Ενεργειακή Μετάβαση: Διεθνείς Καλές Πρακτικές και ο Κυπριακός Ενεργειακός Τομέας

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- **EU energy strategy** – towards 2050
- **Development of optimization algorithms** – advance simulation tools
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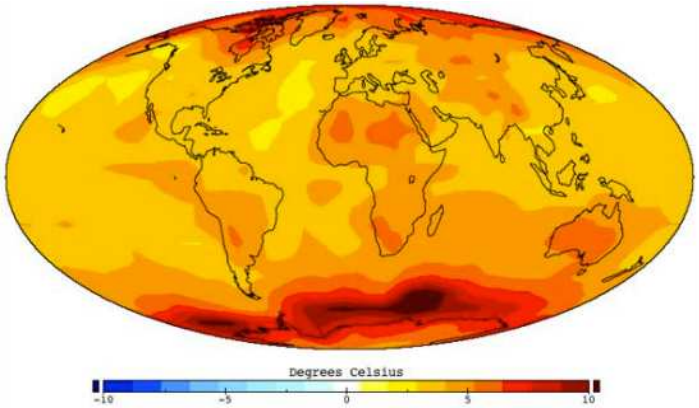
- **Challenges in electricity markets** – large scale integration of RES, storage and H_2
- **Long term energy strategy for Cyprus** – regional cooperation towards hydrogen economy

EU energy strategy

towards 2050

Future energy systems

- **Climate change**



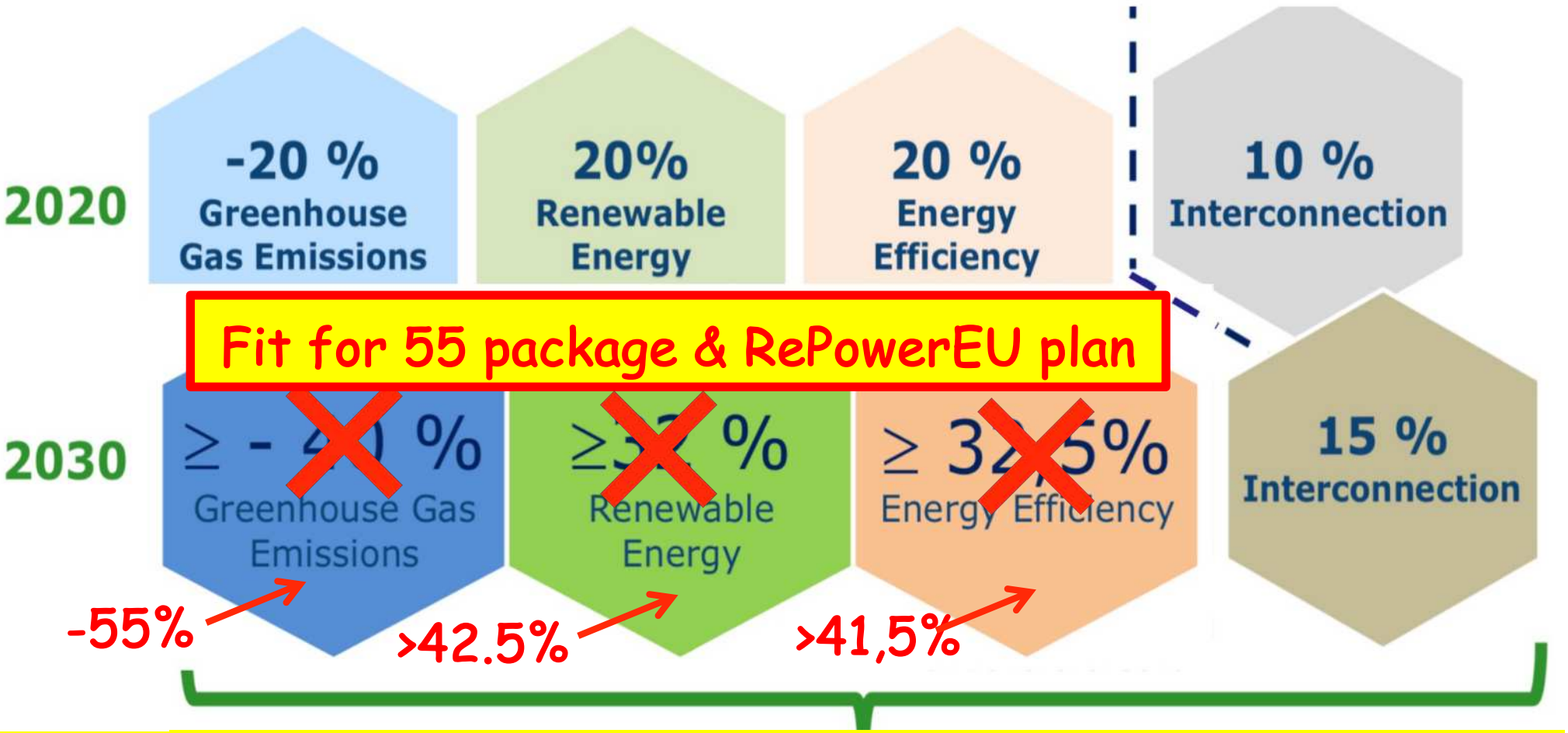
- **Third energy revolution**

- **Future energy economics**

Energy transition

- **greenhouse gas reduction**
  - **EU: climate neutral by 2050**
- **sustainable production and consumption**
- **competition in electricity and natural gas markets**
- **security of supply**

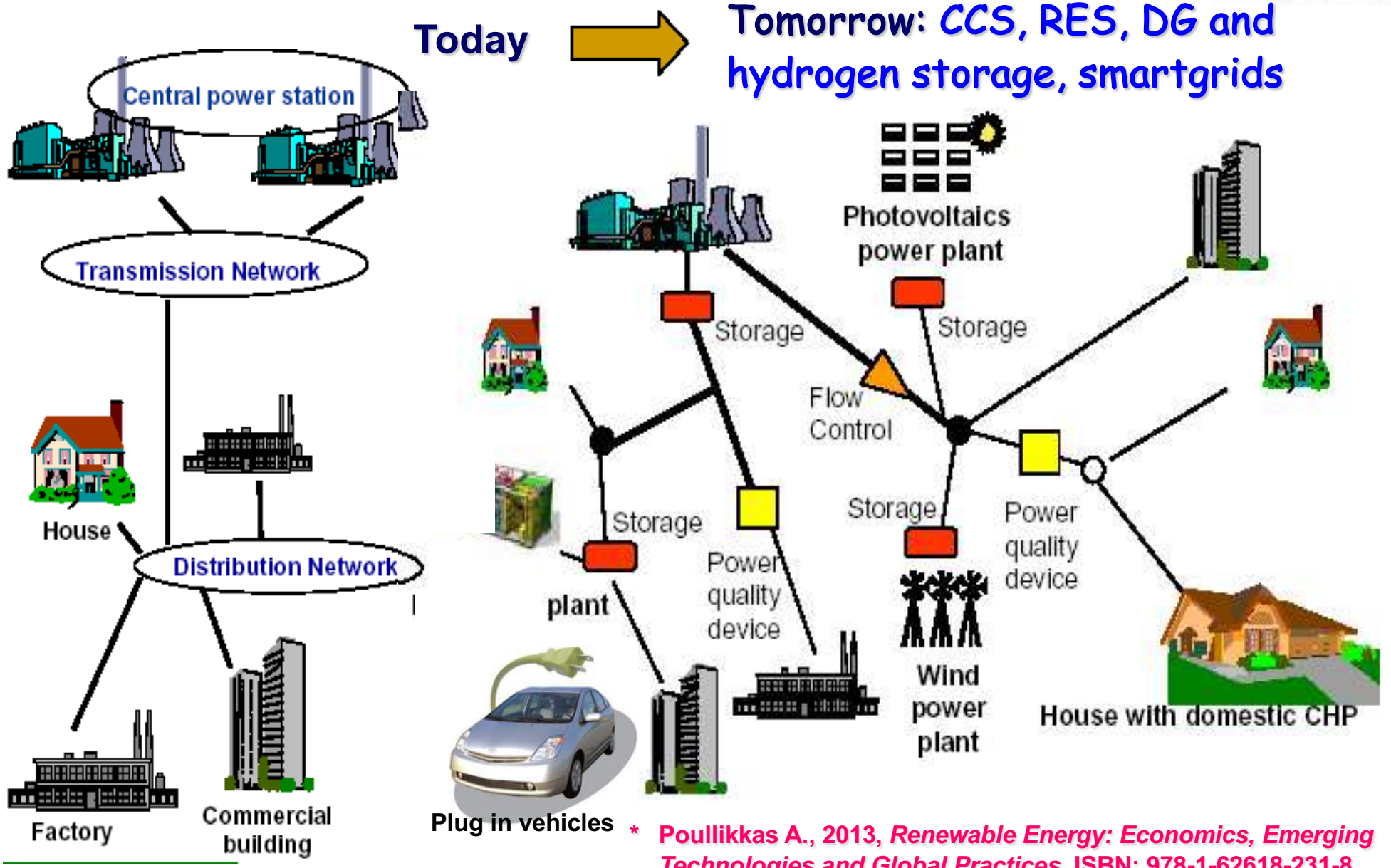
EU medium and long term targets



2050 **Climate-Neutral**

(an economy with net-zero greenhouse gas emissions)

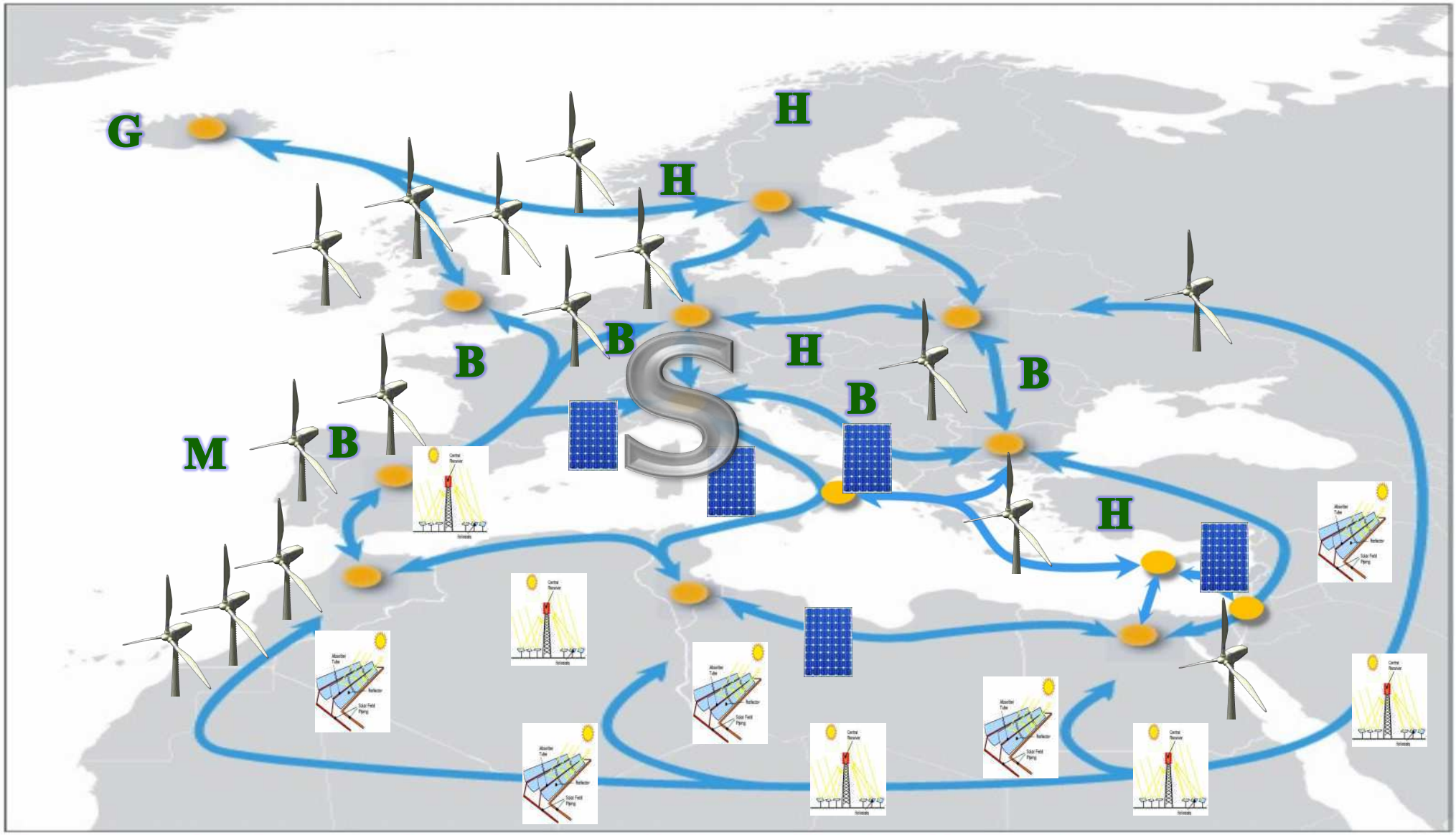
Future power systems*



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

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

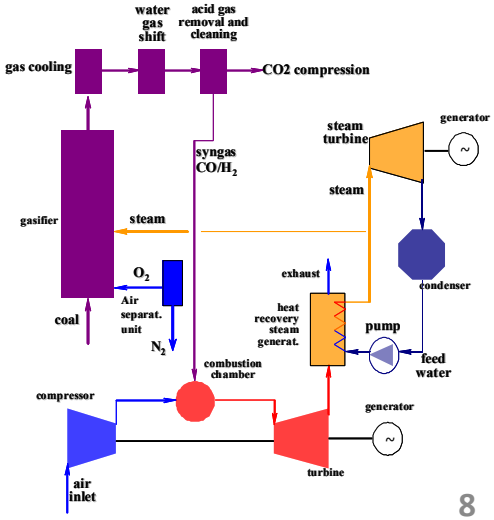
ρυθμιστική αρχή ενέργειας κύπρου
cyprus energy regulatory authority



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

Long term EU energy strategy (2050)

- **A vision of climate 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

Development of optimization algorithms

Advanced simulation tools

The problem

The need

- **Large scale integration of sustainable systems**
  - **e.g., EU RES targets by 2020, 2030, 2050 …**

Main objective

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

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

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

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

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

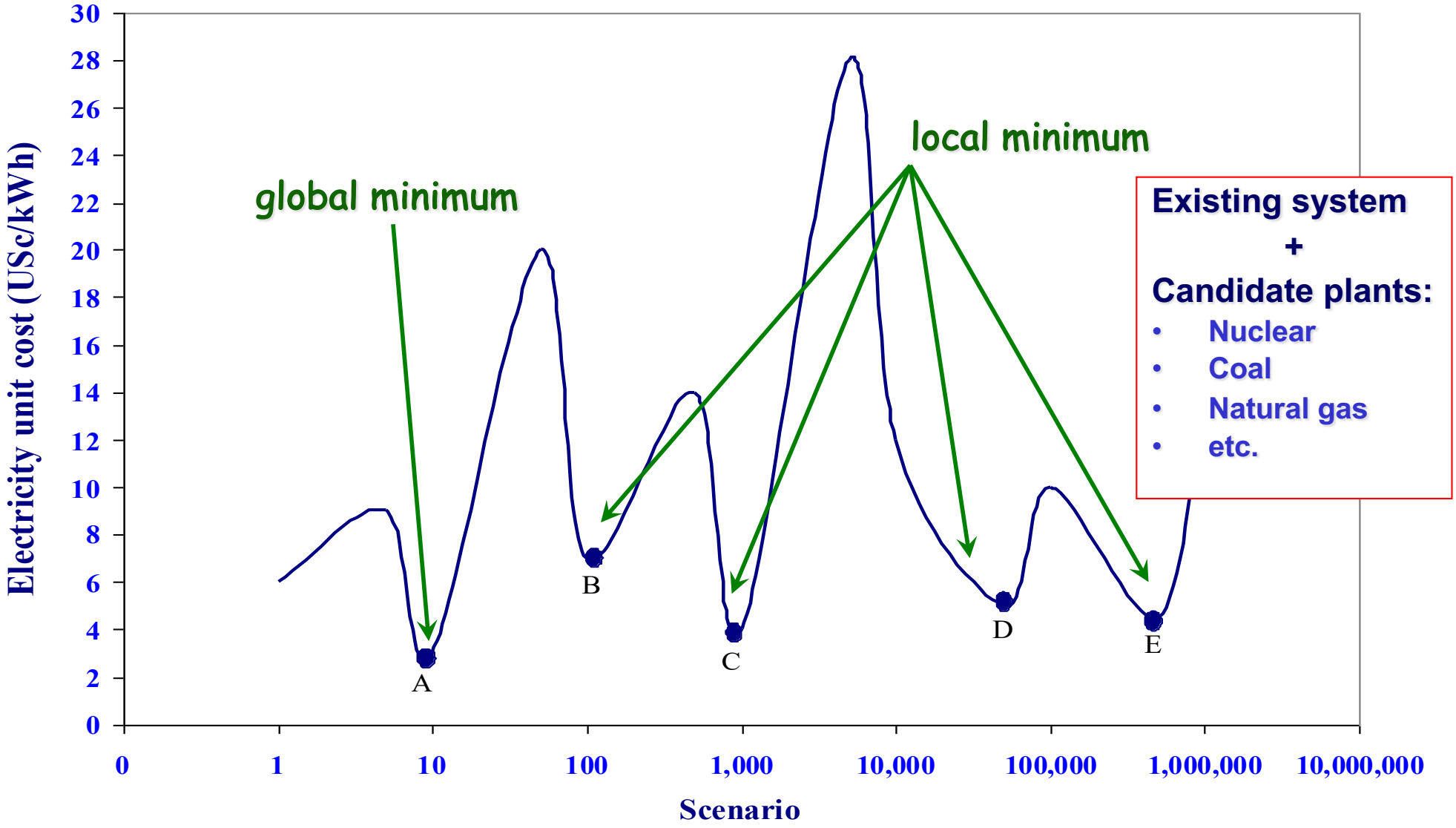
$$R_{S(t)} \le \sum_i r_{s(i,t)} I_{(i,t)} \qquad r_{s(i,t)} = \min\left[10 MSR_i, P_{g,\max(i)} - P_{(i,t)}\right]$$

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

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

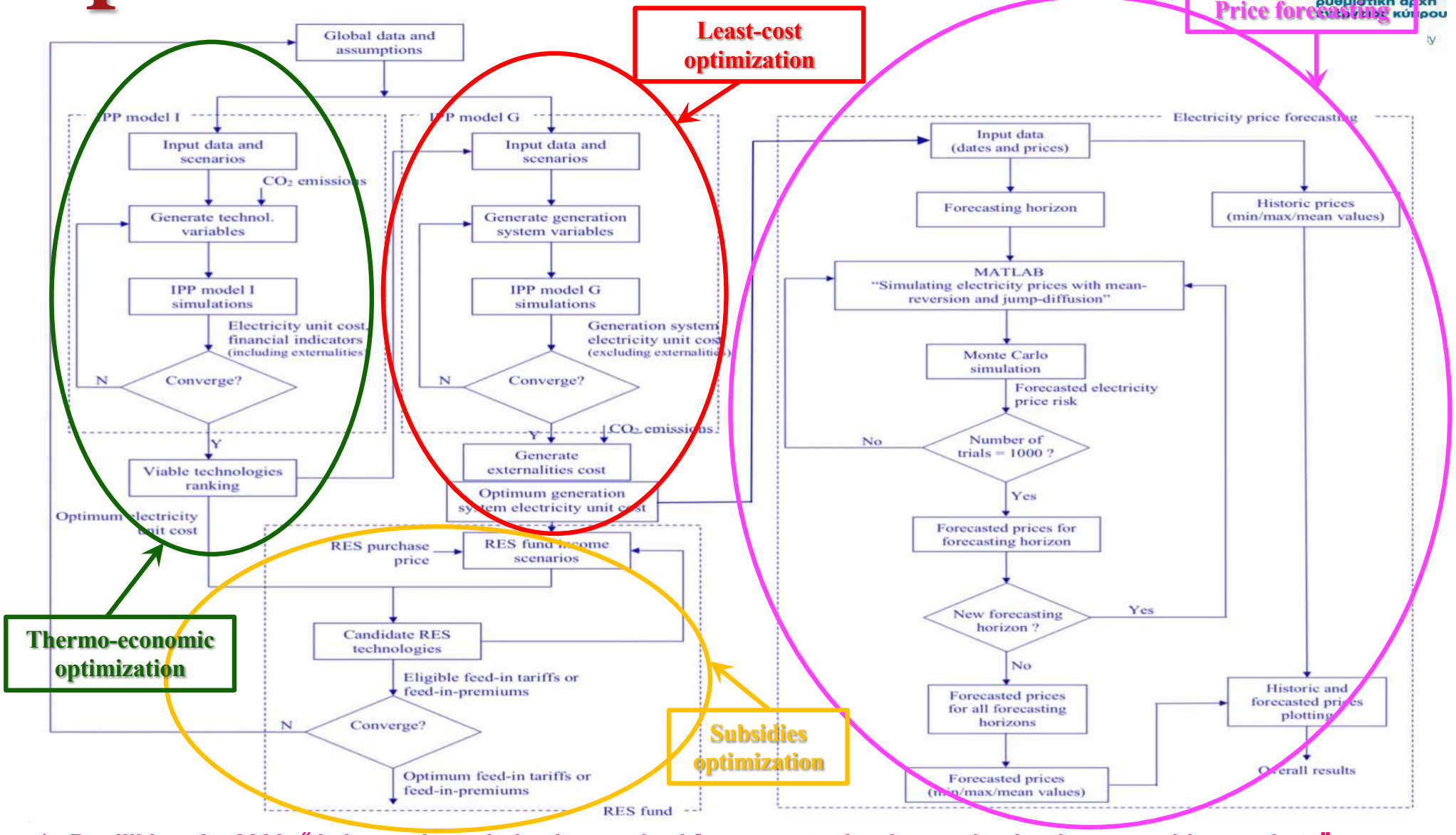
* Poullikkas A., 2009, "A decouple optimization method for power technology selection in competitive markets", *Energy Sources*

Typical shape of objective function*



* Poullikkas A., *IPP algorithm version 3.0*, User manual, © 2000-2022.

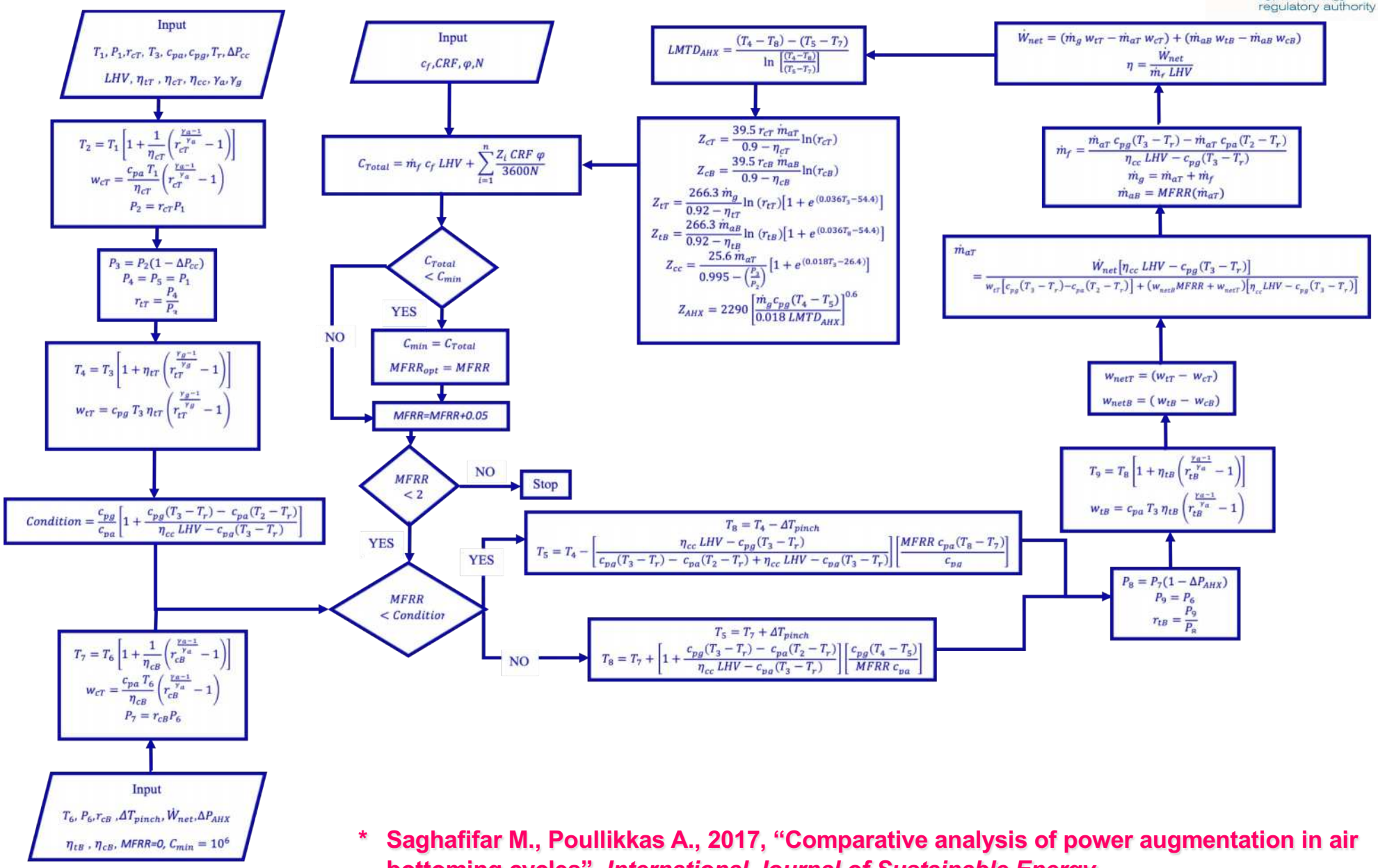
Optimization model*,**



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

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

Example of thermo-economic optimization*



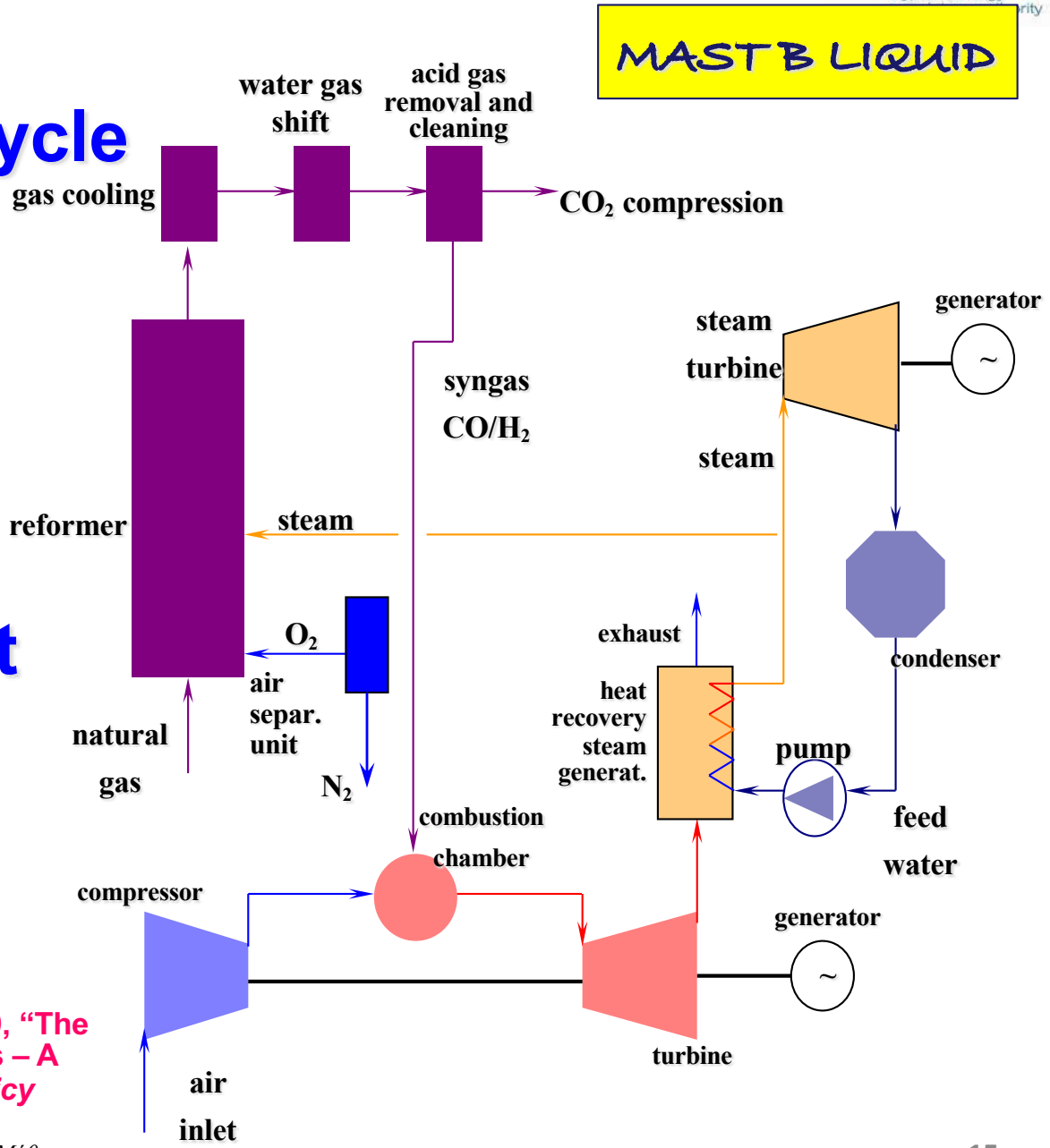
* Saghafifar M., Poullikkas A., 2017, "Comparative analysis of power augmentation in air bottoming cycles", *International Journal of Sustainable Energy*.

Natural gas combined cycle with pre CCS*

- **Brayton-Rankine cycle**
- **Efficiency**

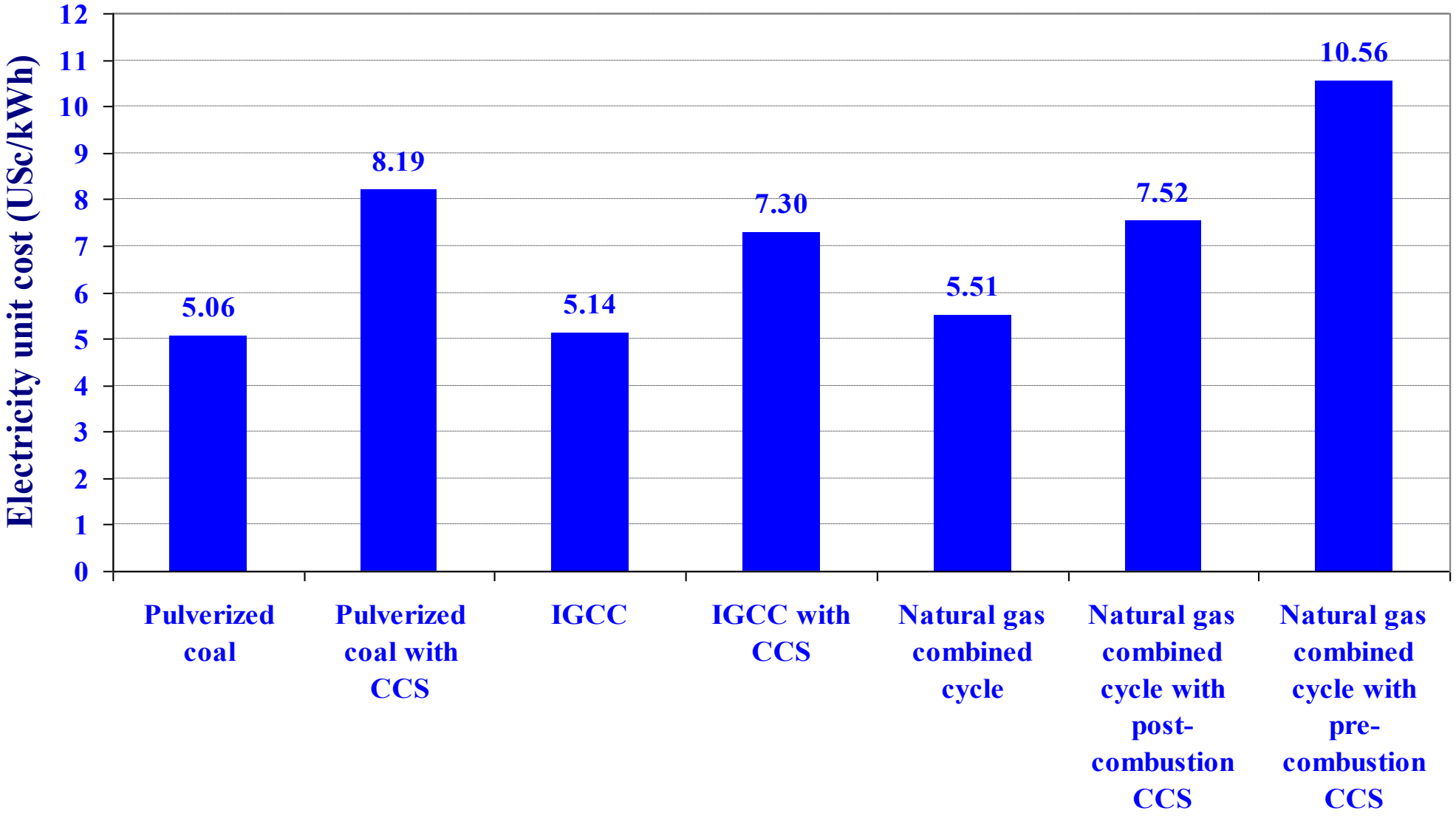
  43 %
- **Electricity unit cost**

  10.56 US$c/kWh



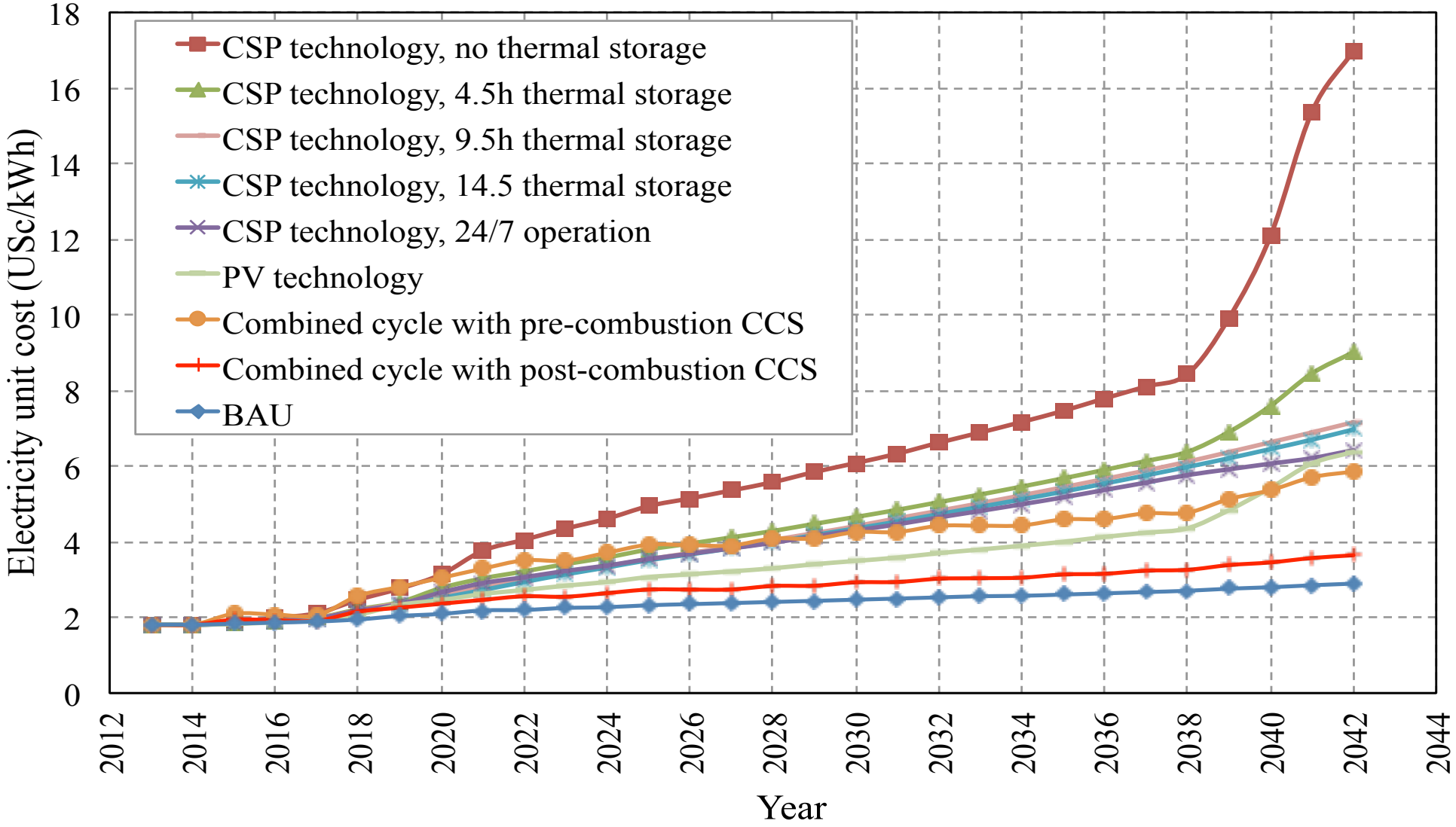
* Poullikkas A., Hadjipaschalis I., Christou C., 2009, "The cost of integration of zero emission power plants – A case study for the island of Cyprus", *Energy Policy*

CCS electricity unit cost* (including transportation and storage costs)



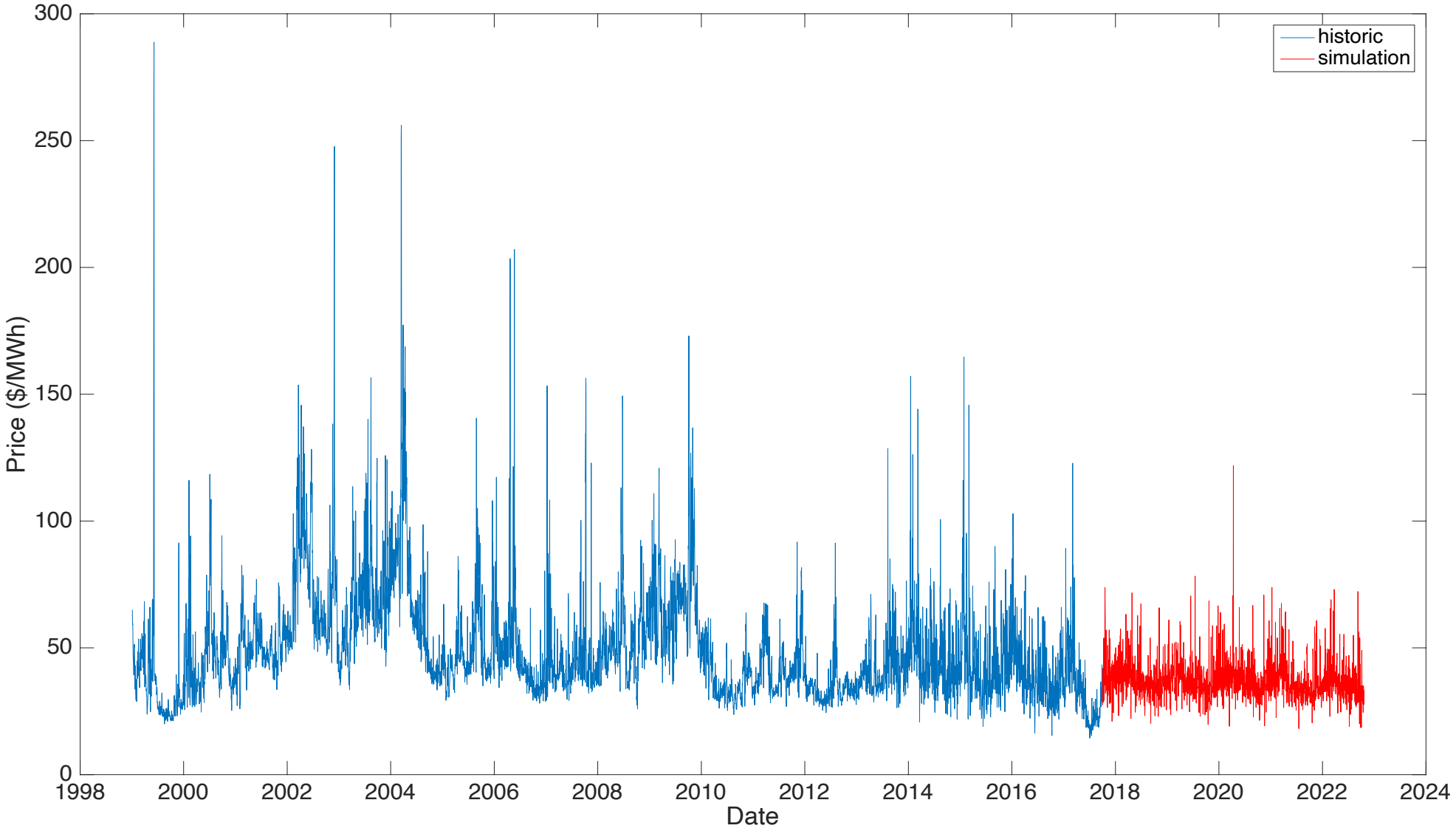
* Hadjipaschalis I., Christou C., Poullikkas A., 2008,"Assessment of future sustainable power technologies with carbon capture and storage", *International Journal of Emerging Electric Power Systems*.

Generation system annual electricity unit cost* (in real prices)



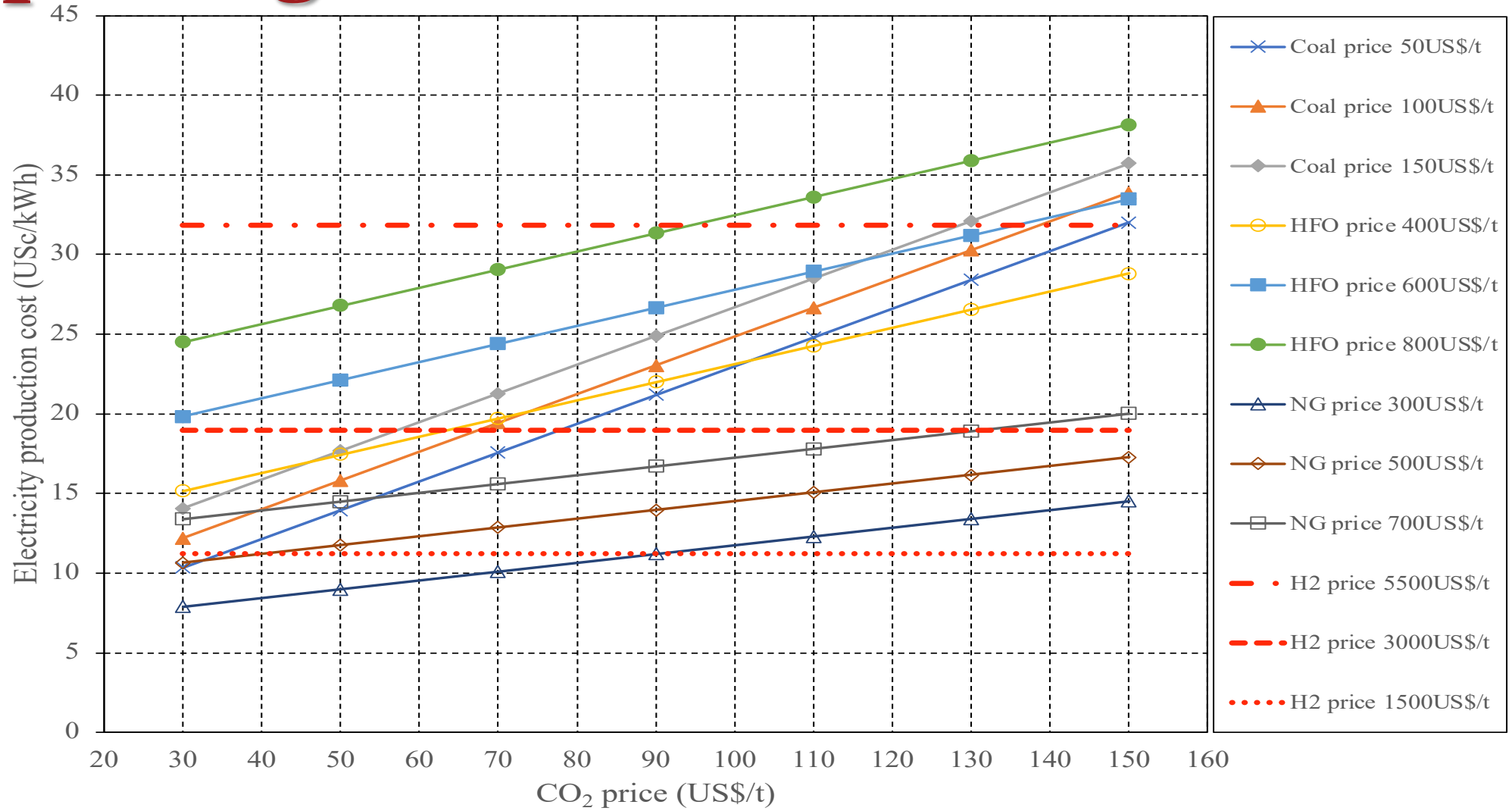
* Poullikkas A., Zueter A.F., Dirar M.H., 2014, "Prospective scenarios for the adoption of sustainable power generation technologies in United Arab Emirates", *International Journal of Sustainable Energy*
(Sharjah Islamic Bank Research Awards, 3rd Prize)

Electricity price forecasting*



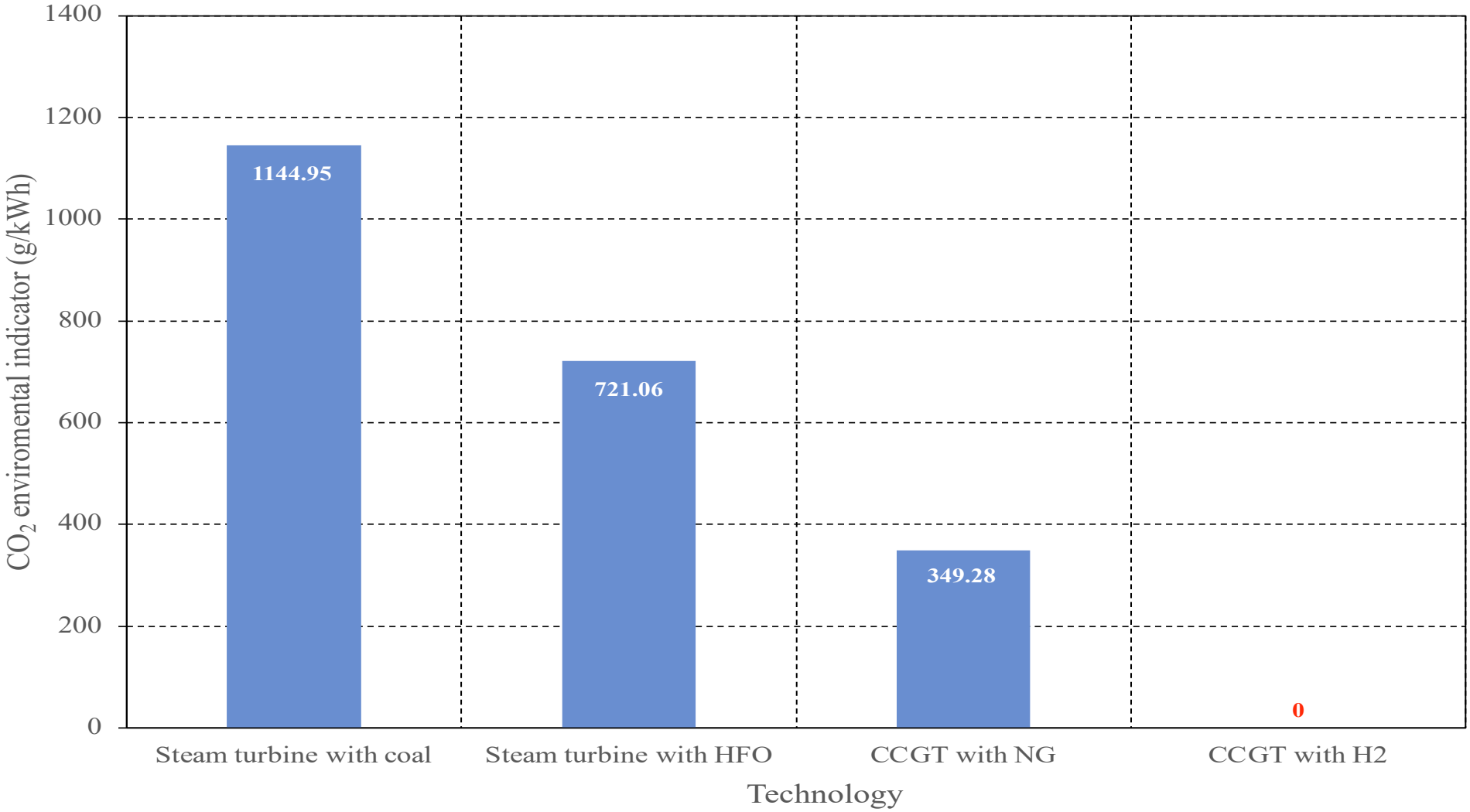
* **Poullikkas A., 2018, "An adaptive longterm electricity price forecasting modelling using Monte Carlo simulation", *Journal of Power Technologies***

Carbon price *vs* green hydrogen power generation*



* Venizelos V., Poullikkas A., 2023, "The effect of carbon price towards green hydrogen power generation", *in preparation*

Carbon price *vs* green hydrogen power generation* (cont.)



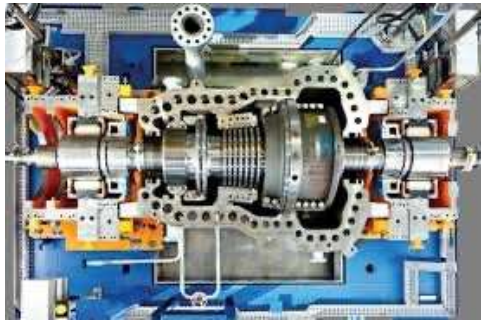
* Nicolaidis P., Poullikkas A., 2023, "Power-to-hydrogen concepts for 100% renewable and sustainable energy systems", *Hydrogen Economy*

Cyprus current electricity and NG systems

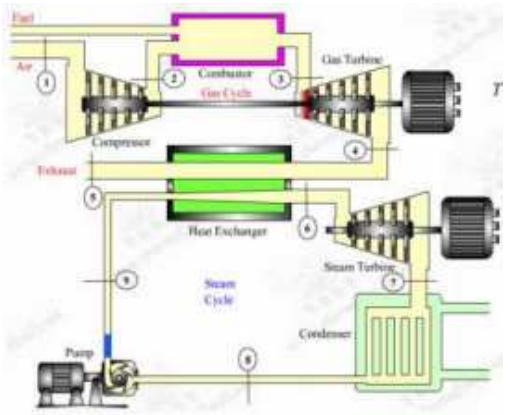
System characteristics

Existing power generation system

- **Steam turbine units (HFO)**
  - Dhekelia power station 6x60MWe
  - Vasilikos power station 3x130MWe



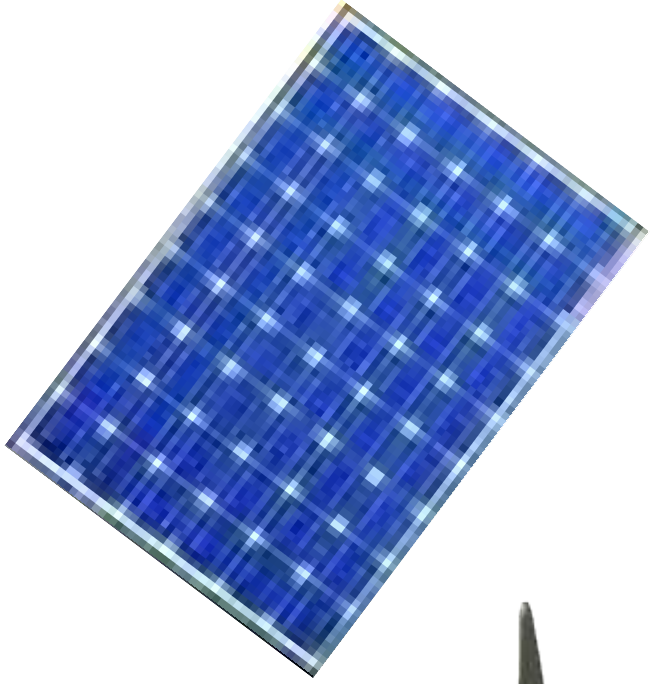
- **Internal combustion engines (HFO)**
  - Dhekelia power station 6x17.5MWe
- **Combined cycles (Diesel)**
  - Vasilikos power station 2x220MWe



- **Gas turbine units (Diesel)**
  - Moni power station 4x37,5MWe
  - Vasilikos power station 1x38MWe

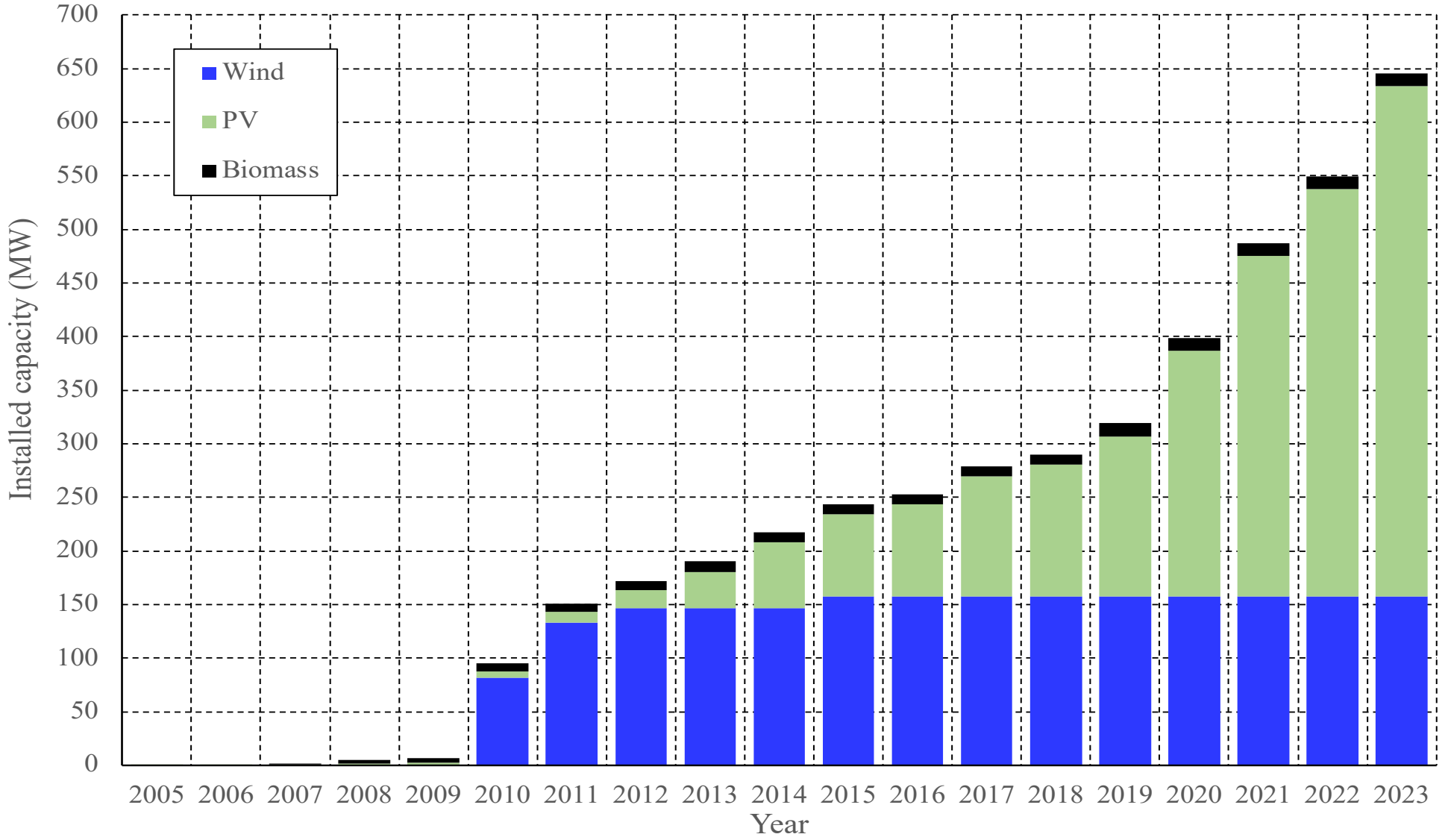
Existing power generation system (cont.)

- **Renewables**
  - **PVs: 476MWe**
  - **Wind: 157MWe**
  - **Biomass: 13MWe**



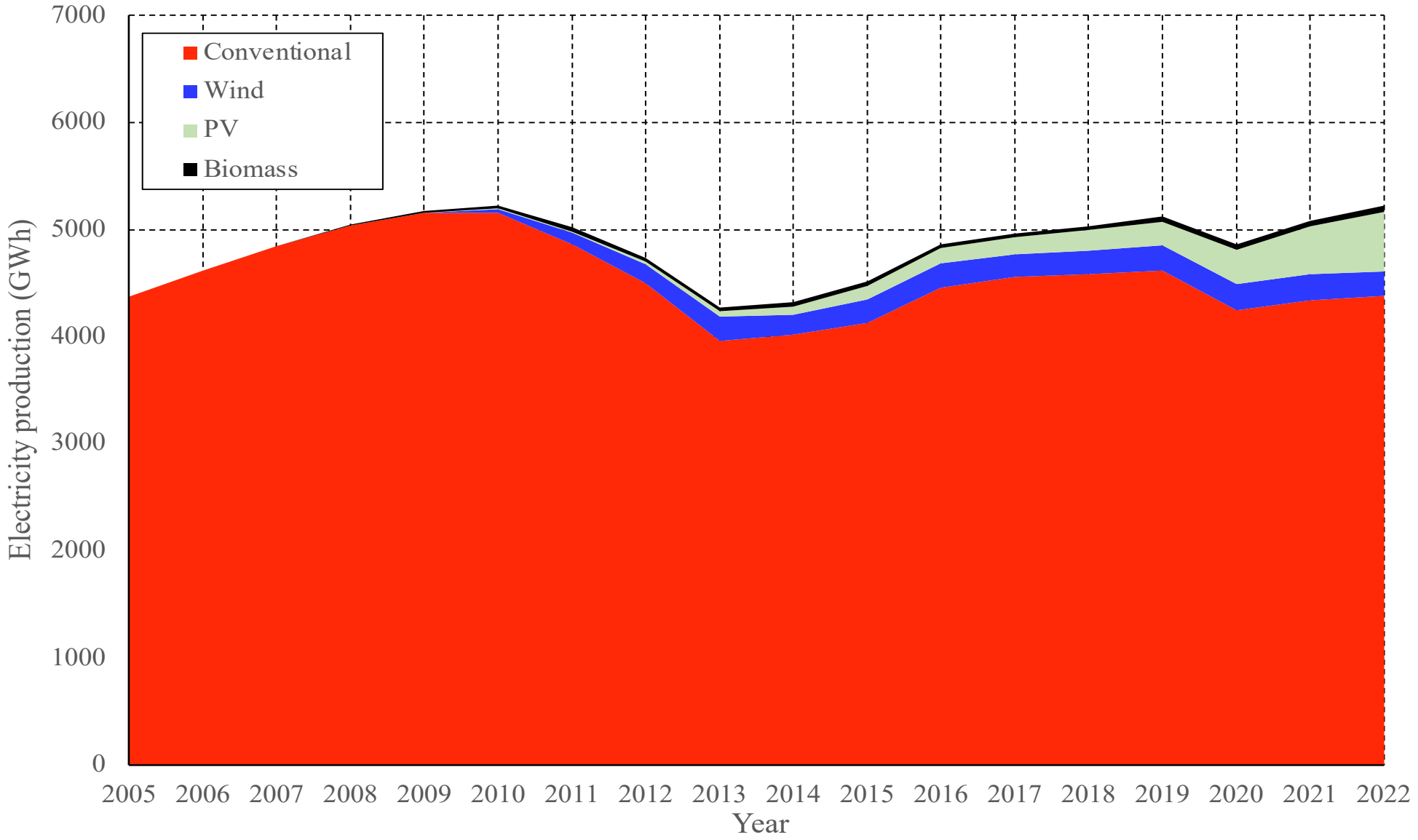
- **Total installed capacity:**
  - **Conventional: 1483MWe**
  - **Renewables: 646MWe**

RES-E installed capacity*



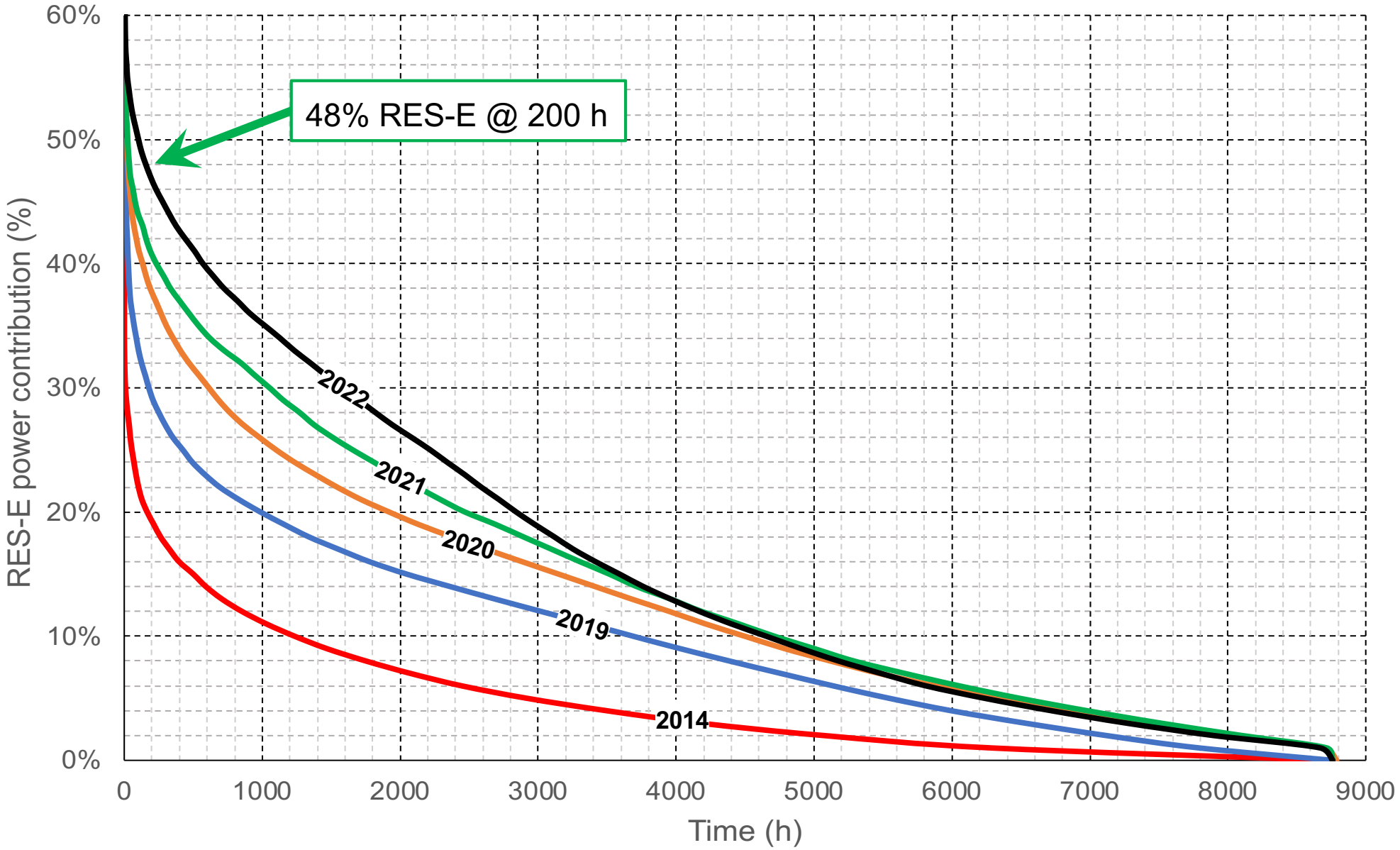
* www.cera.org.cy

Total electricity production per year*

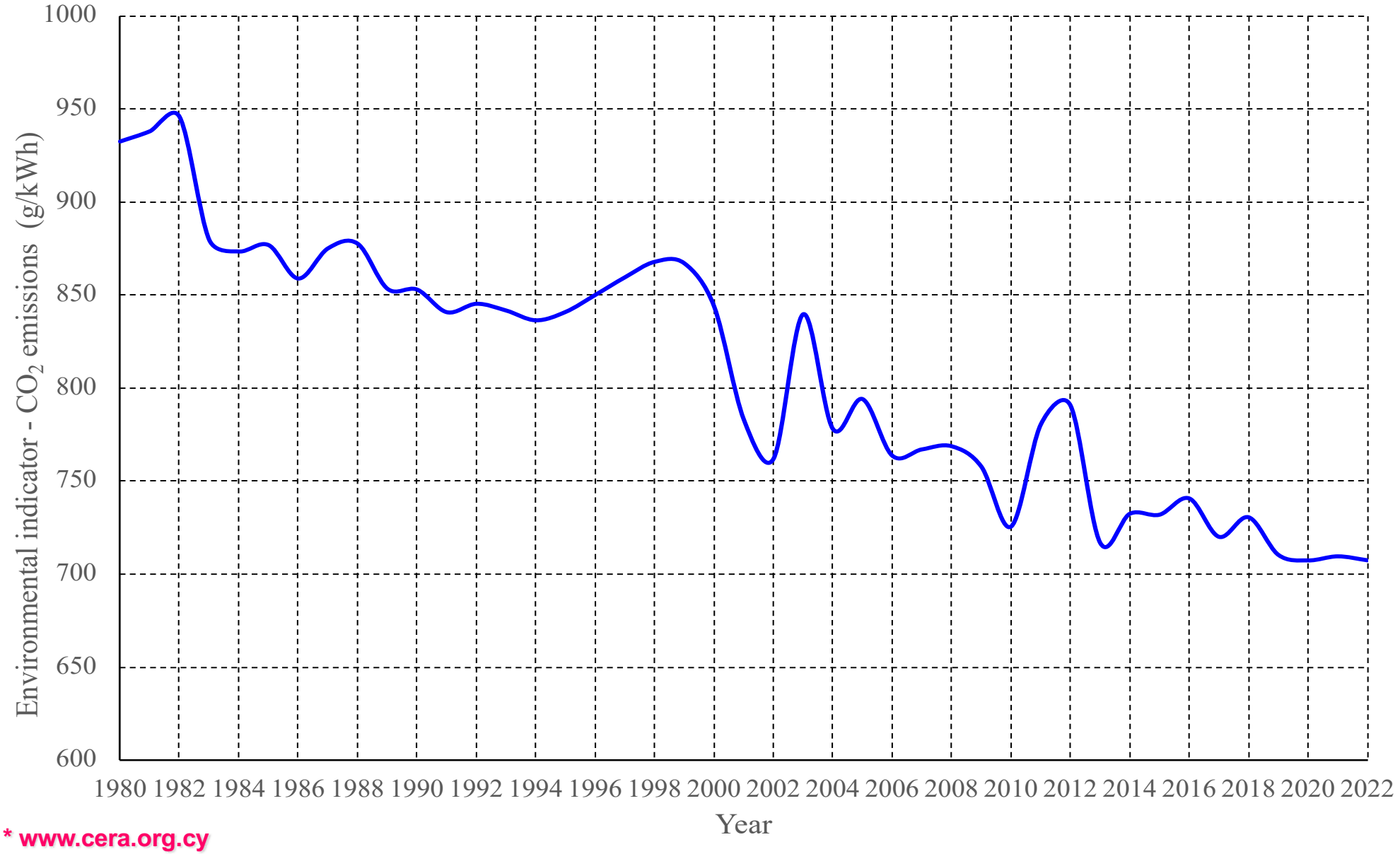


* www.cera.org.cy

RES-E Load Duration Curve



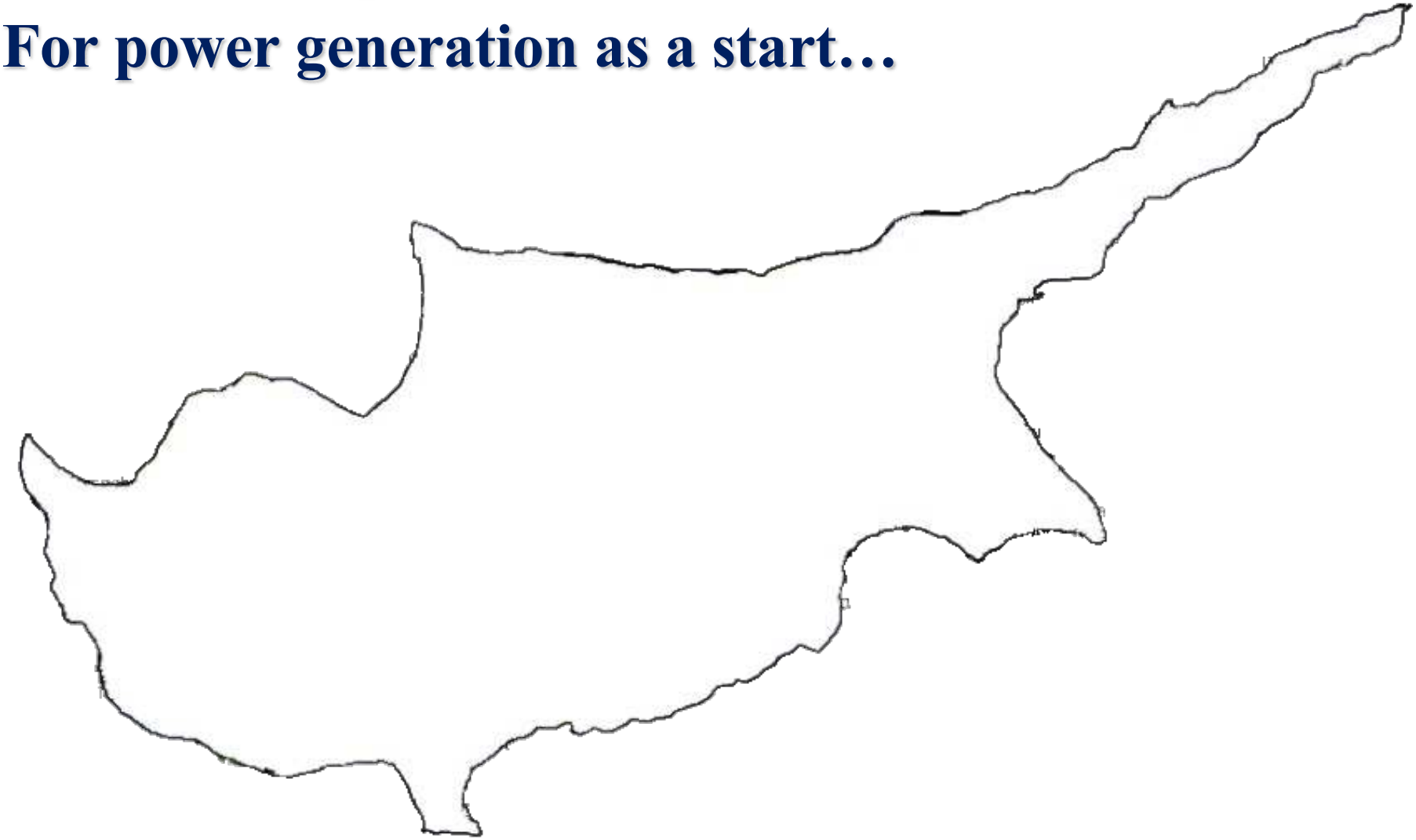
CO_2 environmental indicator*



* www.cera.org.cy

Existing natural gas system

- **Under development !**
- **For power generation as a start…**



Energy transition for island systems

Solutions for isolated systems

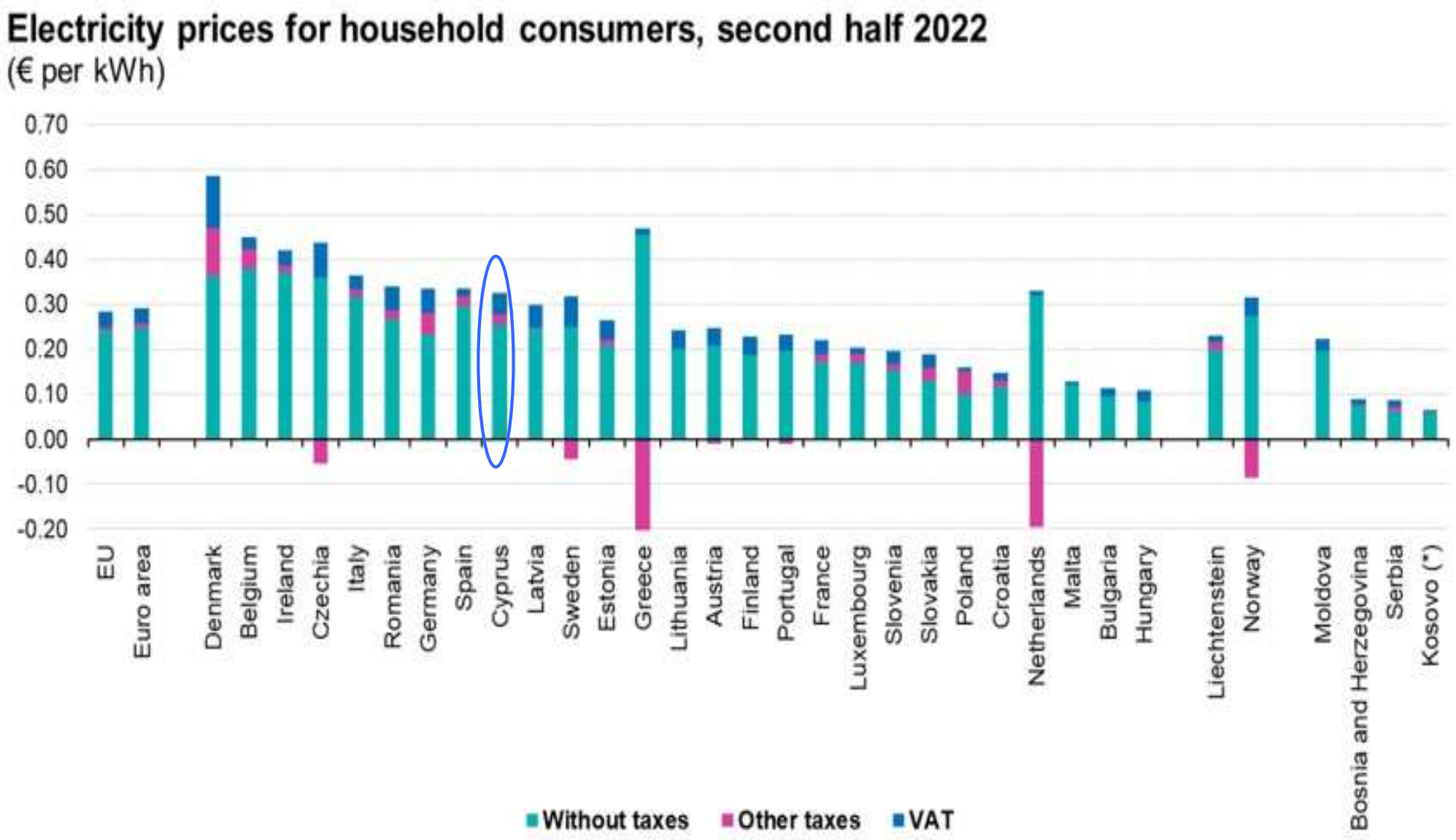
Characteristics of isolated electricity systems*

- **High fuel costs**
  - ~ use of oil derivatives
  - ~ high CO_2 emissions (additional cost)
- **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

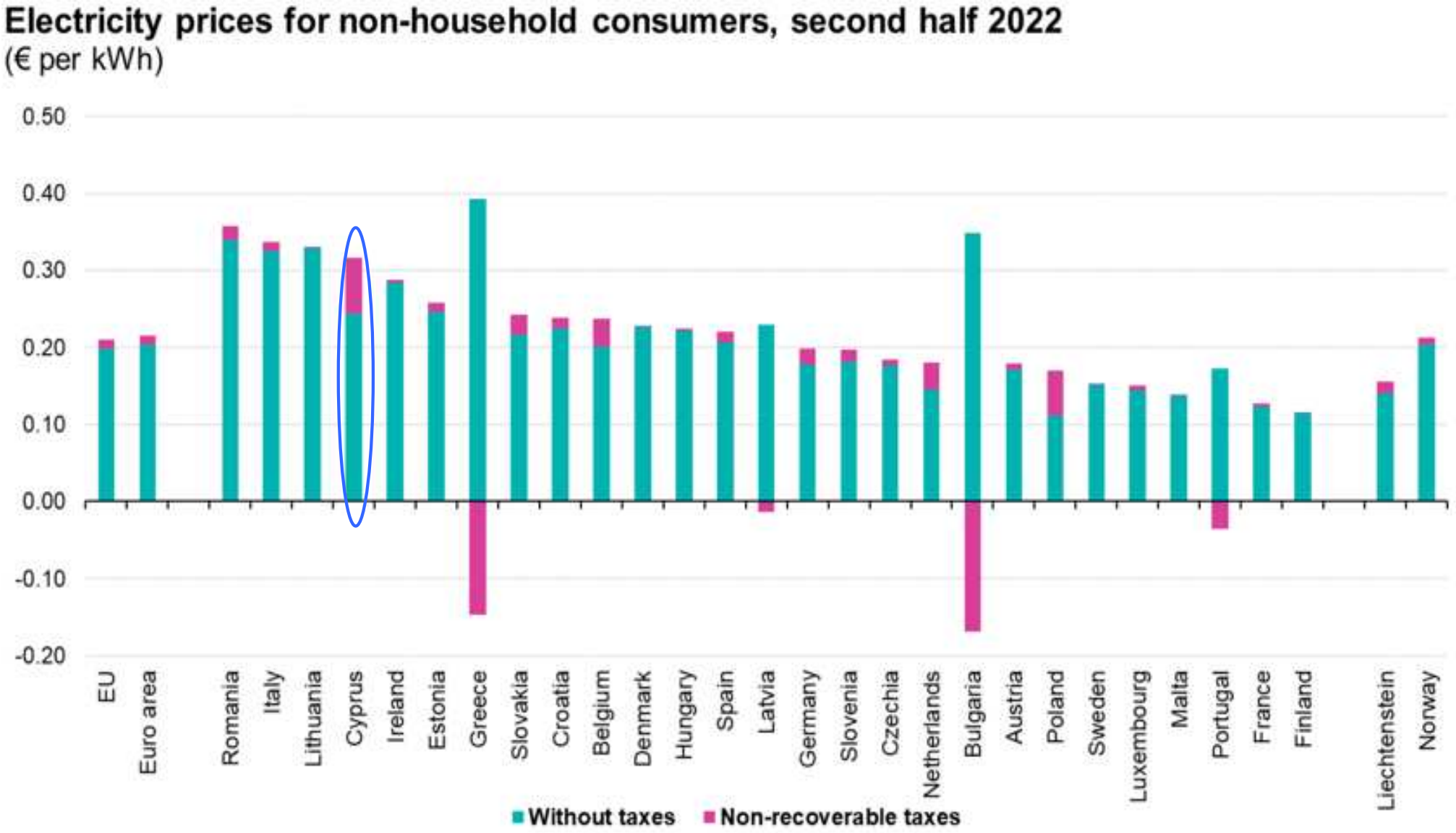
* Poullikkas A., 2015, *Sustainable Energy Policy for Cyprus*, ISBN: 978-9963-7355-6-3

EU statistics*



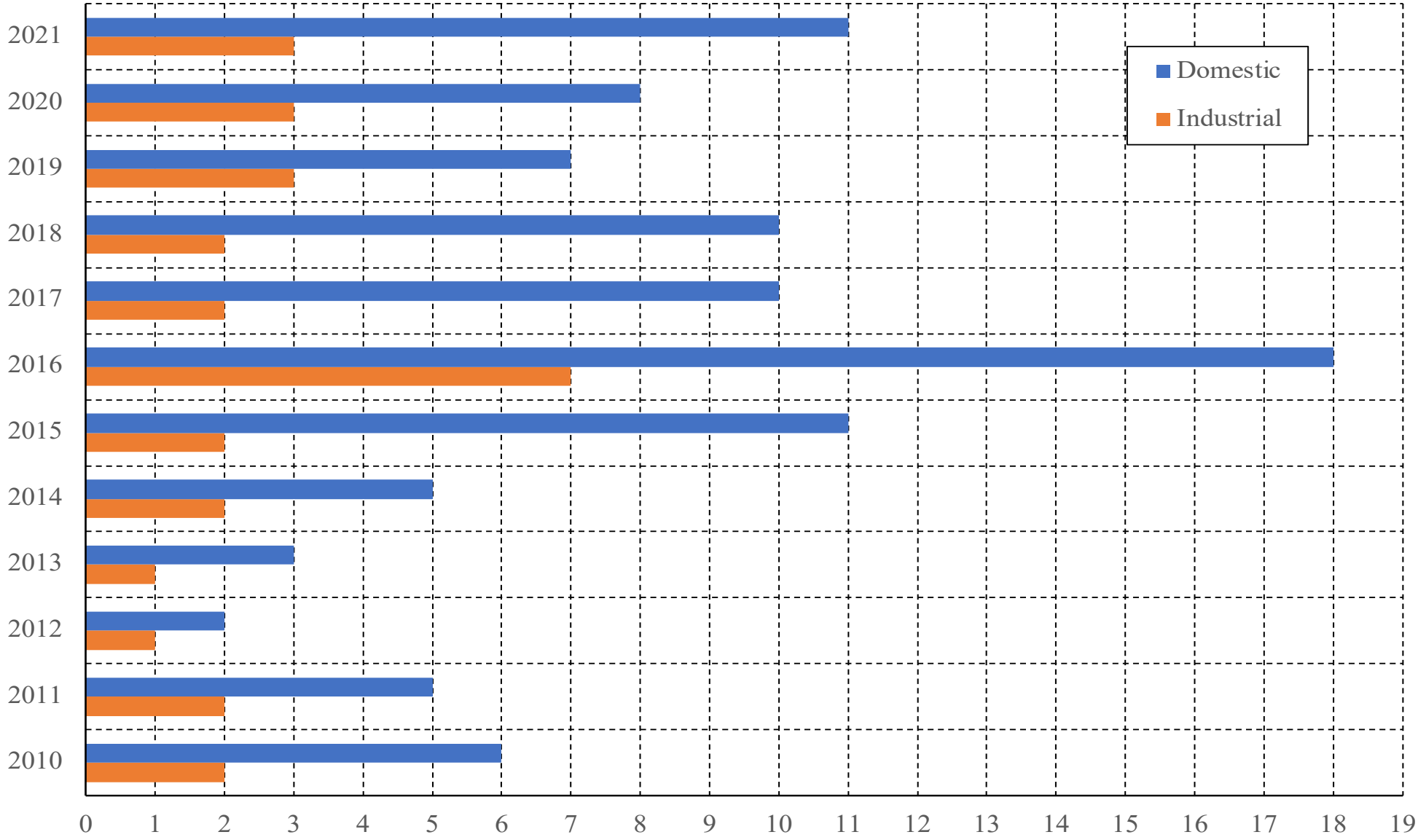
*** Eurostat**

EU statistics* (cont.)



*** Eurostat**

Electricity price - Position of Cyprus in EU*



*** Eurostat**

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

CERA Energy Transition Regulatory Decisions

- **Regulatory Decision 01/2017 (ΚΔΠ 34/2017): A detailed schedule for the implementation of EU electricity market target model**
- **Regulatory Decision 02/2018 (ΚΔΠ 259/2018): The mass installation of an Advanced Metering Infrastructure including smartmeters to all electricity consumers**
- **Regulatory Decision 02/2019 (ΚΔΠ 204/2019): The establishment of basic principles of a regulatory framework for the operation of electricity storage systems in the wholesale electricity market**
- **Regulatory Decision 03/2019 (ΚΔΠ 224/2019): The redesign of the power grid to become smart and bi-directional in order to allow integration of large quantities of renewable energy sources in combination with energy storage systems**

CERA Energy Transition Regulatory Decisions (in preparation)

- **Regulatory framework: Energy communities and Renewable energy communities**
- **Regulatory framework: Electrical interconnections**
- **Regulatory framework: Hydrogen market**
- **Regulatory framework: Price comparison tools**
- …

Challenges in electricity markets

Large scale integration of RES and storage

Electricity market functions

- **Generation** (competition)

- **Transmission** (monopoly)

- **Distribution** (monopoly)

- **Supply** (competition)

Competition vs monopoly



Transmission grid




Distribution grid

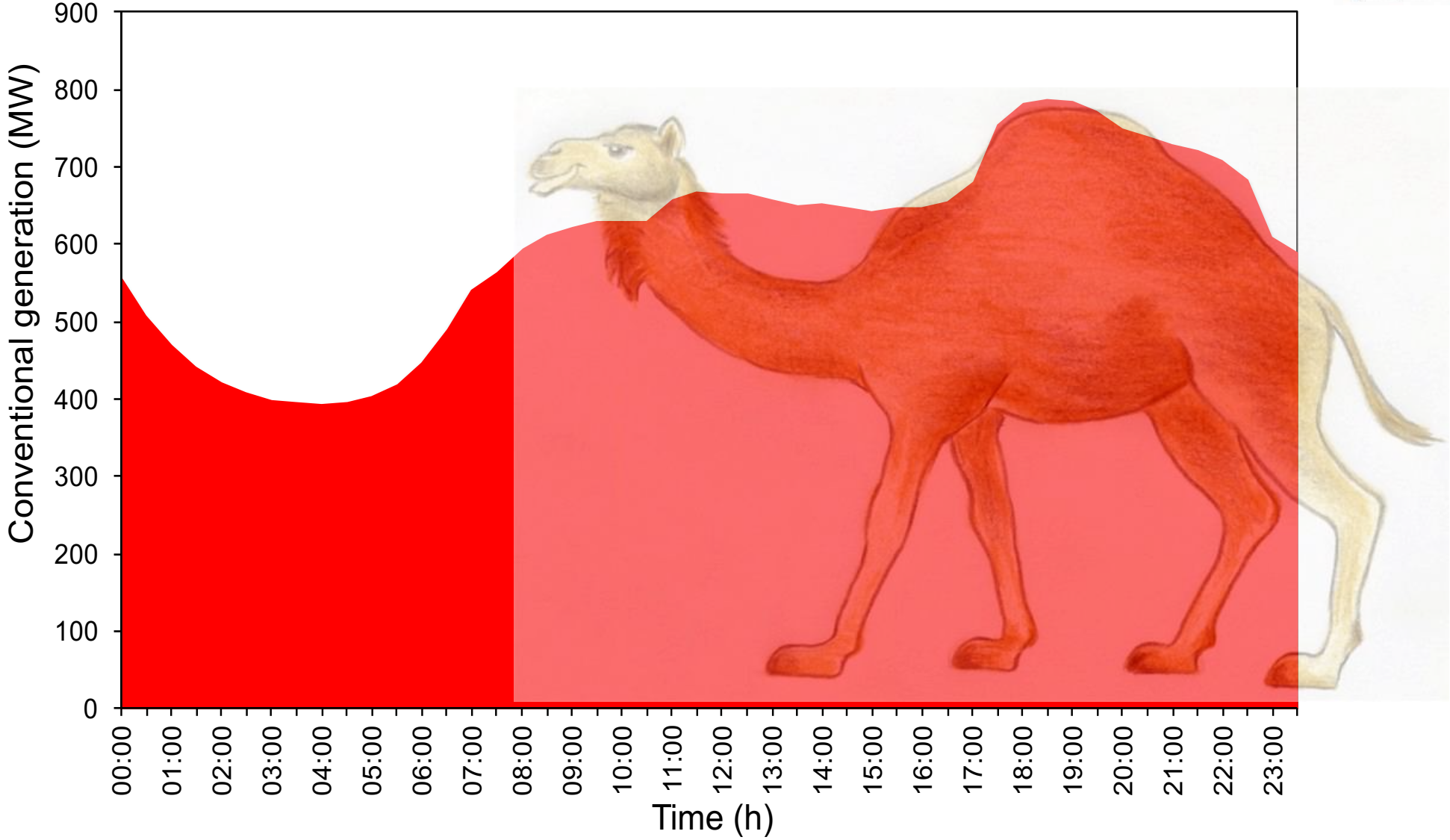


EU electricity market target model

Integration of RES*: LCOE *vs* Reliability

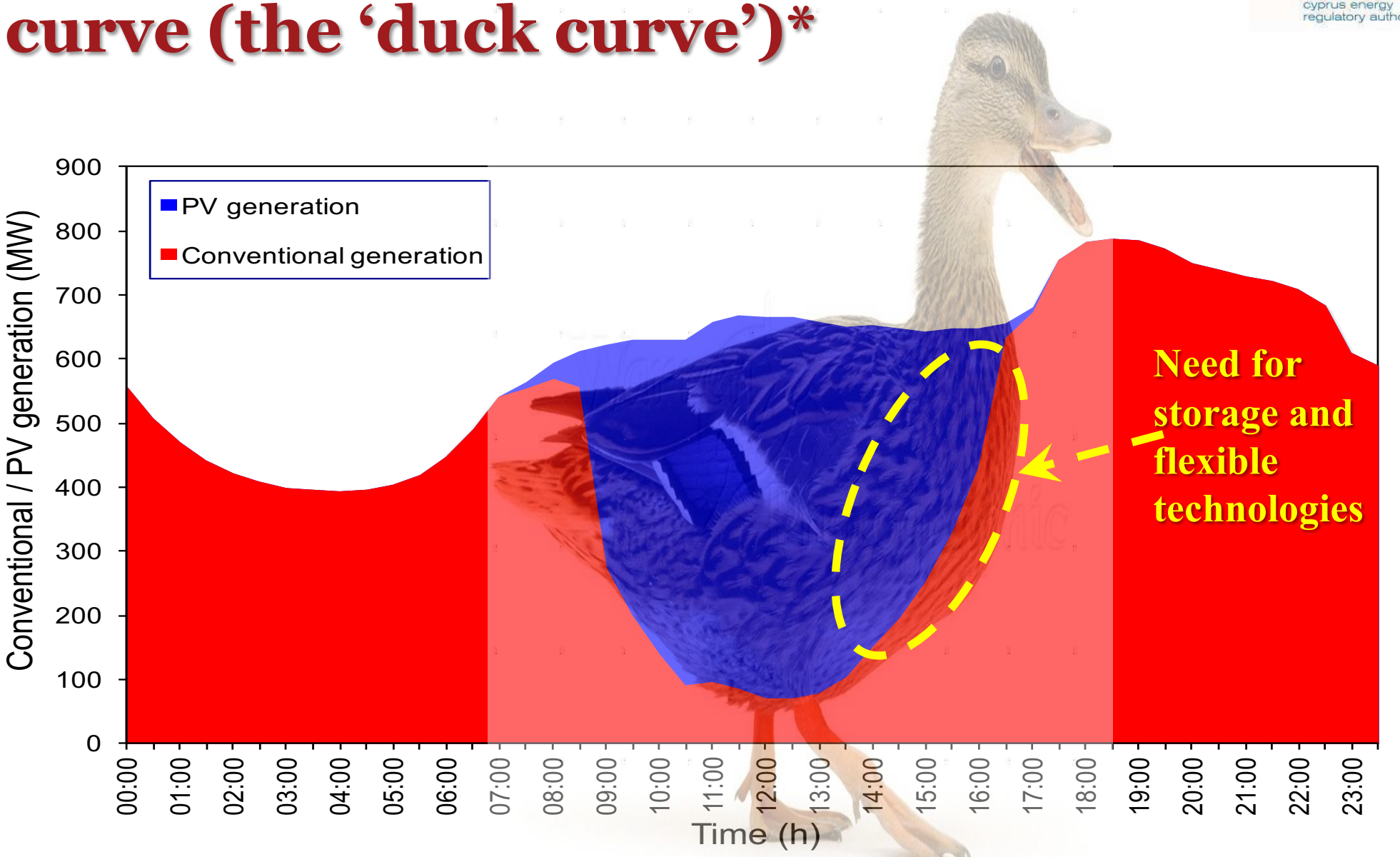
* Nicolaidis P., Chatzis S., Poullikkas A., 2018, "Renewable energy integration through optimal unit commitment and electricity storage in weak power networks", *International Journal of Sustainable Energy*

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*

Storage and flexible technologies are the missing links

Energy storage

Flexible technologies

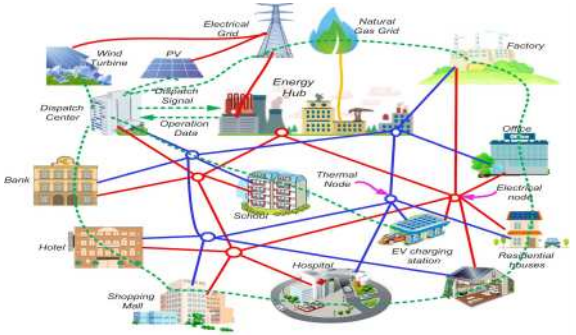
Hydrogen technologies

CERA

Storage, Flexible Technologies and Hydrogen Regulatory Frameworks

Ιστορικό ΑΑΗ

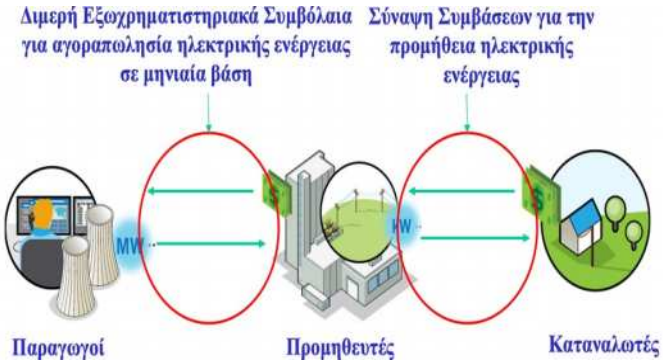
- **2013-2014**
  - **χρηματοδοτούμενες μελέτες από την ΕΕ**
  - **επαφές με Οργανισμό Συνεργασίας των Ρυθμιστικών Αρχών Ενέργειας της ΕΕ (ACER)**
  - **επιλογή Υβριδικού Μοντέλου (Net-Pool) - πλήρες συμβατό με μοντέλο στόχος ΕΕ**



- **2015**
  - **Δημόσια διαβούλευση**
  - **Δημοσίευση Ρυθμιστικής Απόφασης 01/2015 (ΚΔΠ 164/2015): Ο λεπτομερής σχεδιασμός για διαφοροποίηση του πλαισίου ρύθμισης της λειτουργίας της αγοράς ηλεκτρισμού της Κύπρου**

Ιστορικό (συνέχεια)

- **2015-σήμερα** (κύριες ενέργειες)
  - Ρυθμιζόμενες διατιμήσεις ΑΗΚ
  - Διαχωρισμένοι Λογαριασμοί ΑΗΚ
  - Λειτουργικός Διαχωρισμός ΑΗΚ
  - Νέοι Κανόνες Αγοράς Ηλεκτρισμού
  - Αναθεώρηση Κανόνων Μεταφοράς και Διανομής
  - Αναθεώρηση Νομοθεσίας
  - Νομικός διαχωρισμός ΔΣΜΚ από λ.δ. καθετοποιημένη ΑΗΚ
  - ΔΣΔ: λογισμικό MDMS
  - ΔΣΜΚ: λογισμικό MMS - σε δοκιμαστική φάση
- **2017: Μεταβατική ρύθμιση**
  - Δραστηριοποίηση ανεξάρτητων προμηθευτών (έτος 2021)
  - Δραστηριοποίηση ανεξάρτητων παραγωγών
  - Διμερή συμβόλαια – εκκαθάριση ανά μήνα



2014: Υβριδικό Μοντέλο (Net-Pool)

- **Ένταξη των ΑΠΕ, με βέλτιστο τρόπο και με όρους της αγοράς**
  - **ένταξη και συμμετοχή των ΑΠΕ στην αγορά ηλεκτρισμού με τα ίδια δικαιώματα αλλά και υποχρεώσεις όπως οι συμβατικές μονάδες ηλεκτροπαραγωγής - ανάληψη των υποχρεώσεων των παραγωγών ΑΠΕ για τα θέματα εφεδρείας και εξισορρόπησης με παρόμοιο τρόπο όπως οι συμβατικές μονάδες ηλεκτροπαραγωγής**

- **Επιτρέπει την δραστηριοποίηση προμηθευτών ηλεκτρισμού για να μπορούν οι καταναλωτές να έχουν επιλογή - συγκράτηση του κόστους ηλεκτρισμού**

EU electricity market target model

Διμερή συμβόλαια, κλπ

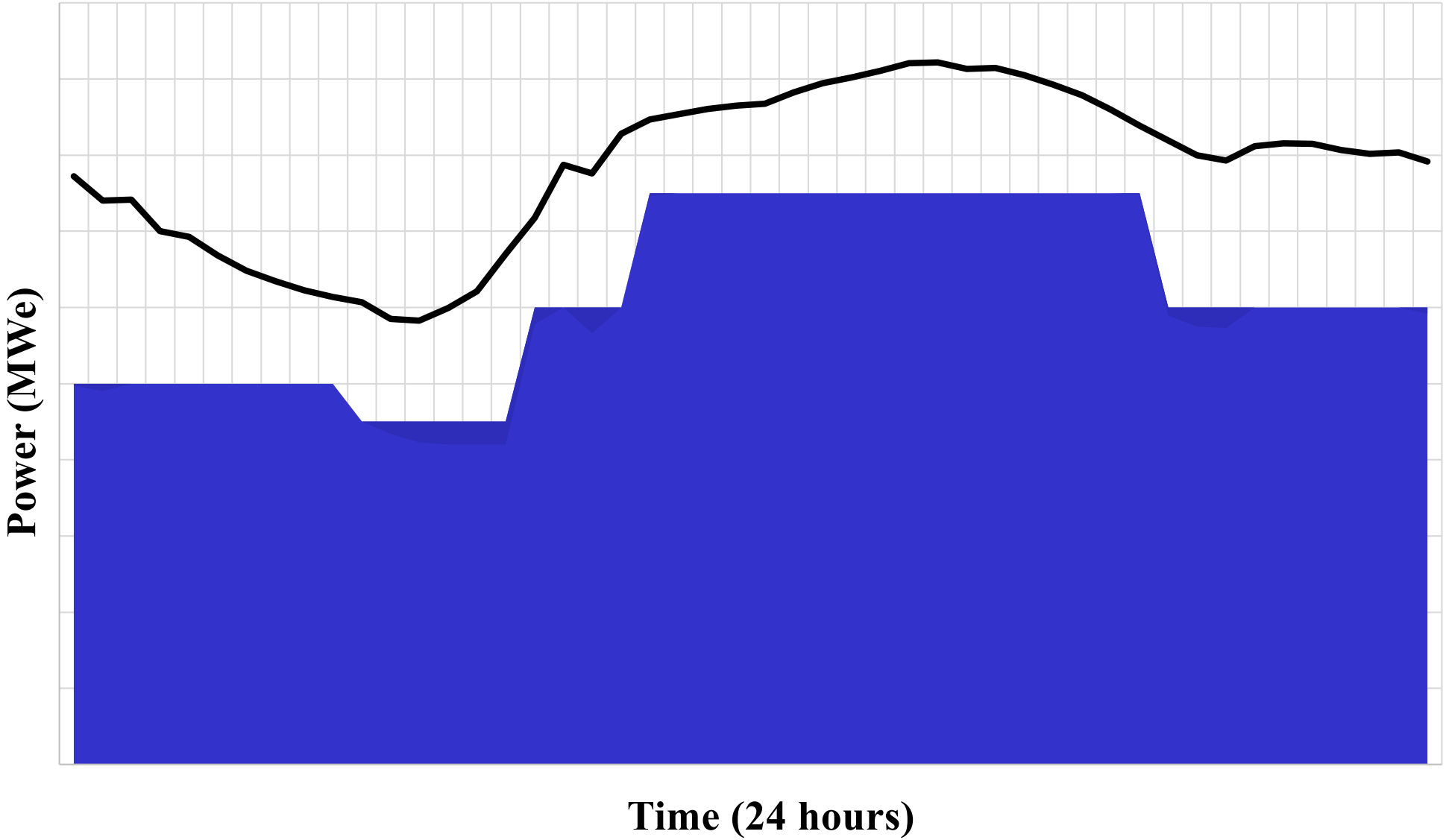
Αγορά άμεσης παράδοσης (spot) προηγούμενης ημέρας

Αγορά άμεσης παράδοσης (spot) ίδιας ημέρας

Αγορά εξισορρόπησης

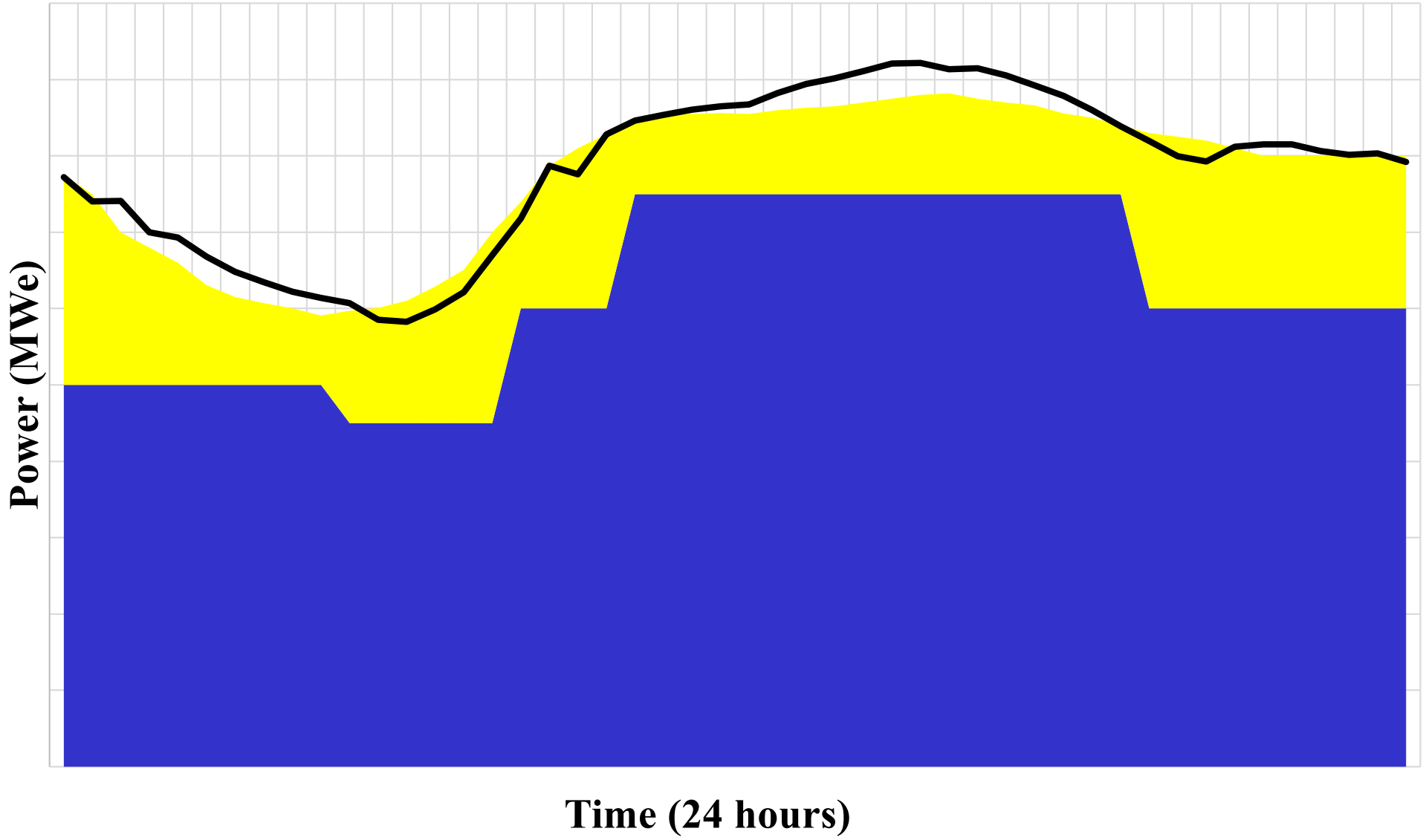
Electricity market operation

- **Forward market**



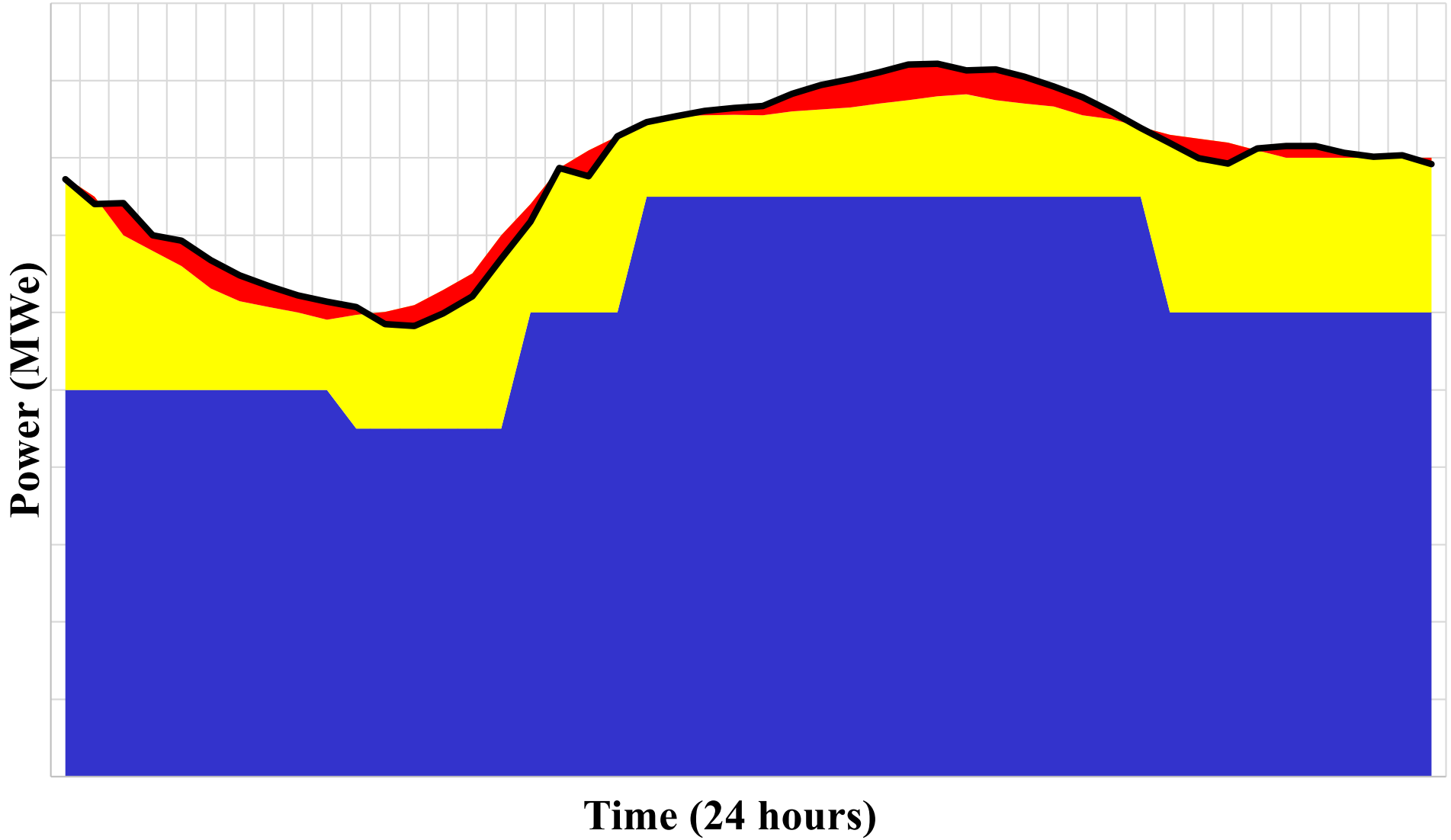
Electricity market operation

- **Forward market + Day ahead market**



Electricity market operation

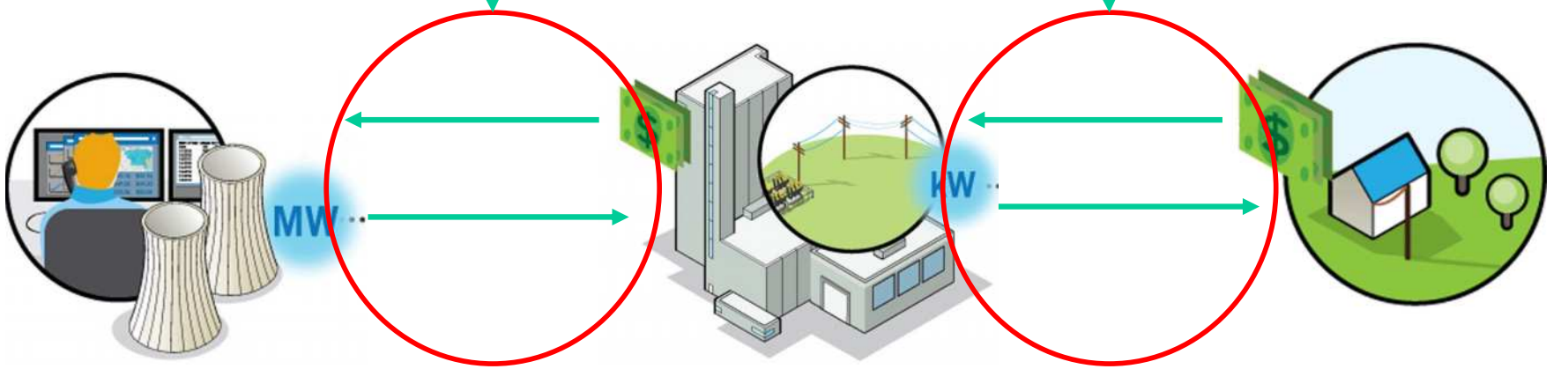
- **Forward market + Day ahead market + Balancing market**



Κύρια χαρακτηριστικά Μεταβατικής Ρύθμισης

Διμερή Εξωχρηματιστηριακά Συμβόλαια για αγοραπωλησία ηλεκτρικής ενέργειας σε μηνιαία βάση

Σύναψη Συμβάσεων για την προμήθεια ηλεκτρικής ενέργειας



Παραγωγοί **Προμηθευτές** **Καταναλωτές**

Κάλυψη διαδικασιών αγορών ηλεκτρισμού

Α/Α	Πυλώνες αγοράς	Μεταβατική Ρύθμιση	
1	Προθεσμιακή Αγορά – διμερή συμβόλαια		Καλύπτεται πλήρως
2	Κεντρικά Οργανωμένη Προθεσμιακή Αγορά		Δεν καλύπτεται
3	Ημερήσια Αγορά		Δεν καλύπτεται
4	Ενδοημερήσια Αγορά		Δεν καλύπτεται
5	Αγορά Εξισορρόπησης Ισχύος		Δεν καλύπτεται
6	Μηχανισμός Εξισορρόπησης Ισχύος		Δεν καλύπτεται
7	Αγορά Επικουρικών Υπηρεσιών		Δεν καλύπτεται
8	Διαχείριση μετρήσεων		Καλύπτεται μερικώς (μόνο για μετρητές τύπου STOD)
9	Συμβιβασμός εκκαθάρισης		Καλύπτεται
10	Εγγυοδοσία		Καλύπτεται
11	Διαχείριση μονάδων ΑΠΕ		Καλύπτεται
12	Πληροφοριακή υποδομή		Δεν απαιτείται ειδικό λογισμικό αγοράς
13	Χρόνος υλοποίησης πληροφοριακής υποδομής		Δεν απαιτείται ειδικό λογισμικό αγοράς

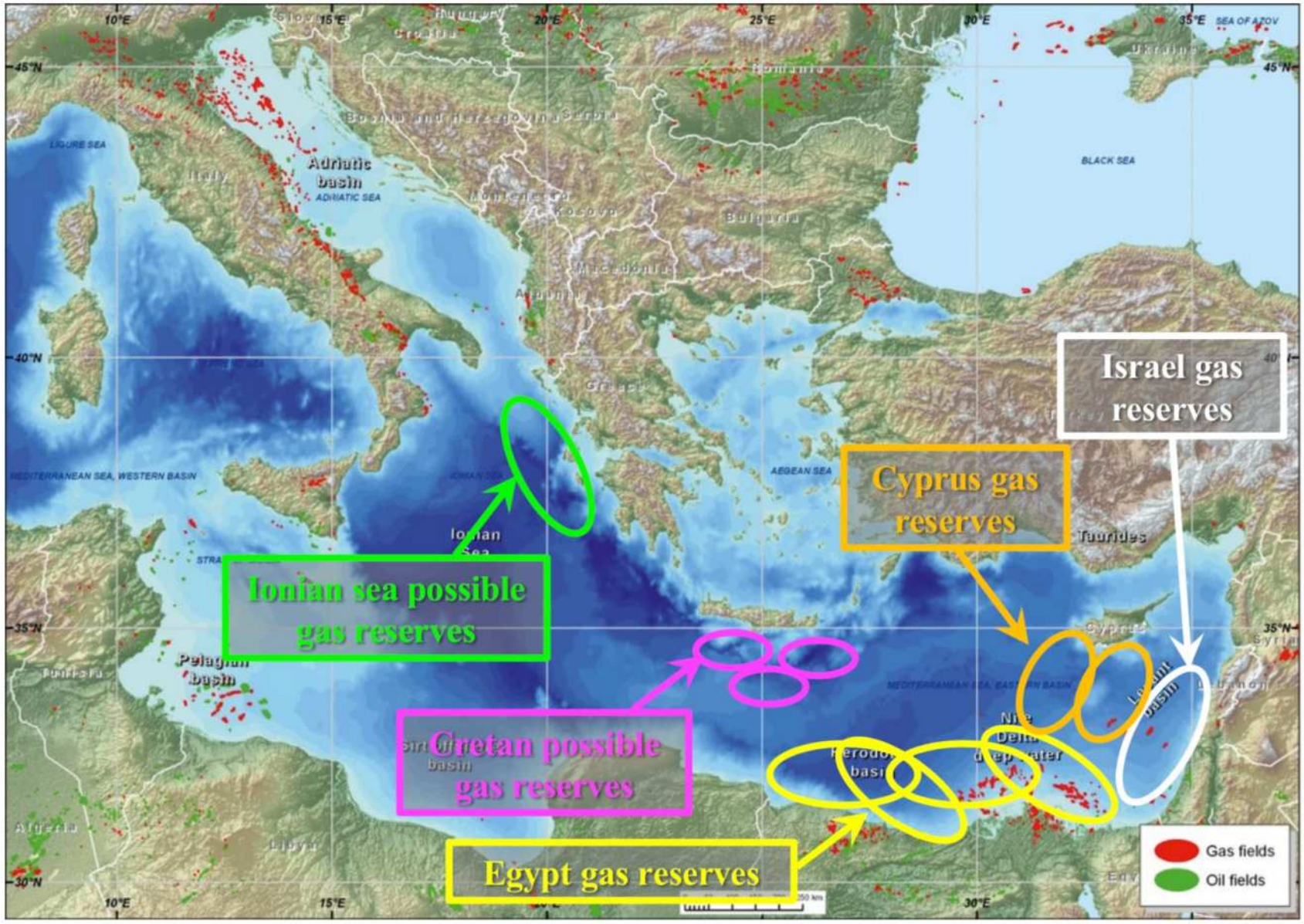
Long-term energy strategy for Cyprus

Regional cooperation towards hydrogen economy

Regional primary energy sources

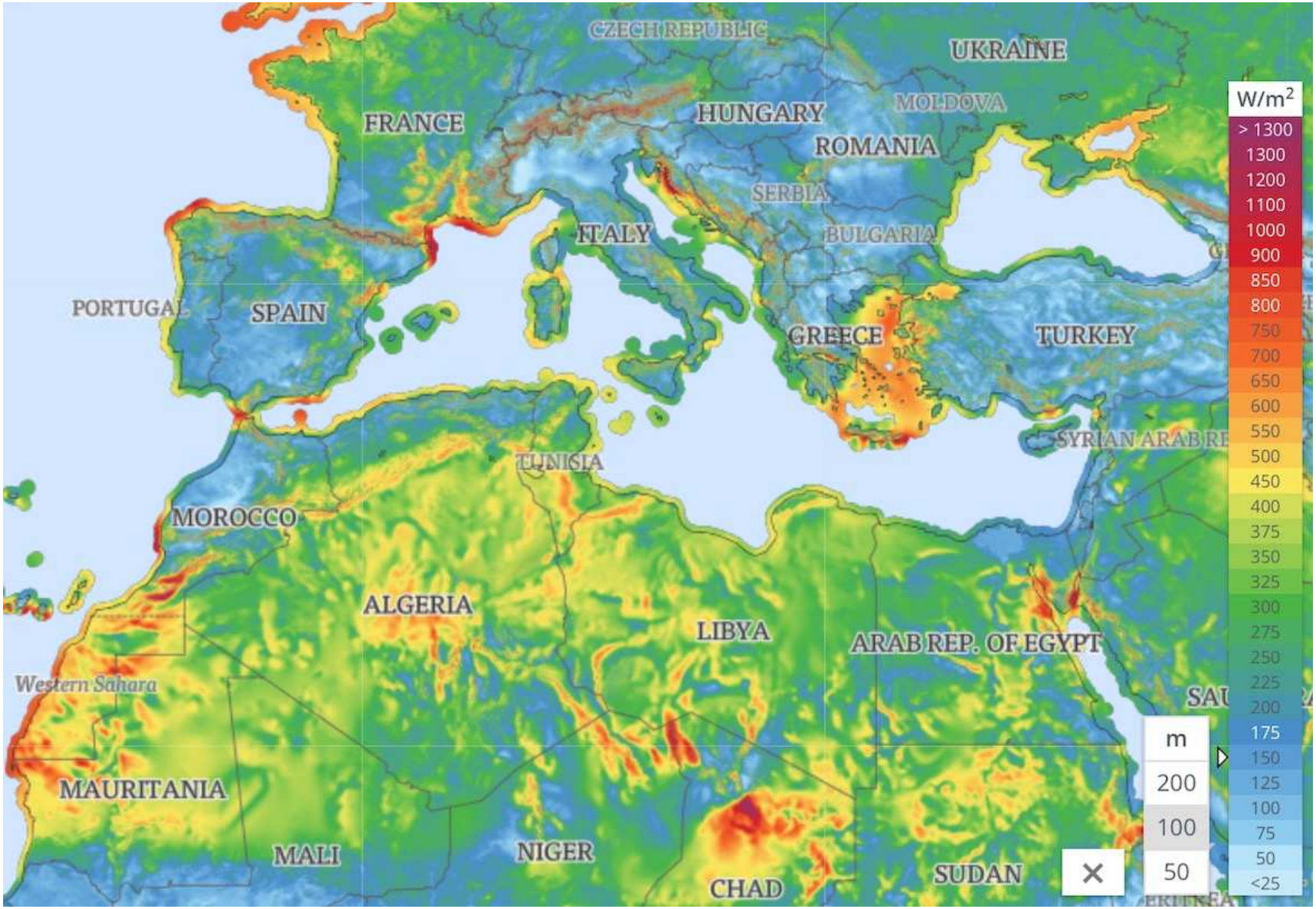
Indigenous energy sources

Gas reserves in SE Mediterranean region*



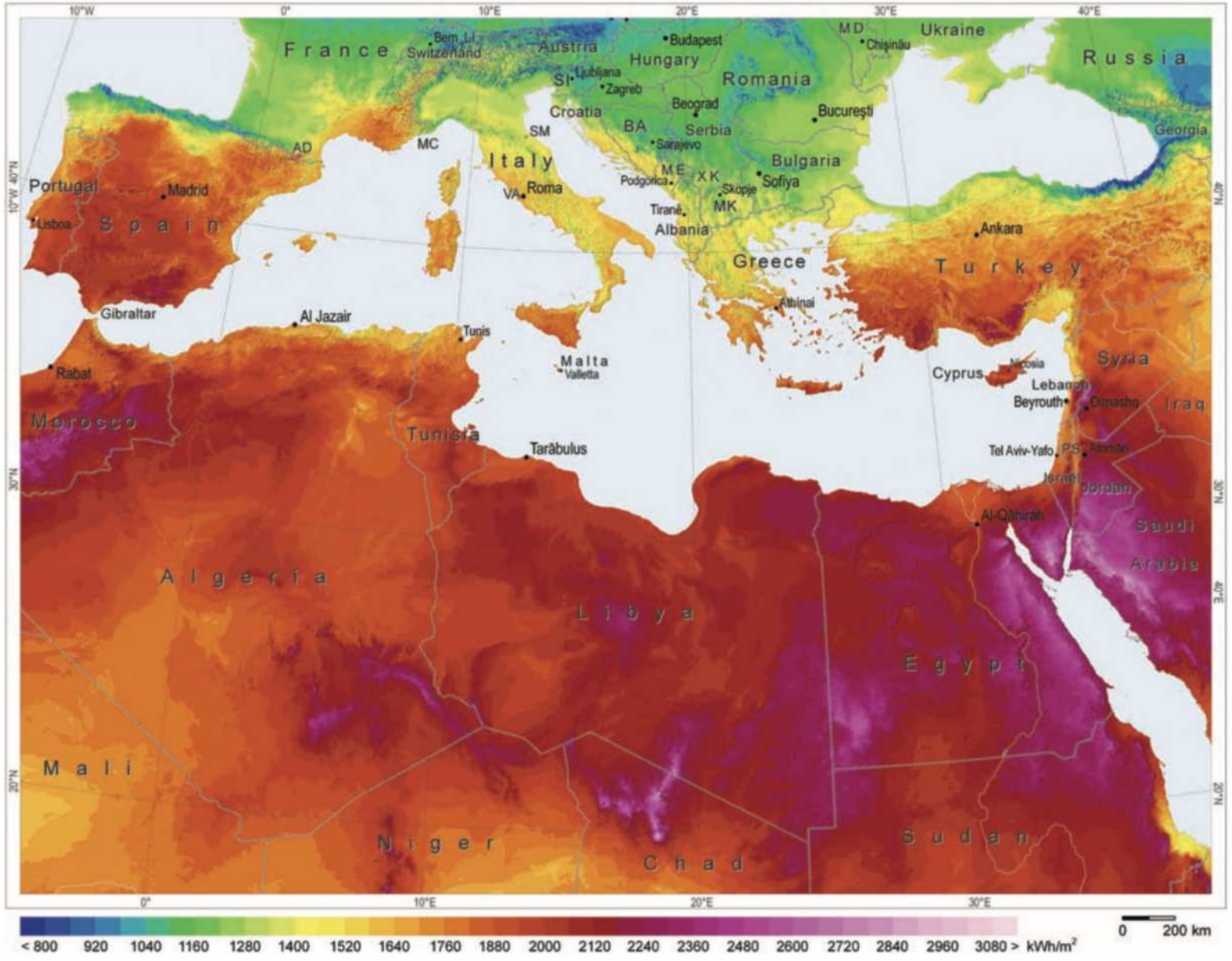
* A. Belopolsky, *et al.*, 2012, "New and emerging plays in the Eastern Mediterranean", *Petroleum Geoscience*

Wind potential in SE Mediterranean region*



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

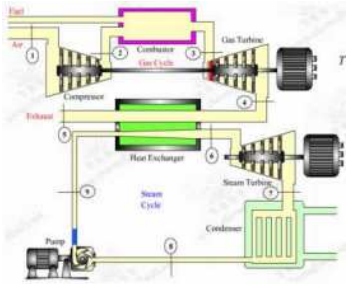
Solar potential in SE Mediterranean region*



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

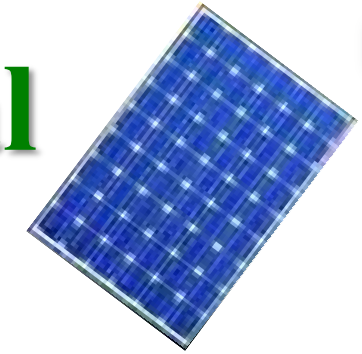
Main indigenous energy sources in SE Mediterranean region

- Natural gas



- Wind potential

- Solar potential



Target-setting for Cyprus' transition to hydrogen economy*

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*

ρυθμιστική αρχή ενέργειας κύπρου
cyprus energy regulatory authority

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

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

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**

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

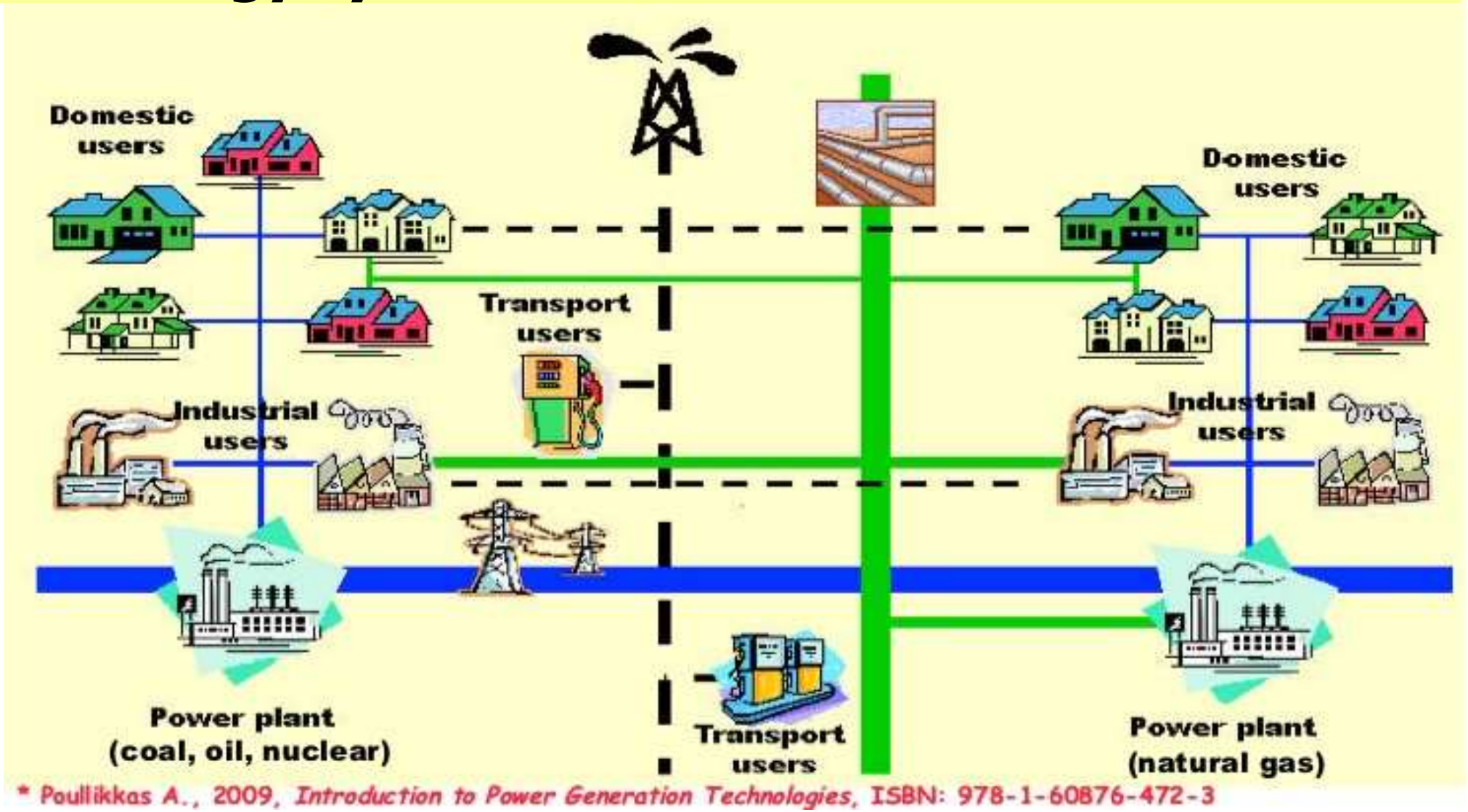
Additional Slides

The energy transition cost

Towards 2050

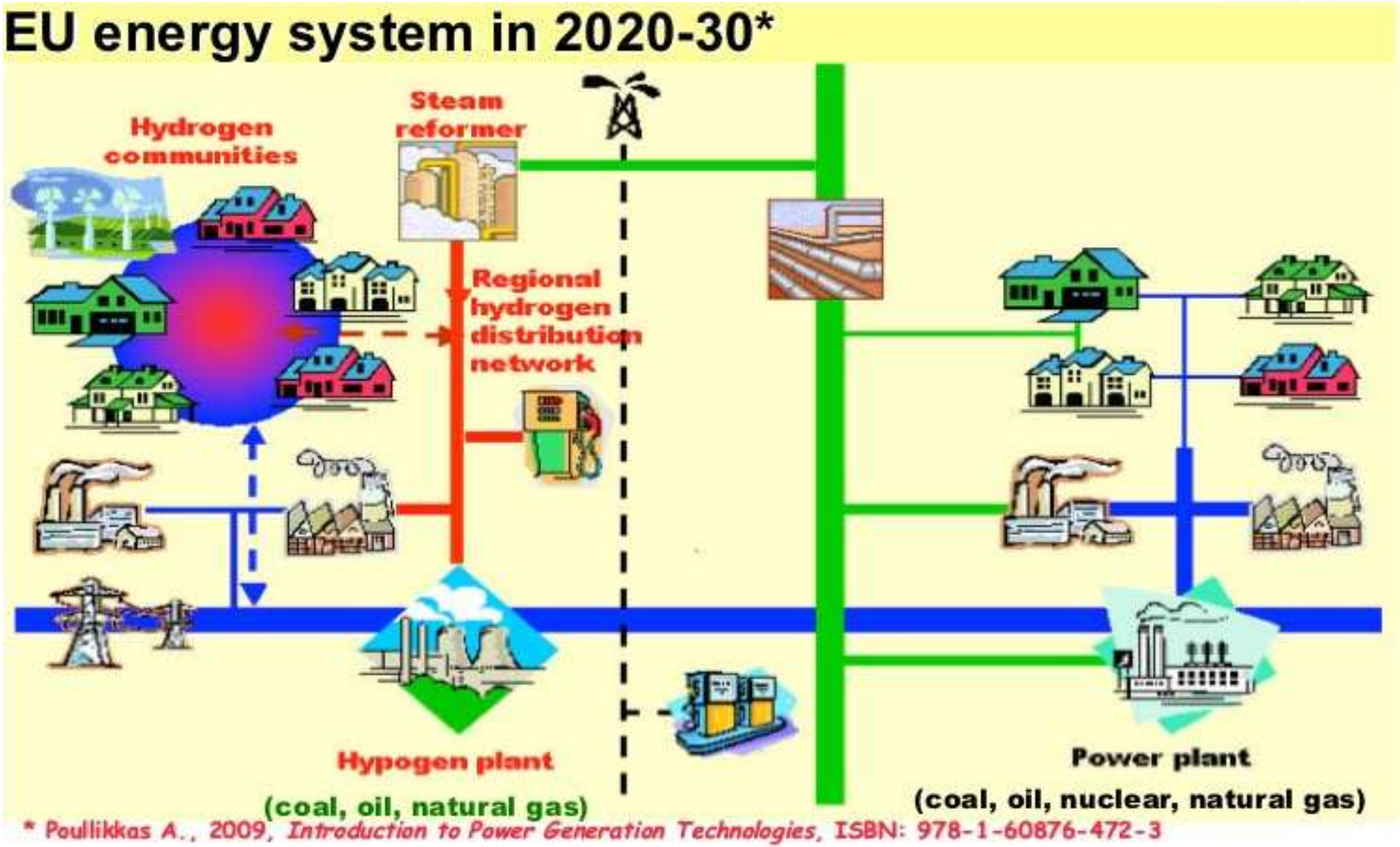
Energy system in 2010

EU energy system in 2010*

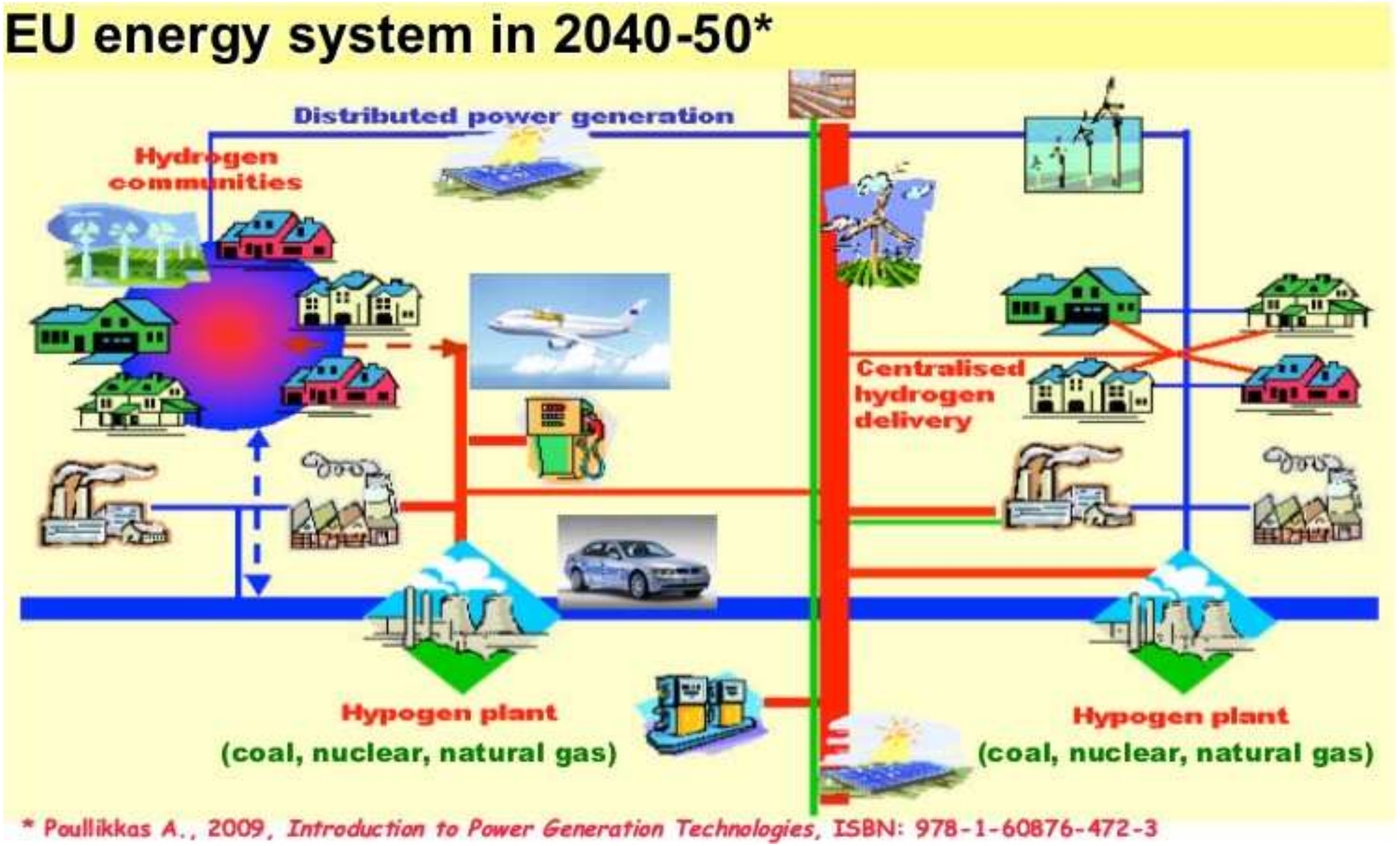


* Poullikkas A., 2009, *Introduction to Power Generation Technologies*, ISBN: 978-1-60876-472-3

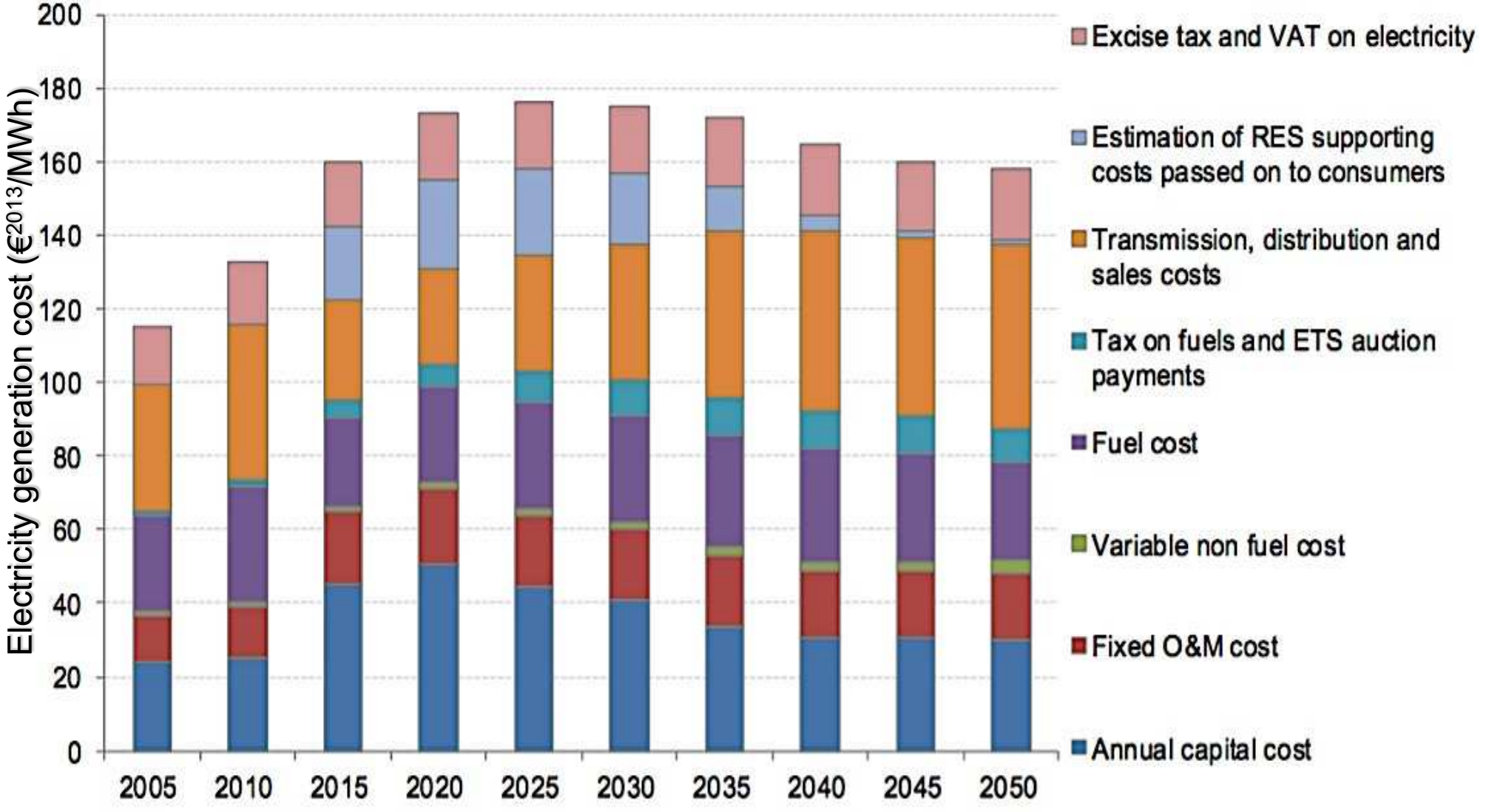
Future energy systems (optimistic scenario)



Future energy systems (optimistic scenario)

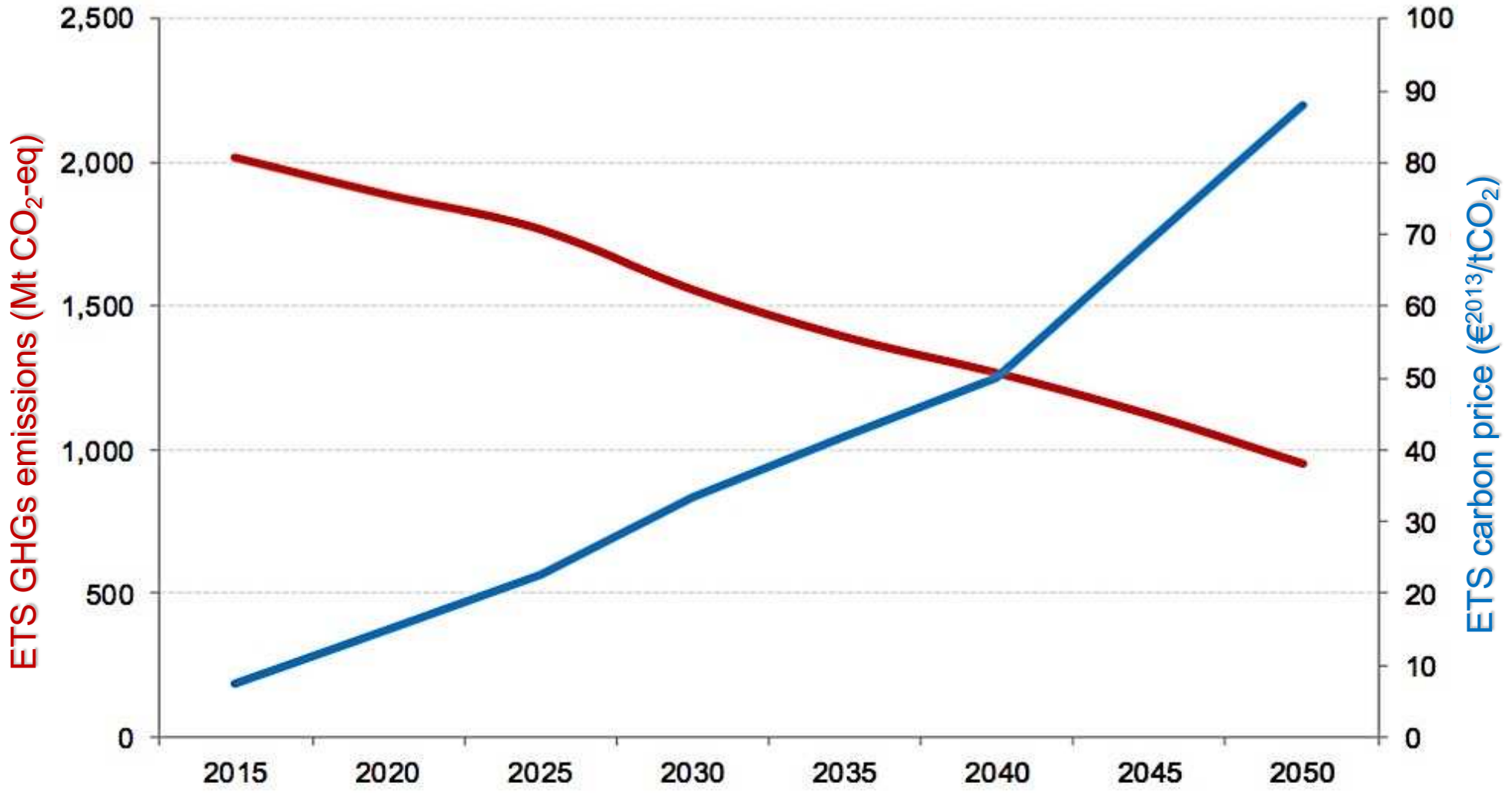


EU reference scenario 2016



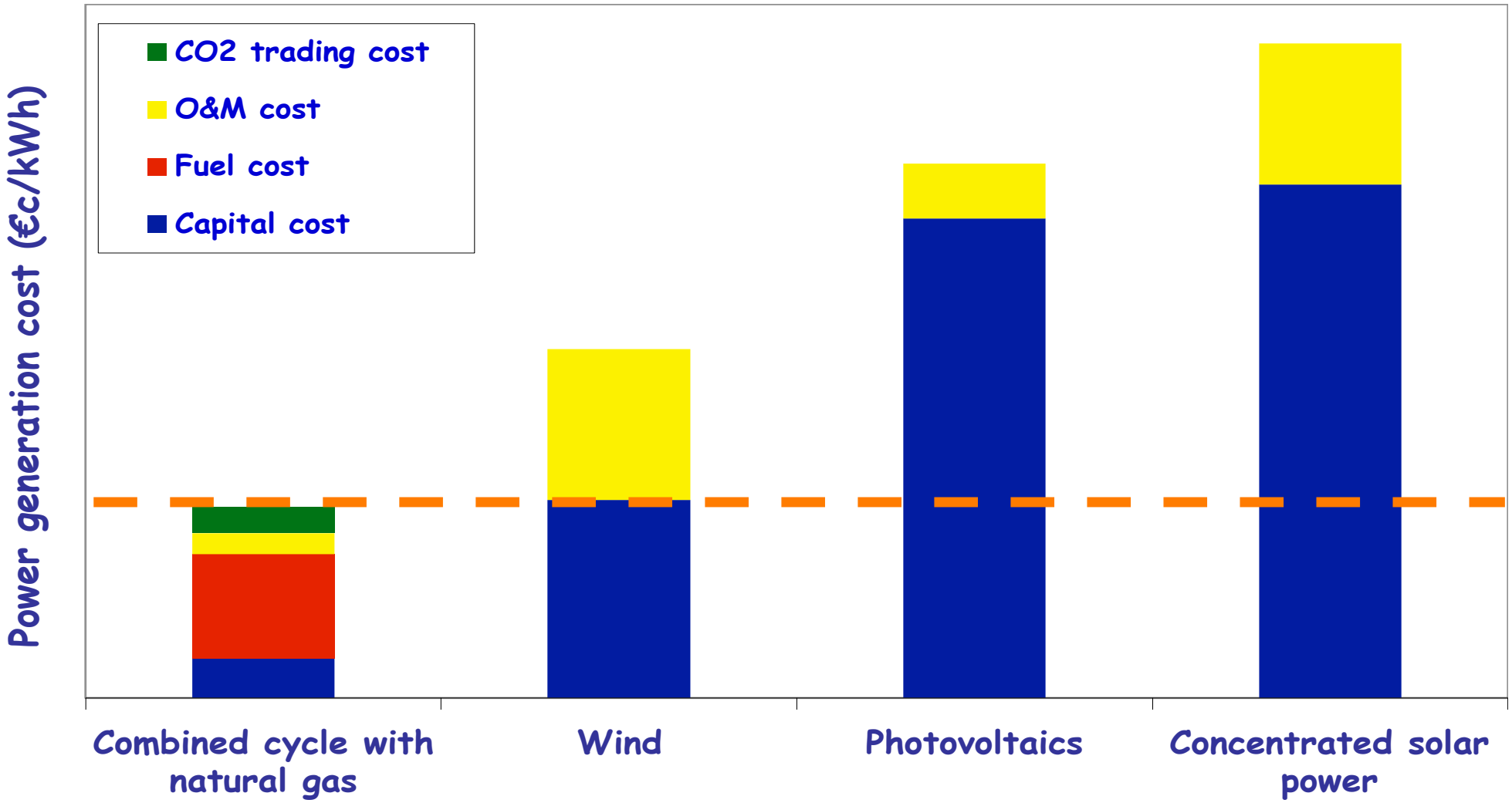
Source: PRIMES

EU reference scenario 2016



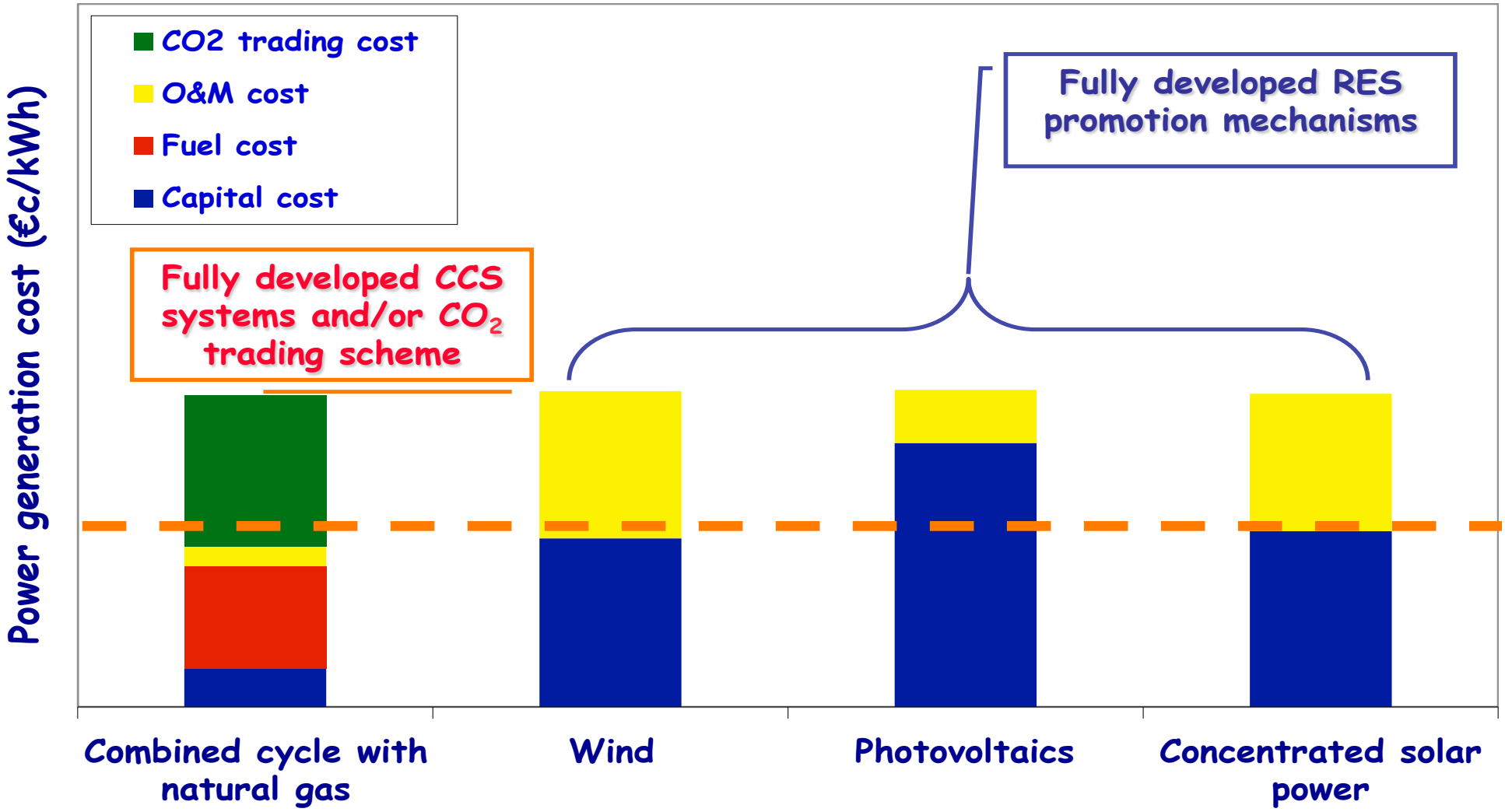
Source: PRIMES, GAINS

Power generation cost (year 2010)*



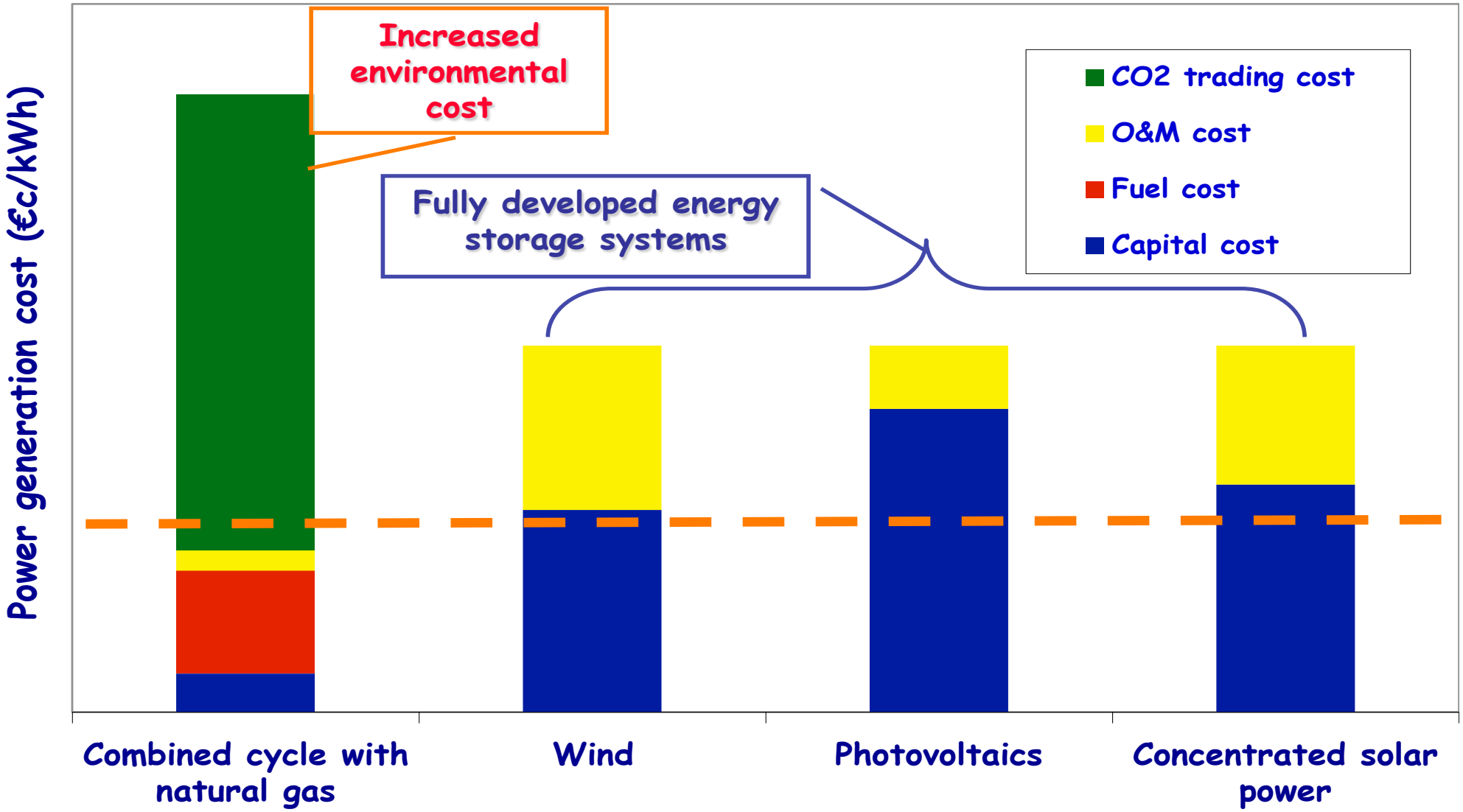
* Poullikkas A., 2010, "The cost of integration of renewable energy sources", *Accountancy*

Power generation cost (year 2020-30)*



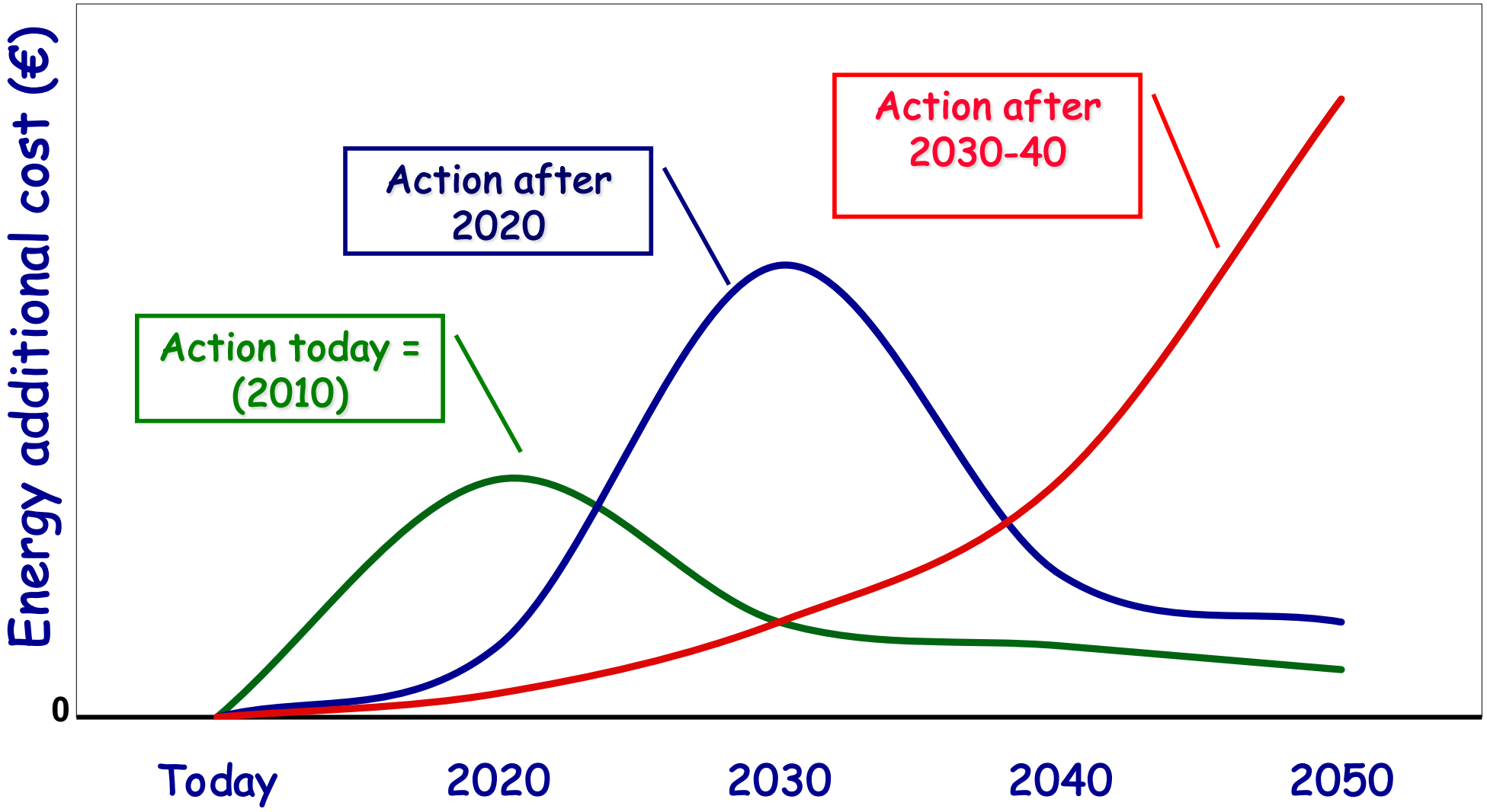
* Poullikkas A., 2010, "The cost of integration of renewable energy sources", *Accountancy*

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*