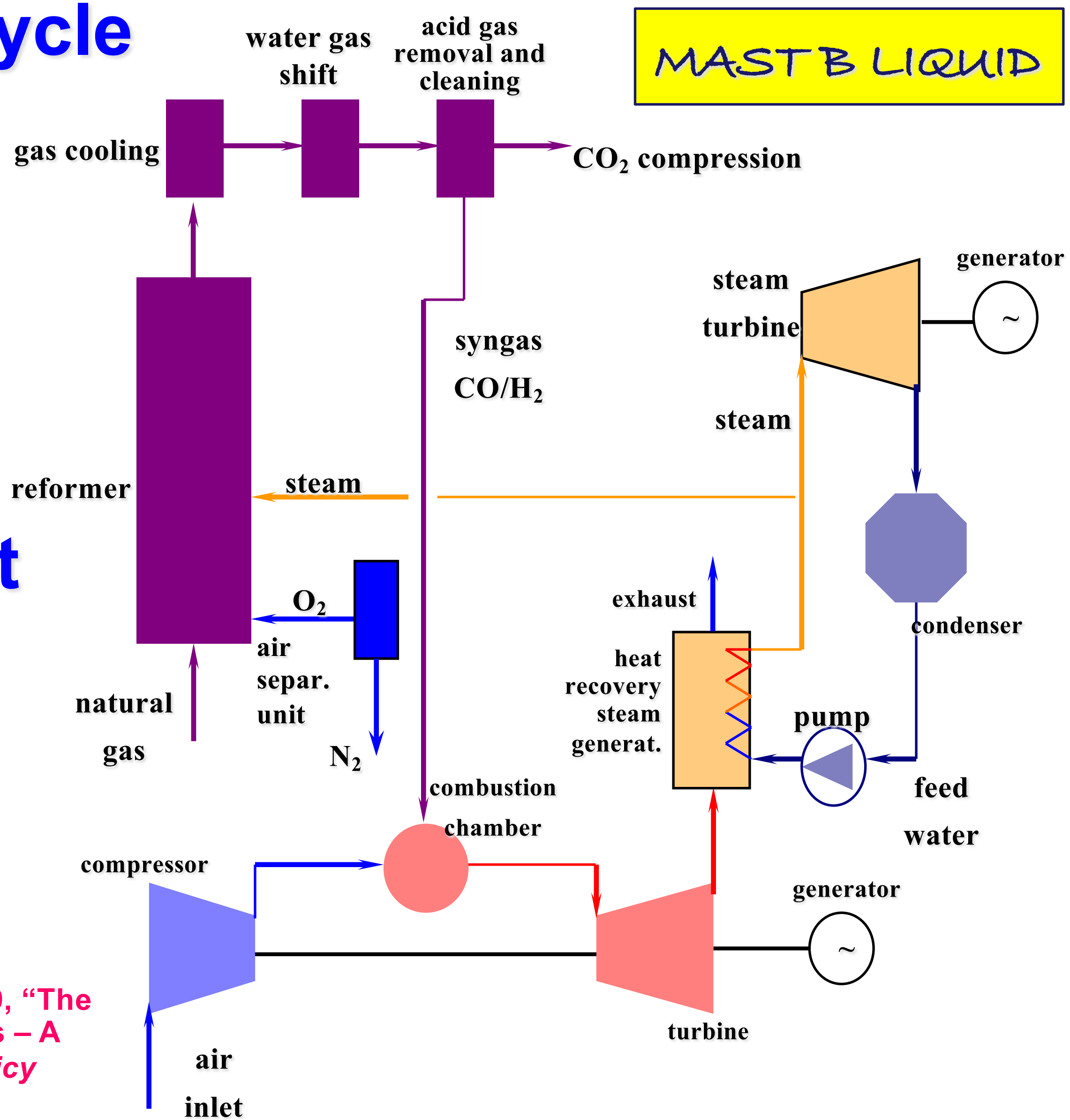
- **Brayton-Rankine cycle**

- **Efficiency**

  43 %

- **Electricity unit cost**

  10.56 US$c/kWh



* Poullikkas A., Hadjipaschalis I., Christou C., 2009, "The cost of integration of zero emission power plants – A case study for the island of Cyprus", *Energy Policy*

7.5MW wind turbine*

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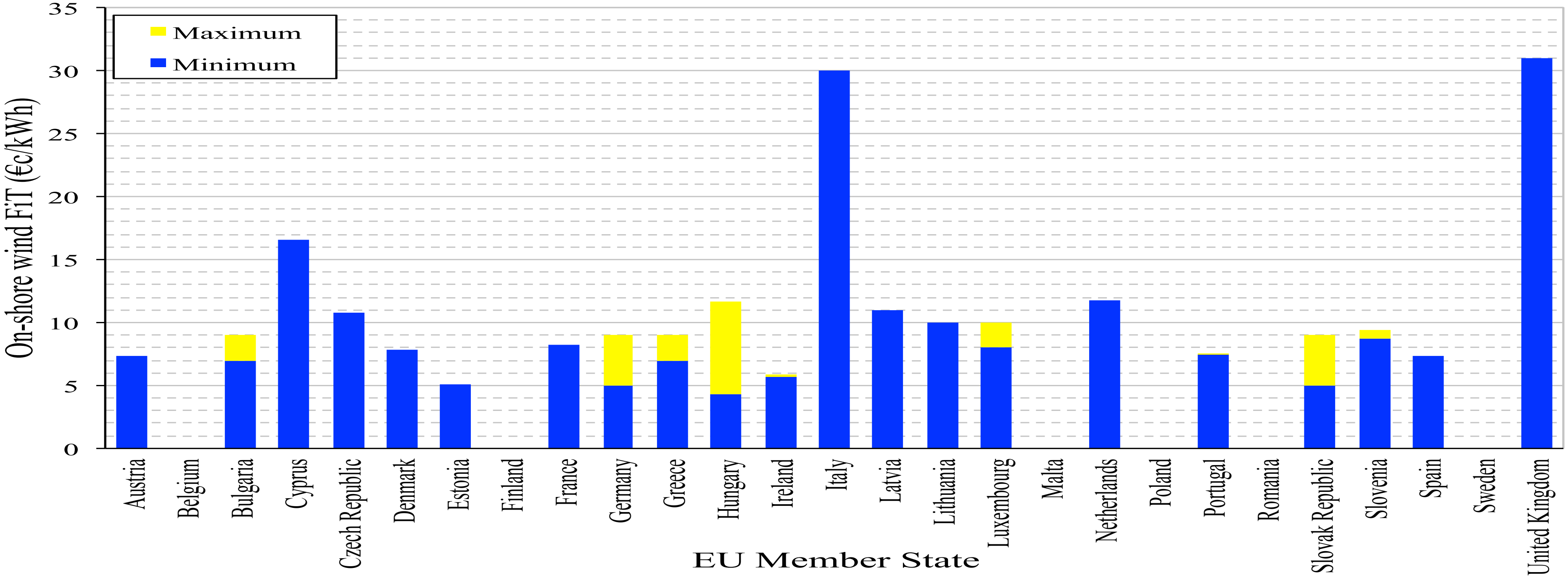
- Design
- Simulation
- Installation
  11x7.5MW

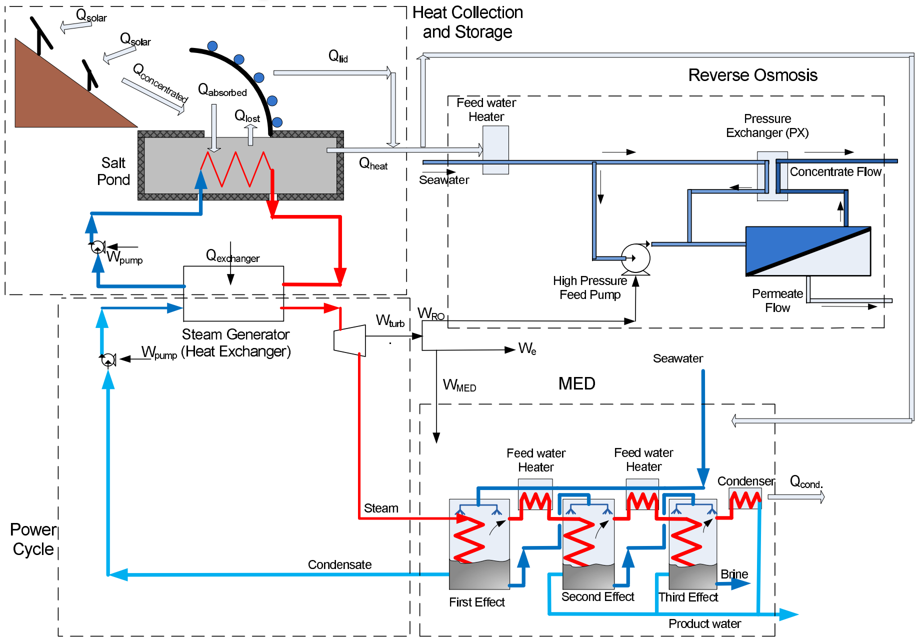


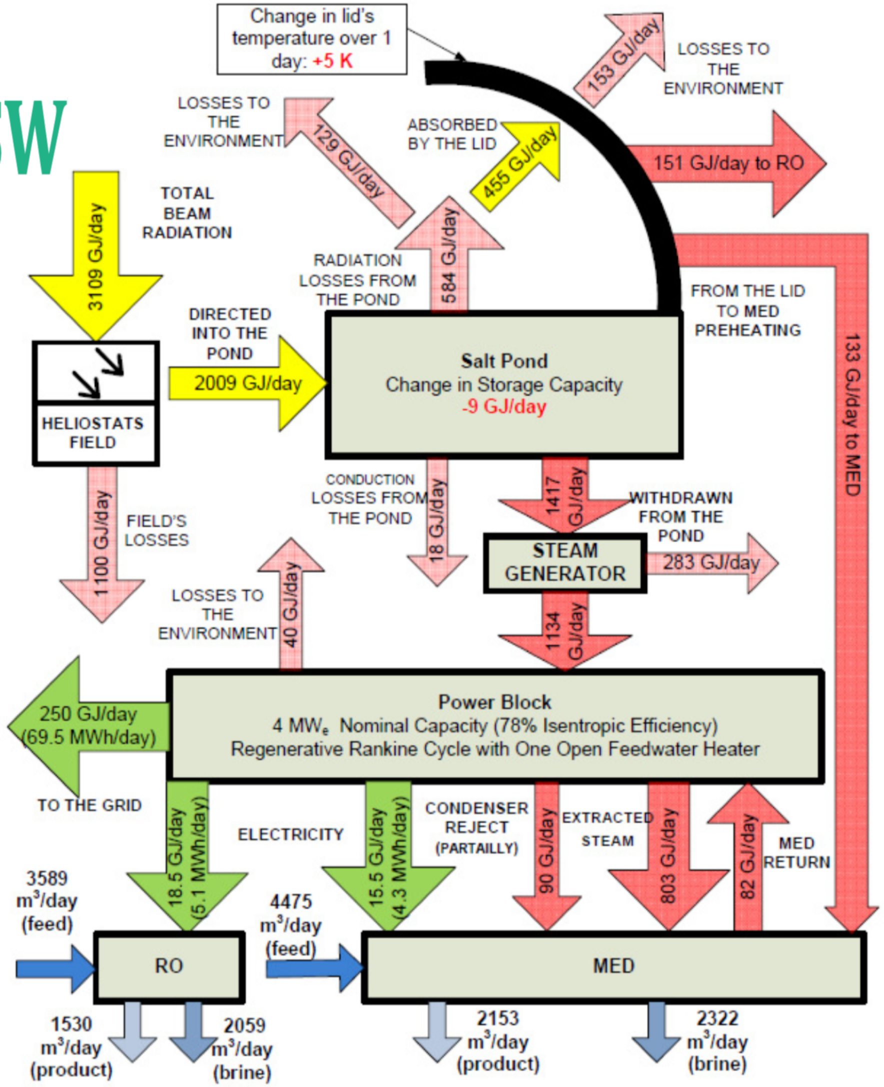
* Poullikkas A., Kourtis G., Hadjipaschalis I., 2012, "An overview of the EU Member States support schemes for the promotion of renewable energy sources", *International Journal of Energy and Environment*

Concentrated solar power*

- Single tank molten salt heat storage
- CSPoD
- Design, simulation
- Pilot plant

CSP-DSW

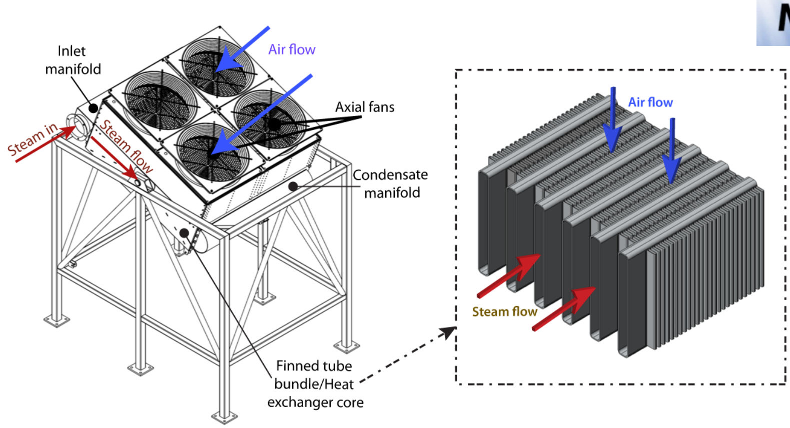


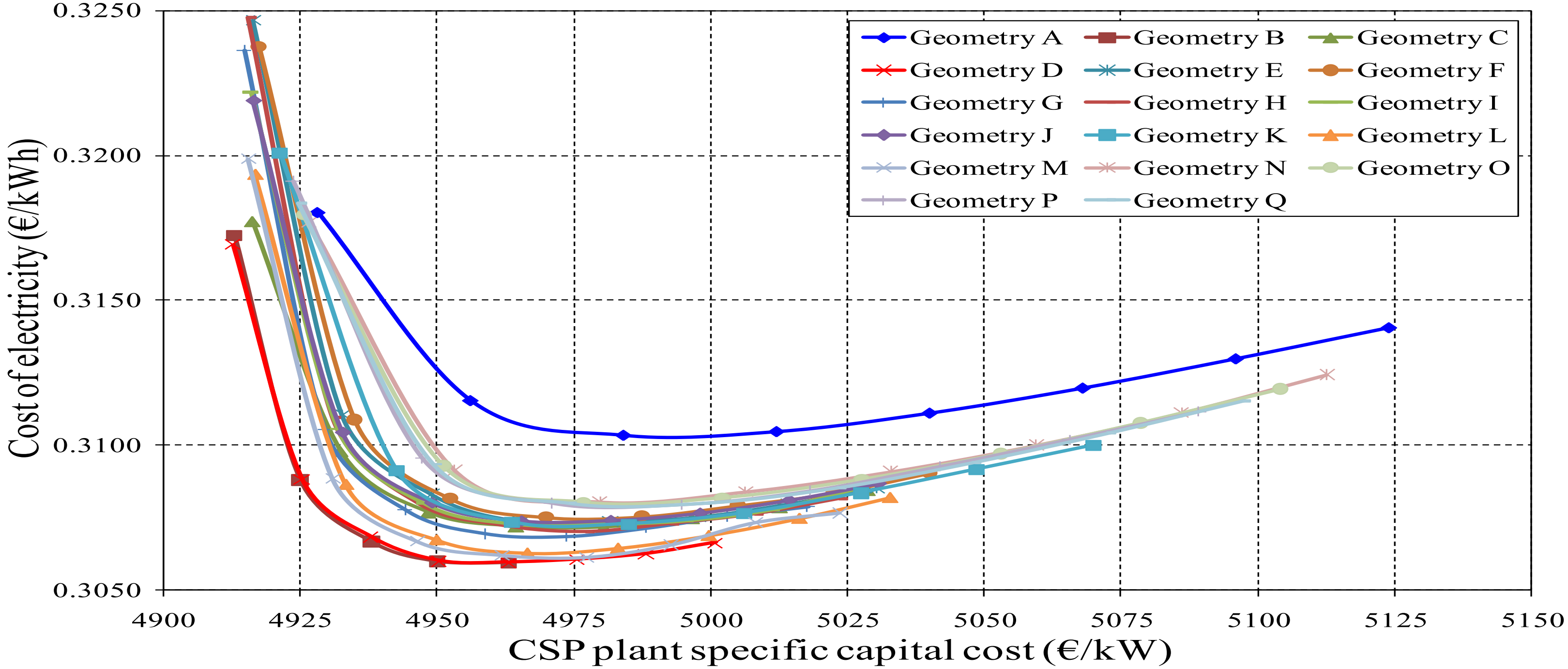


* Poullikkas A., Rouvas C., Hadjipaschalis I., Kourtis G., 2012, "Optimum sizing of steam turbines for concentrated solar power plants", *International Journal of Energy and Environment*

Air-cooled condenser for CSP*

- Design, simulation
- Increase net power output
- Reduce costs
- Pilot plant



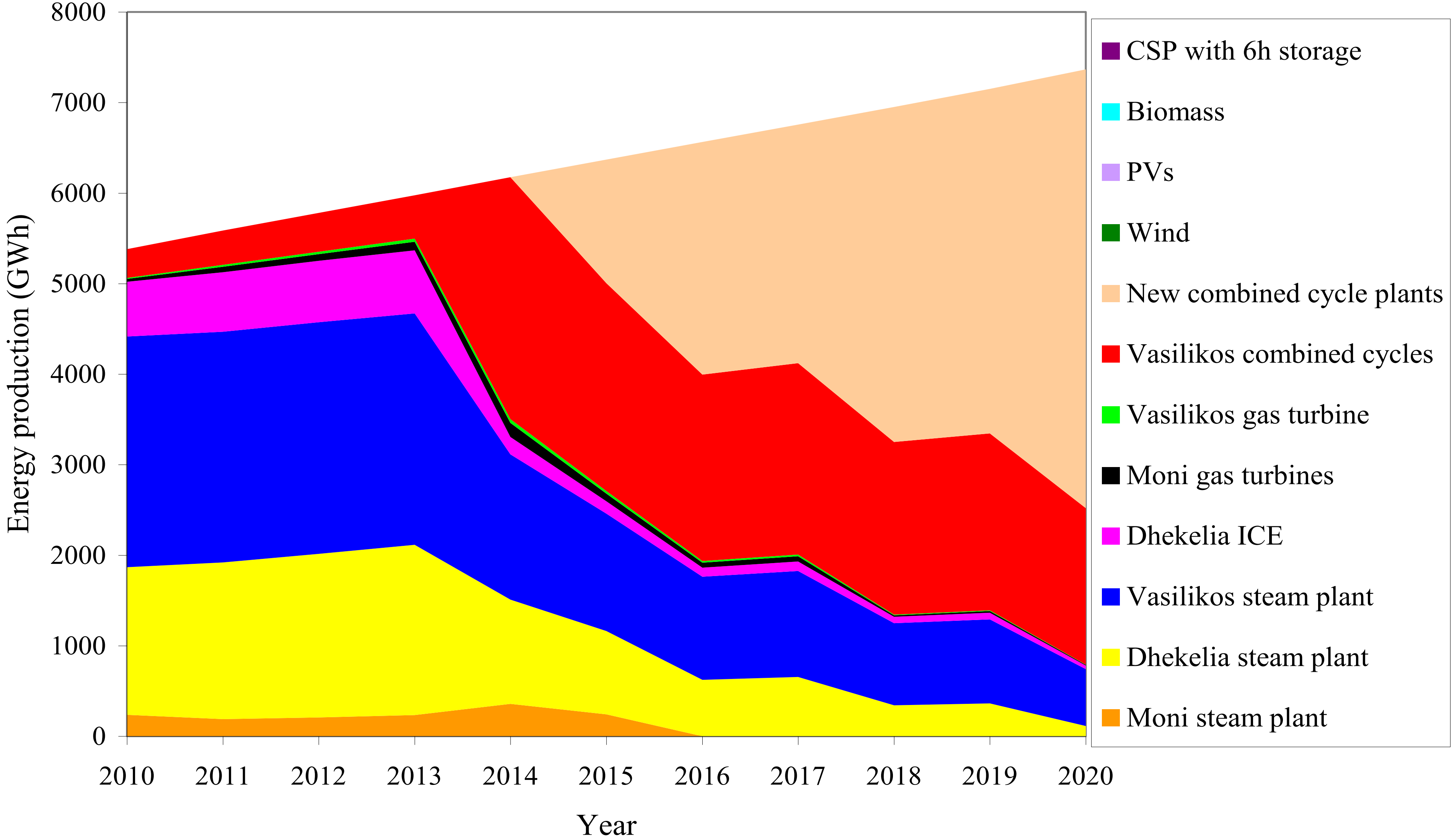


* Poullikkas A., Grimes R., Walsh E., Hadjipaschalis I., Kourtis G., 2013, "Optimal sizing of modular air-cooled condensers for CSP plants", *Journal of Power Technologies*

Development of energy strategies

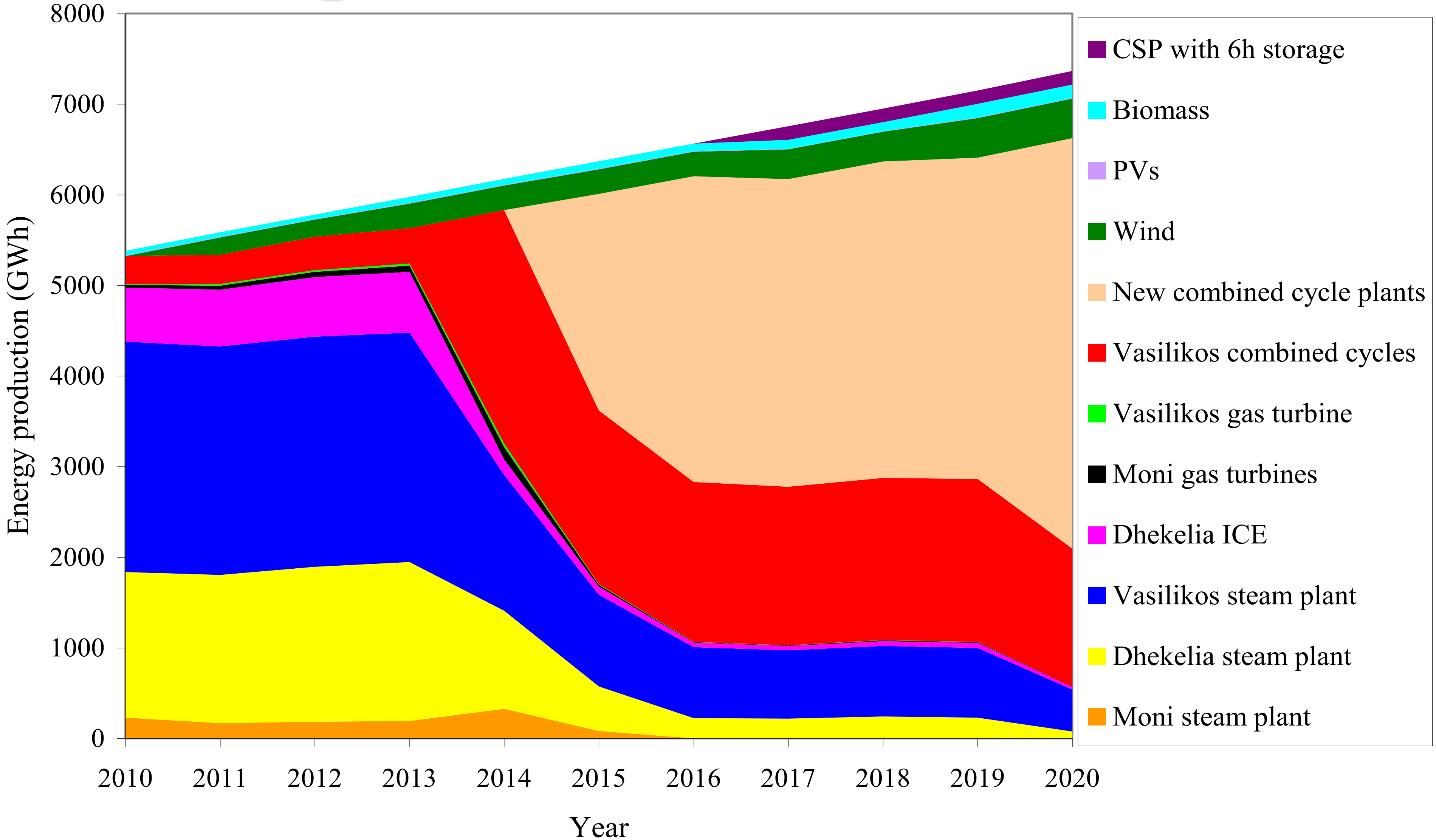
Sustainable energy future

Power generation system energy mix with BAU*



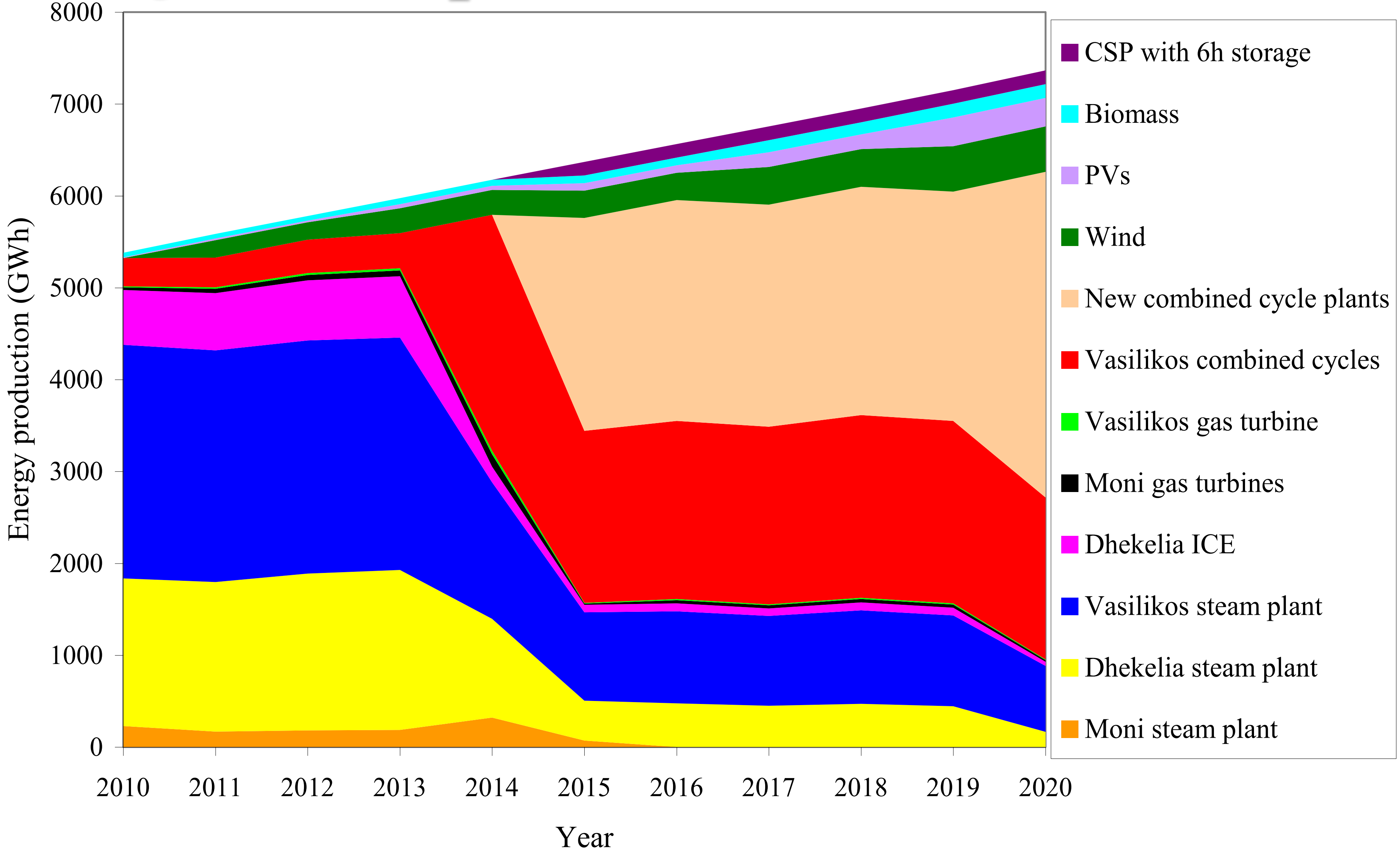
* Poullikkas A., Kourtis G., Hadjipaschalis I., 2011, "A hybrid model for the optimum integration of renewable technologies in power generation systems", *Energy Policy*

Power generation system energy mix with 10% RES-E penetration*



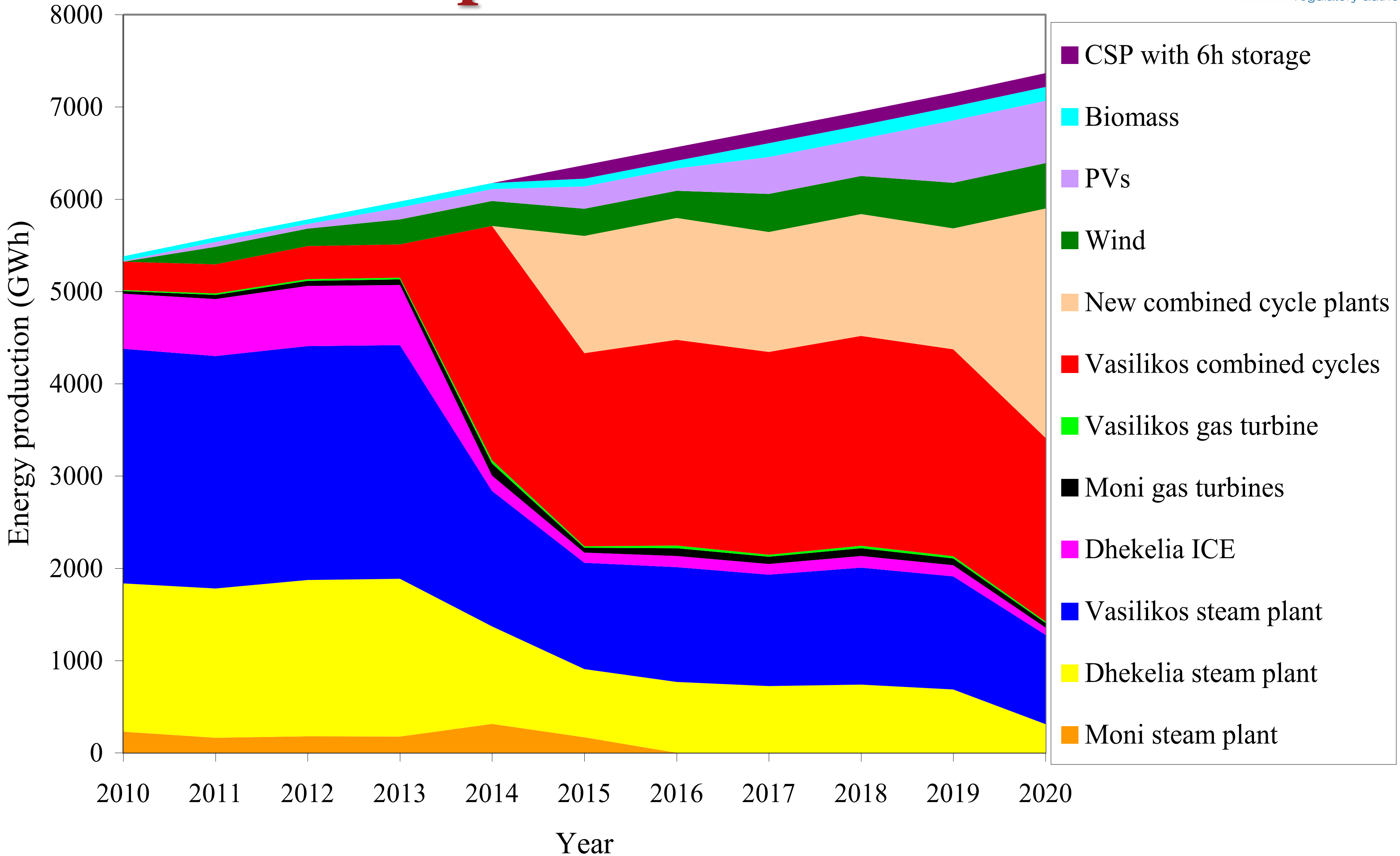
* Poullikkas A., Kourtis G., Hadjipaschalis I., 2011, "A hybrid model for the optimum integration of renewable technologies in power generation systems", *Energy Policy*

Power generation system energy mix with 15% RES-E penetration*



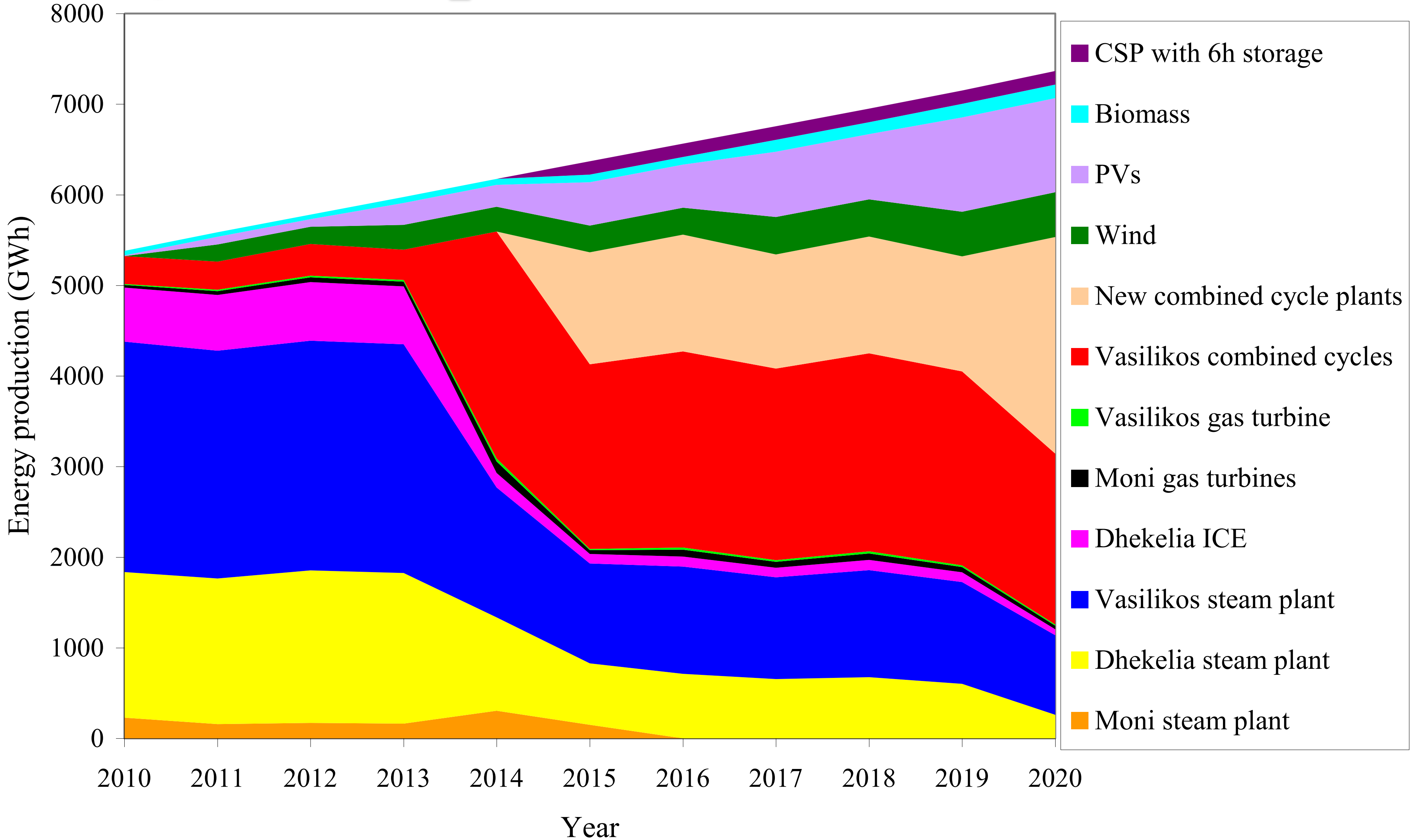
* **Poullikkas A., Kourtis G., Hadjipaschalis I., 2011, "A hybrid model for the optimum integration of renewable technologies in power generation systems", *Energy Policy***

Power generation system energy mix with 20% RES-E penetration*



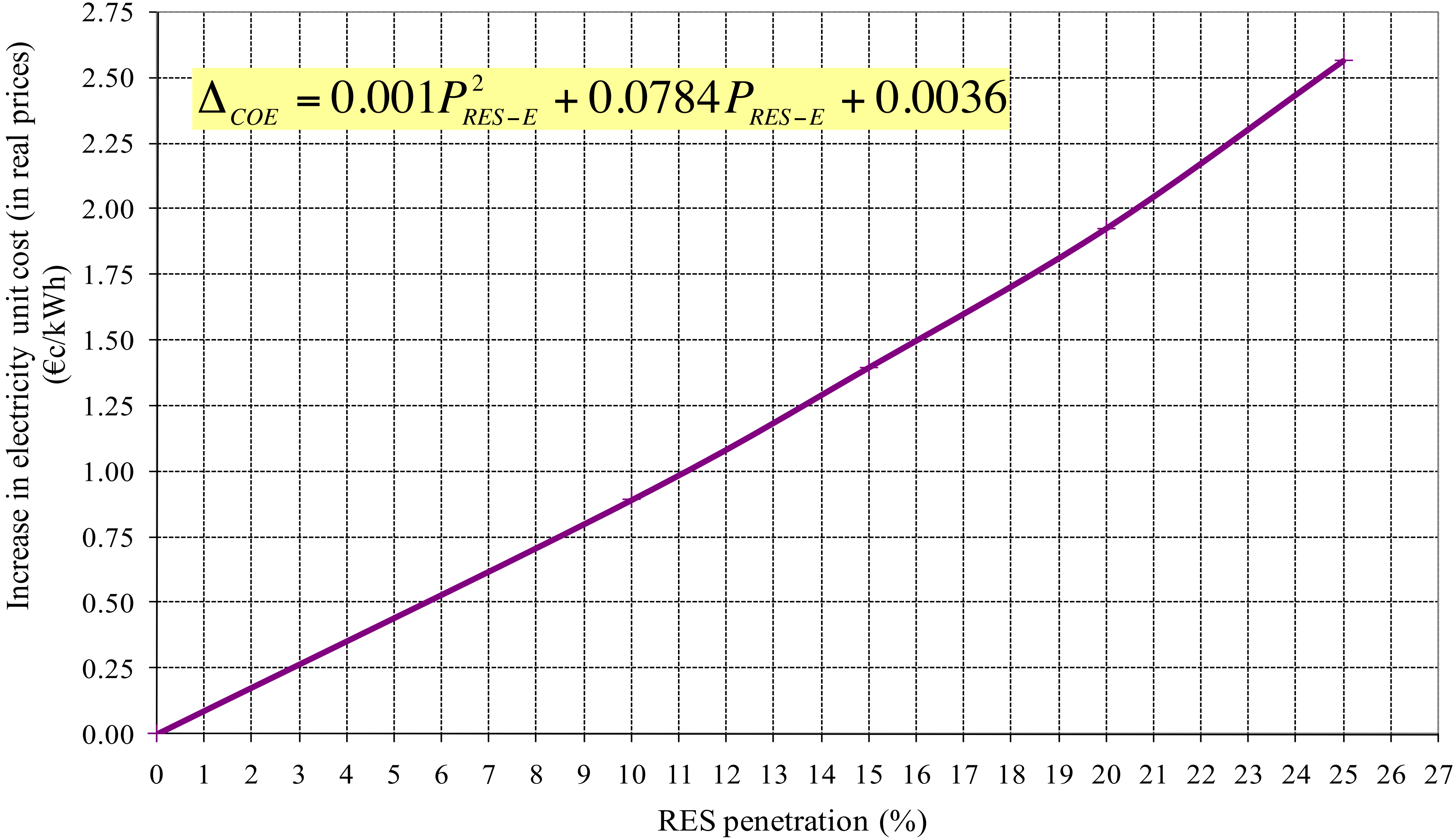
* **Poullikkas A., Kourtis G., Hadjipaschalis I., 2011, "A hybrid model for the optimum integration of renewable technologies in power generation systems", *Energy Policy***

Power generation system energy mix with 25% RES-E penetration*



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

RES-E penetration cost at IRR ~ 12% *



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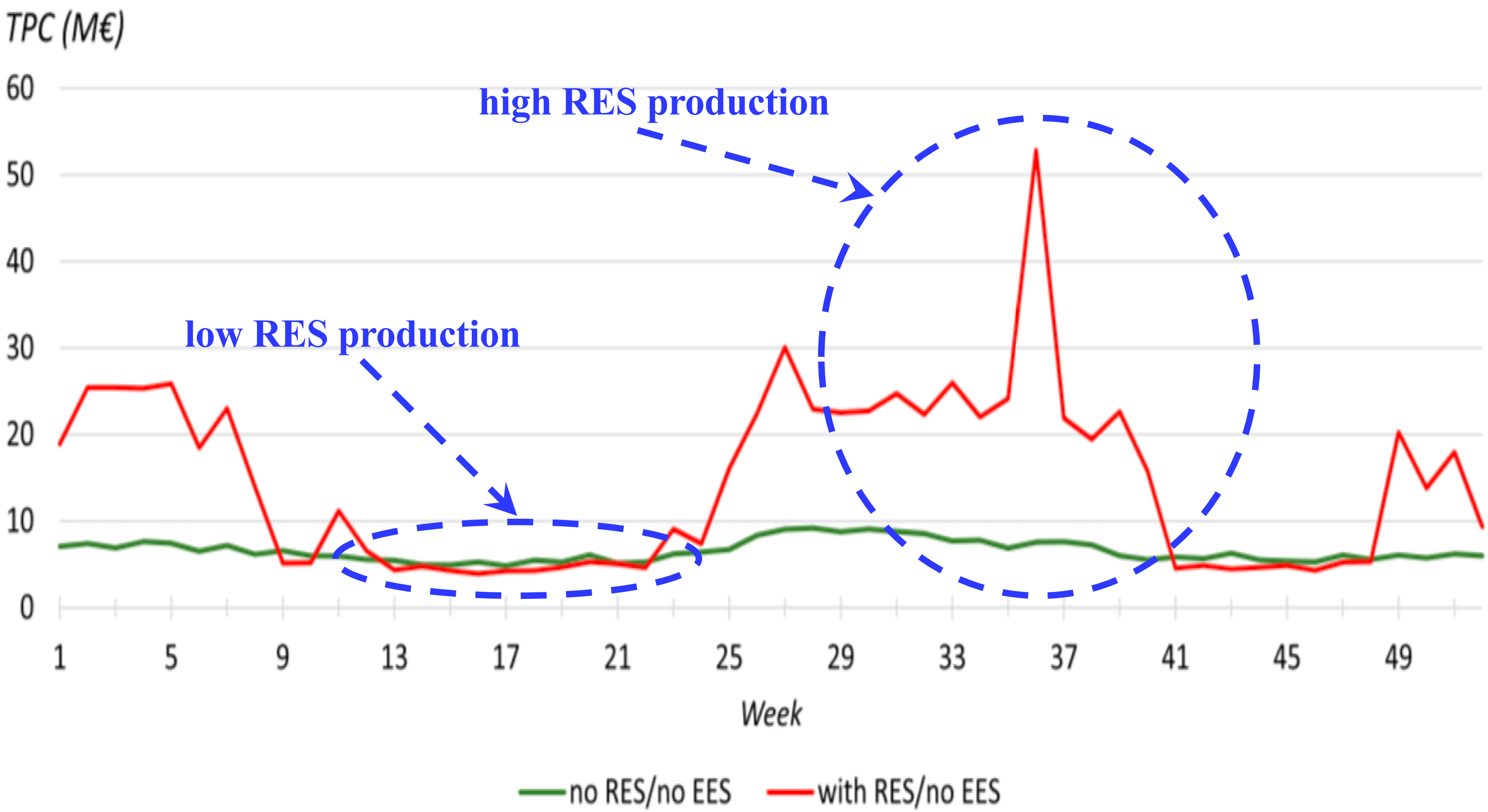
* Poullikkas A., Kourtis G., Hadjipaschalis I., 2011, "A hybrid model for the optimum integration of renewable technologies in power generation systems", *Energy Policy*

Integration of storage

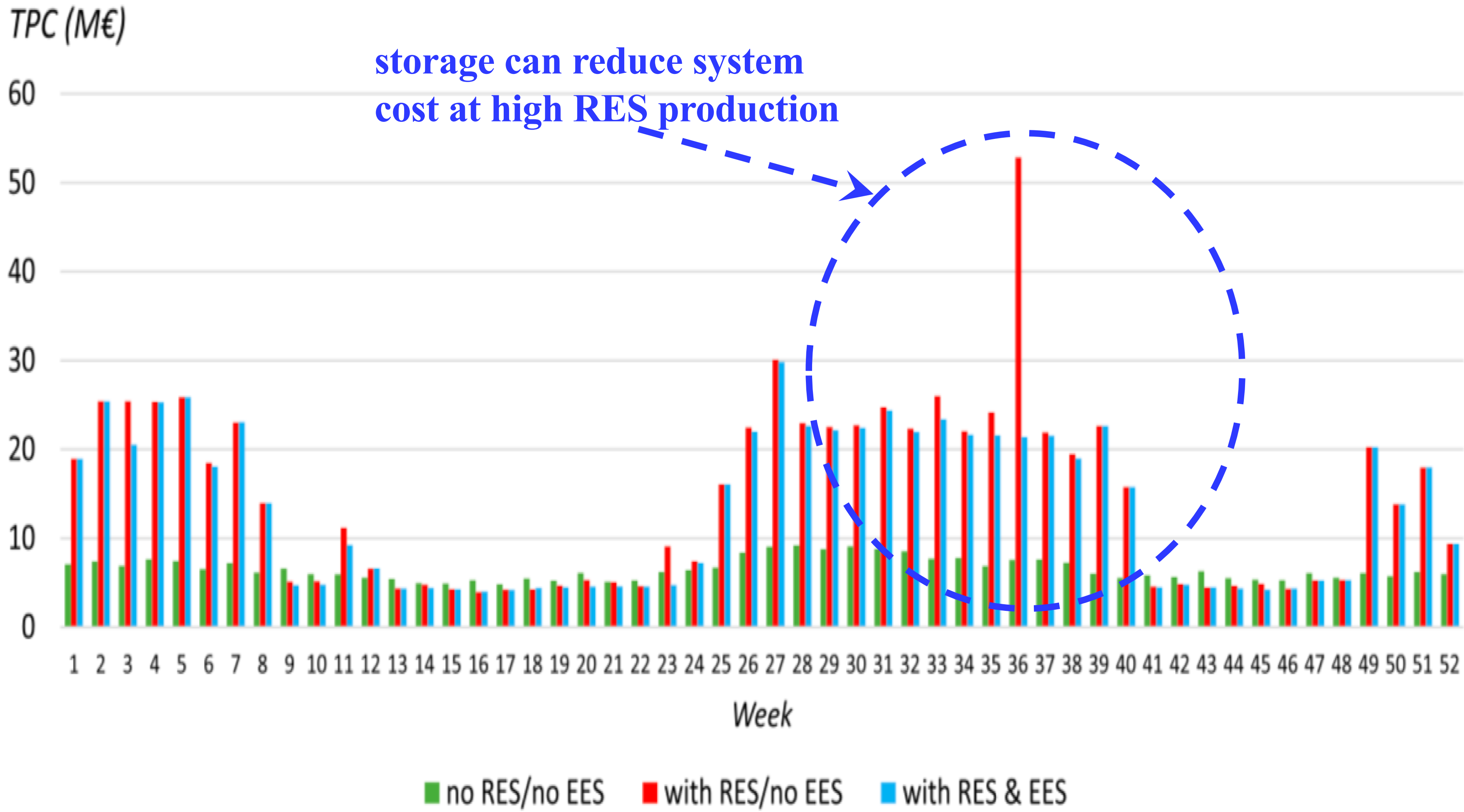
More renewables

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*