ρυθμιστική αρχή ενέργειας κύπρου
cyprus energy regulatory authority

Plenary Talk

Moving towards new energy era

Dr. Andreas Poullikkas

Ph.D, D.Tech, FIET

Chairman, Cyprus Energy Regulatory Authority

Chairman, Cyprus Energy Strategy Council

andreas.poullikkas@eecei.cut.ac.cy

Contents

ρυθμιστική αρχή ενέργειας κύπρου
cyprus energy regulatory authority

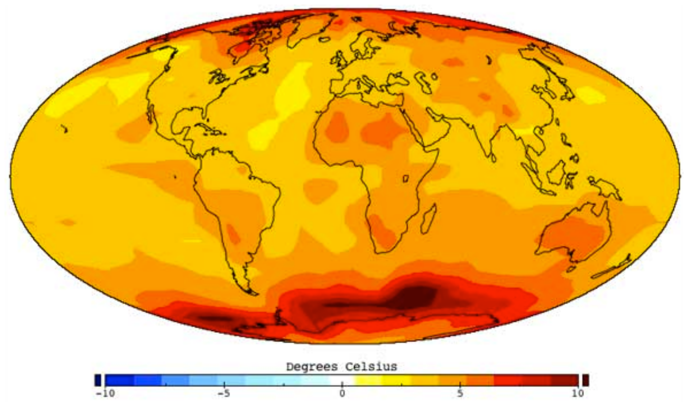
- EU energy strategy - 2020, 2030, 2050
- Challenges in electricity markets
- Modeling for optimum large scale integration of RES
- Sustainable energy strategies for UAE

EU energy strategy

2020, 2030, 2050

Future energy systems

- **Climate change**

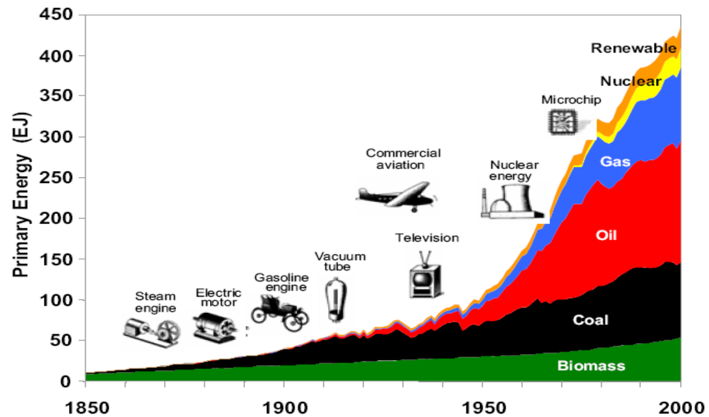


- **Third industrial revolution**

- **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

ρυθμιστική αρχή ενέργειας κύπρου
cyprus energy regulatory authority

2020

-20 %
Greenhouse Gas Emissions

20%
Renewable Energy

20 %
Energy Efficiency

10 %
Interconnection

2030

≥ - 40 %
Greenhouse Gas Emissions

≥27 %
Renewable Energy

≥ 27%*
Energy Efficiency

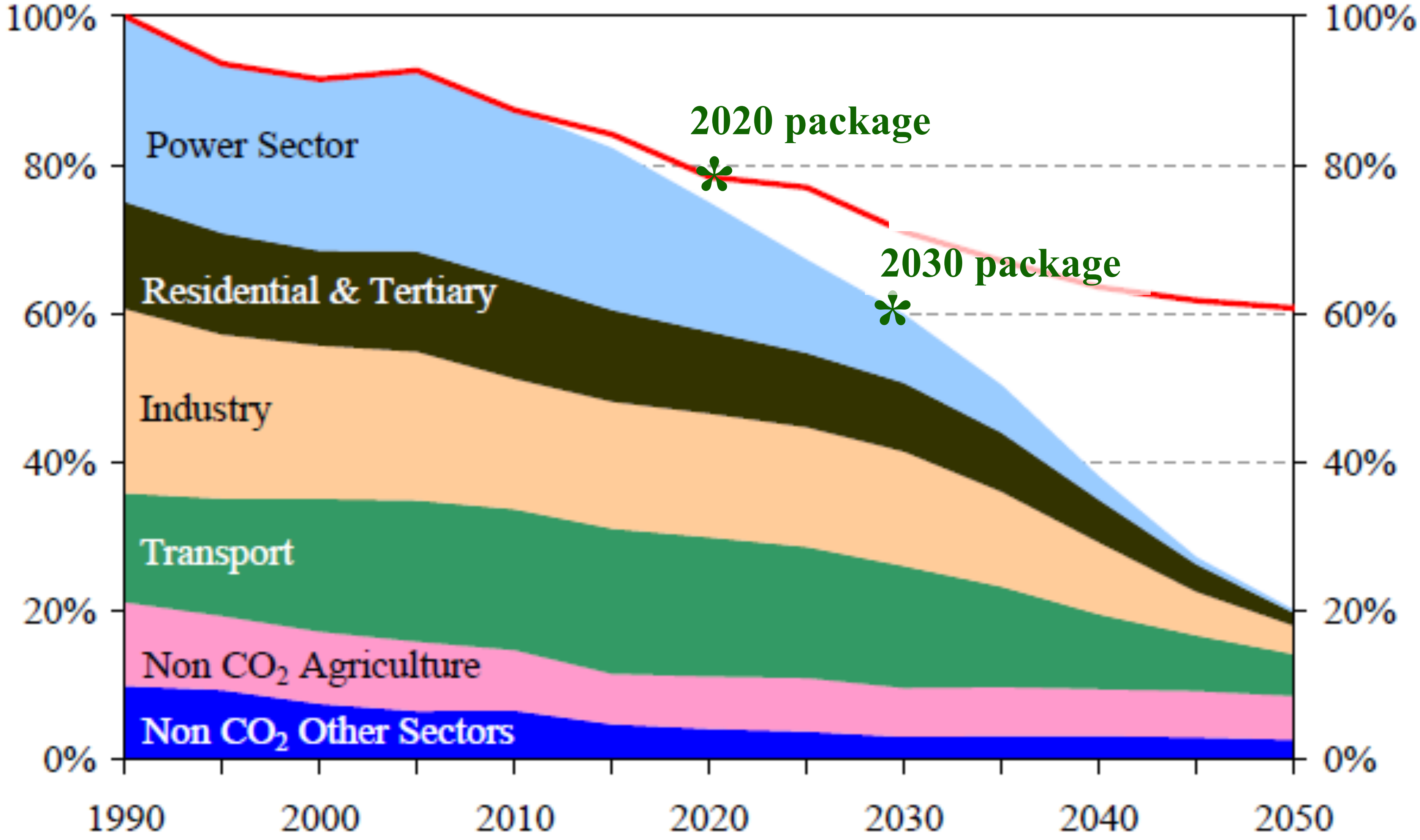
15 %
Interconnection

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

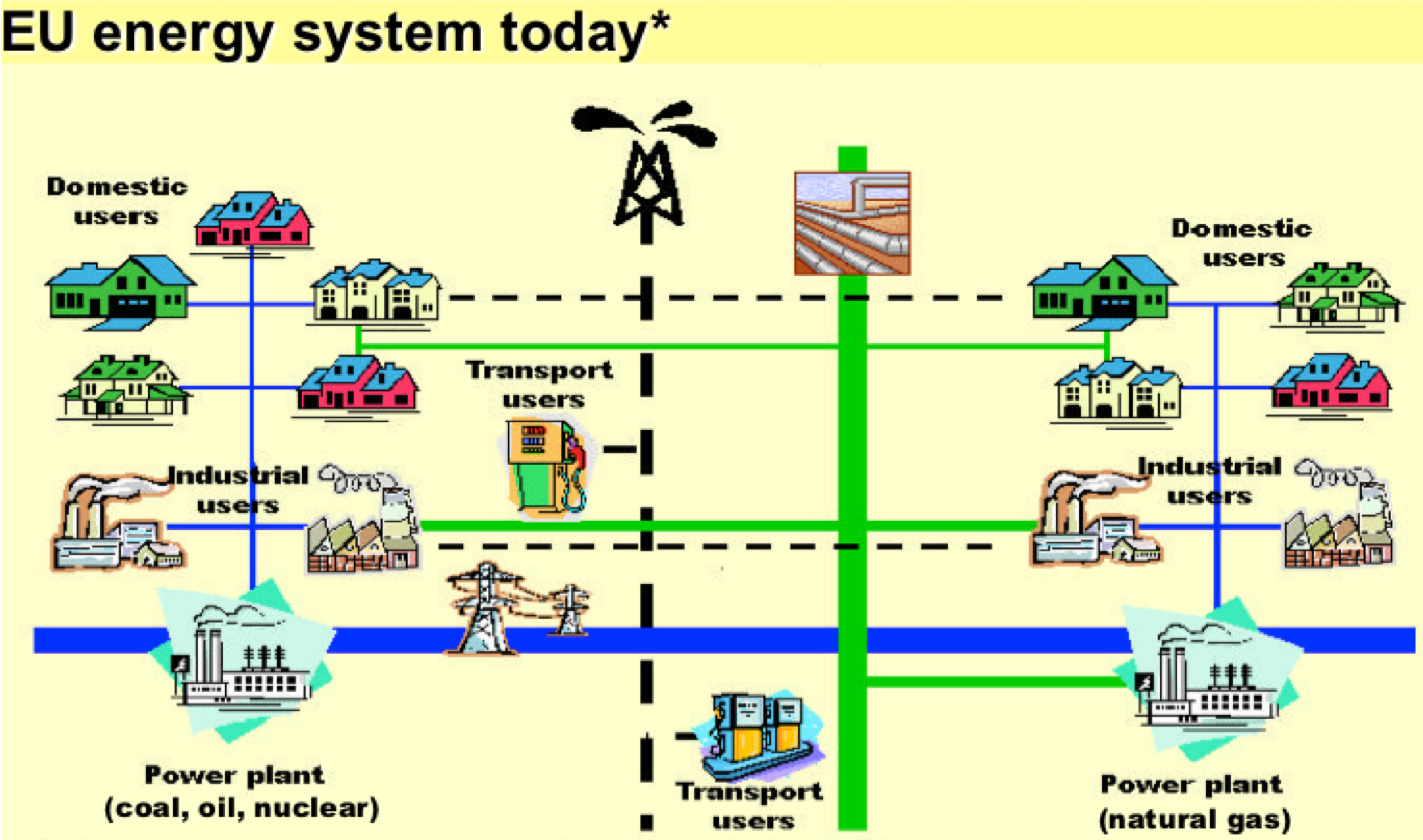
New governance system + indicators

2050 -80% Greenhouse Gas Emissions

EU reduction in greenhouse gas emissions



Current energy system

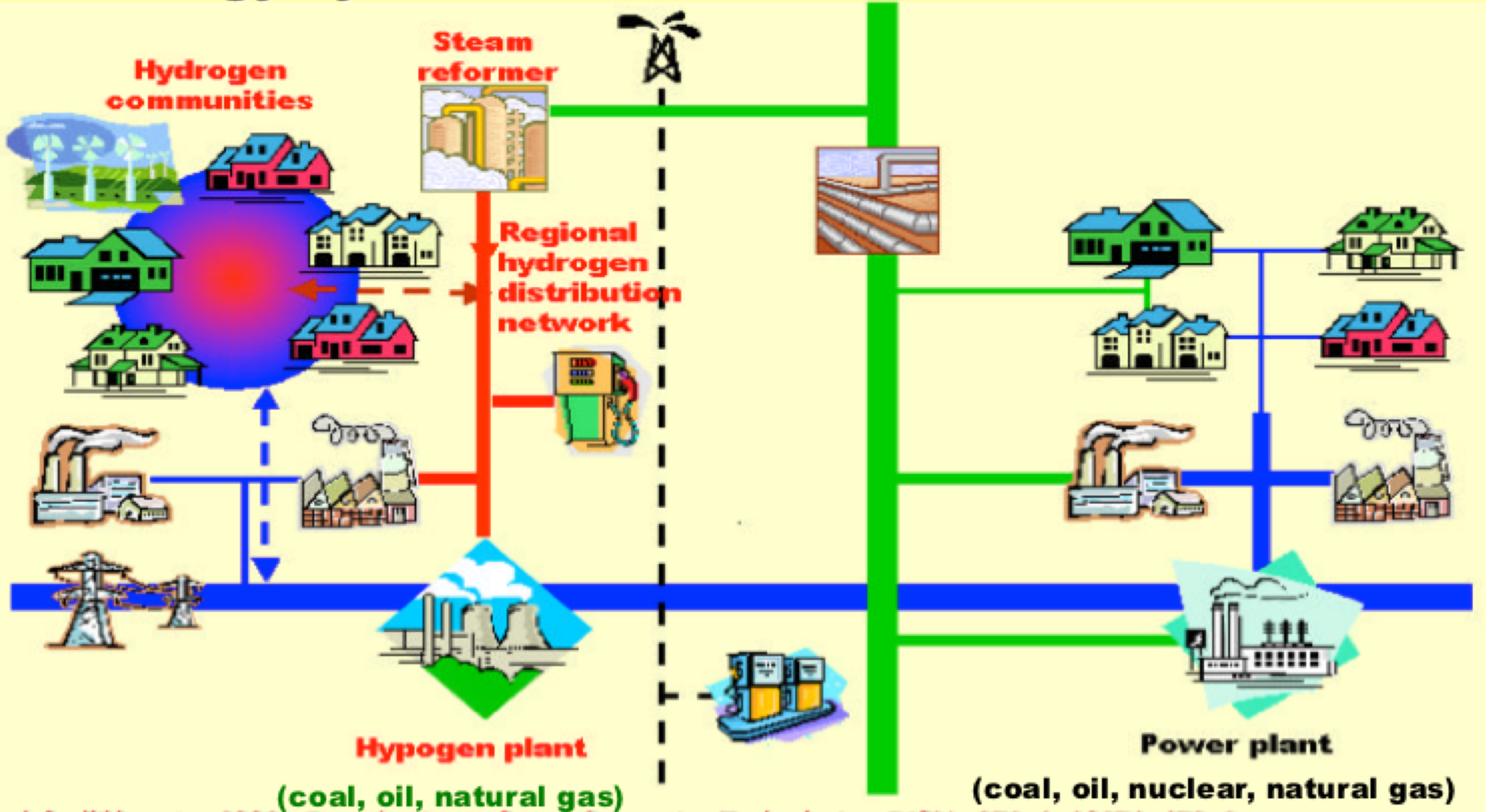


* Poullikkas A., 2009, *Introduction to Power Generation Technologies*, ISBN: 978-1-60876-472-3

Future energy systems (optimistic scenario)

ρυθμιστική αρχή ενέργειας κύπρου
cyprus energy regulatory authority

EU energy system in 2020-30*

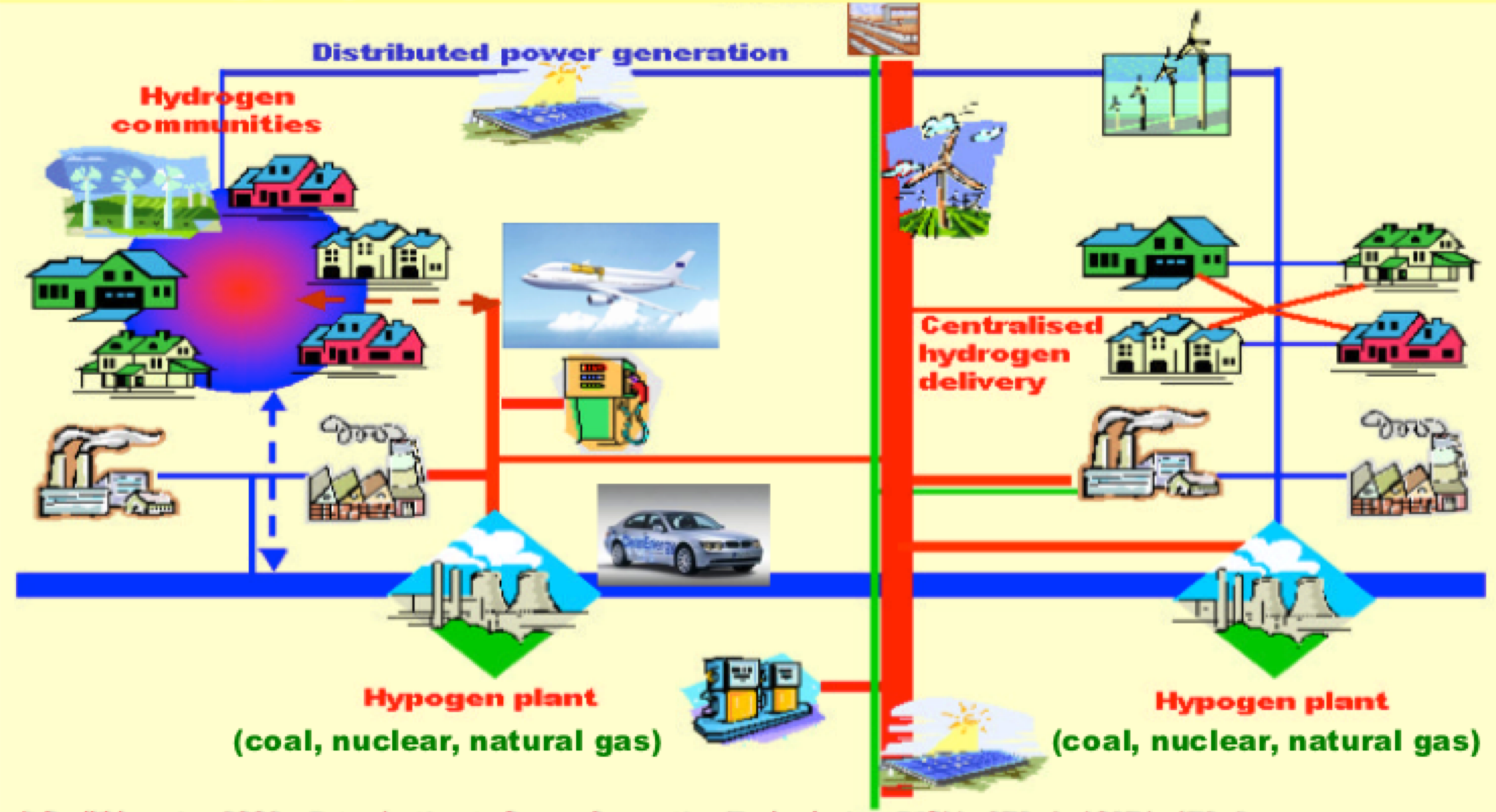


* Poullikkas A., 2009, *Introduction to Power Generation Technologies*, ISBN: 978-1-60876-472-3

Future energy systems (optimistic scenario)

ρυθμιστική αρχή ενέργειας κύπρου
cyprus energy regulatory authority

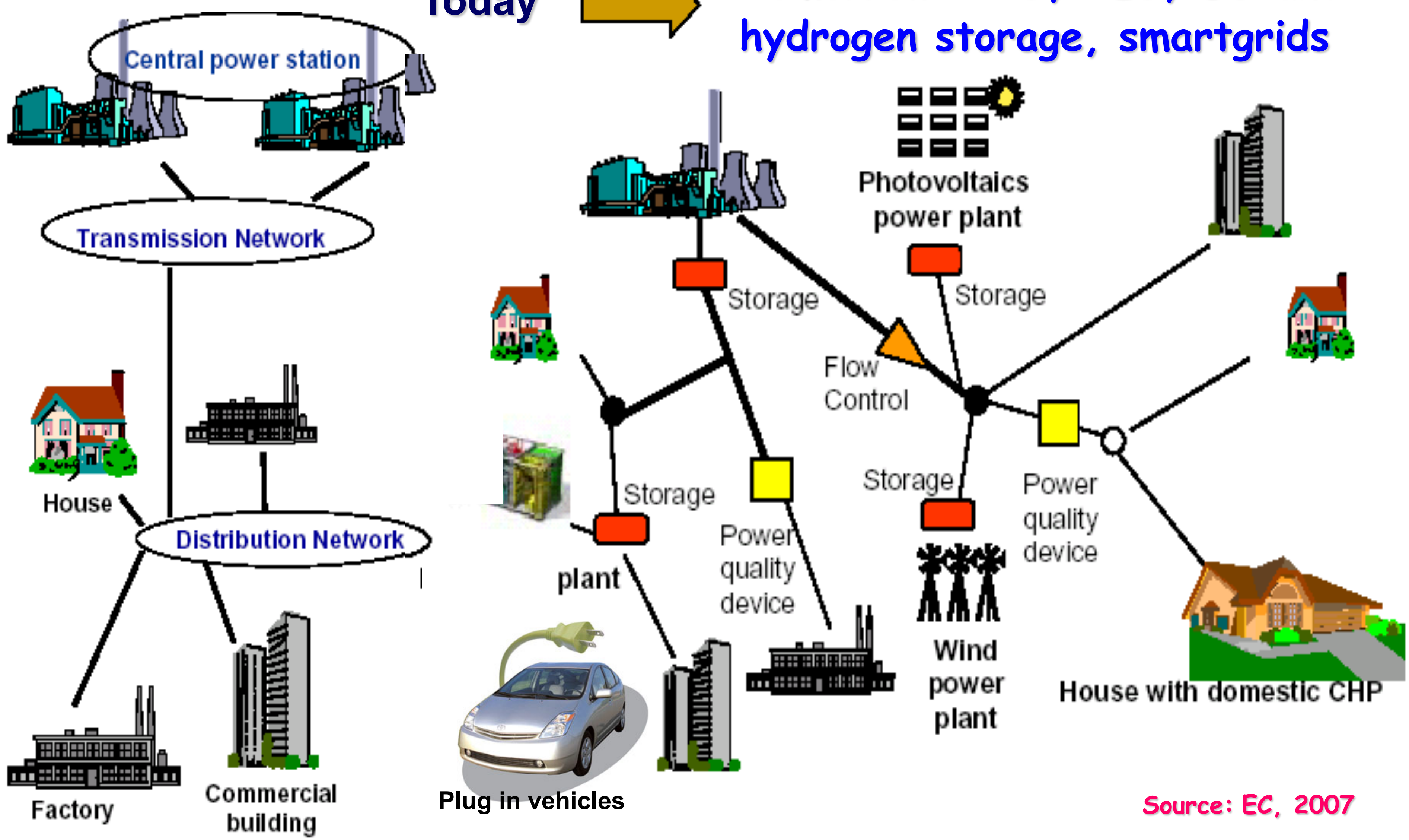
EU energy system in 2040-50*



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

Future power systems

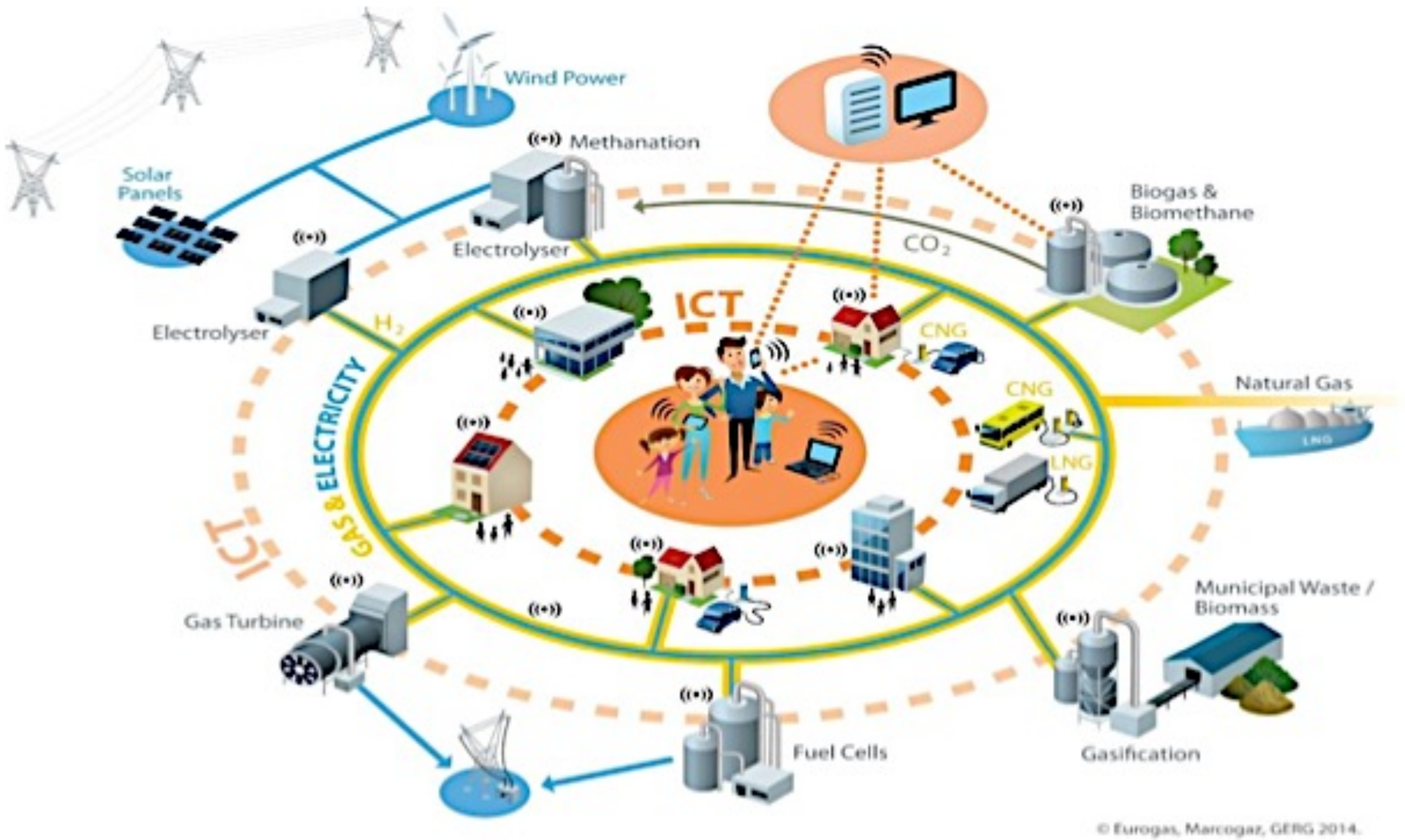
Today → **Tomorrow: CCS, RES, DG and hydrogen storage, smartgrids**



Source: EC, 2007

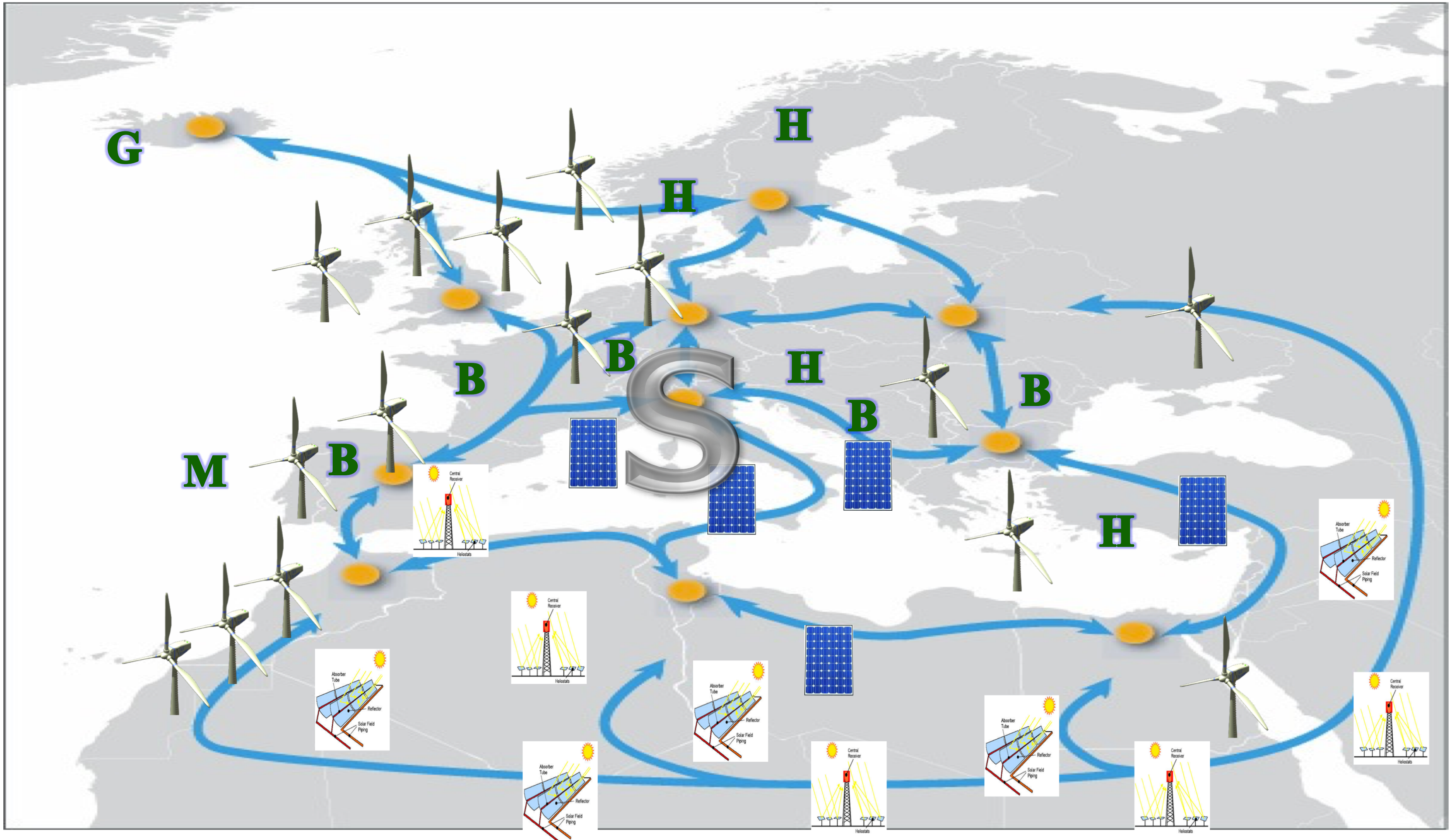
End goal – the smart future

ρυθμιστική αρχή ενέργειας κύπρου
cyprus energy regulatory authority



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

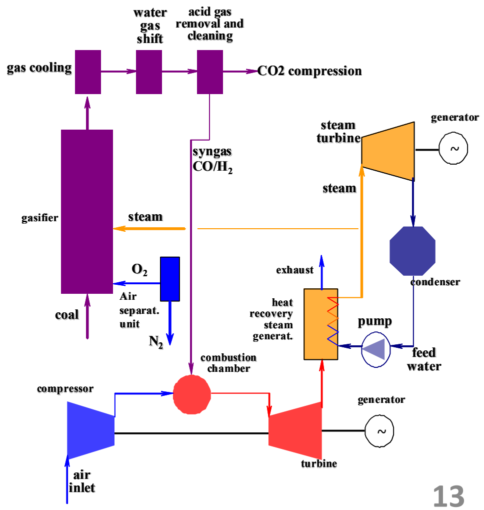
ρυθμιστική αρχή ενέργειας κύπρου
cyprus energy regulatory authority



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

Long term EU energy strategy (2050)

- A vision of 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

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

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

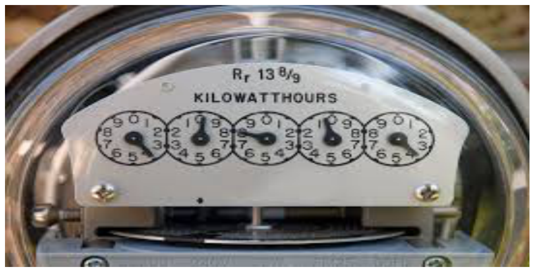
Electricity market functions

- **Generation** (competition)

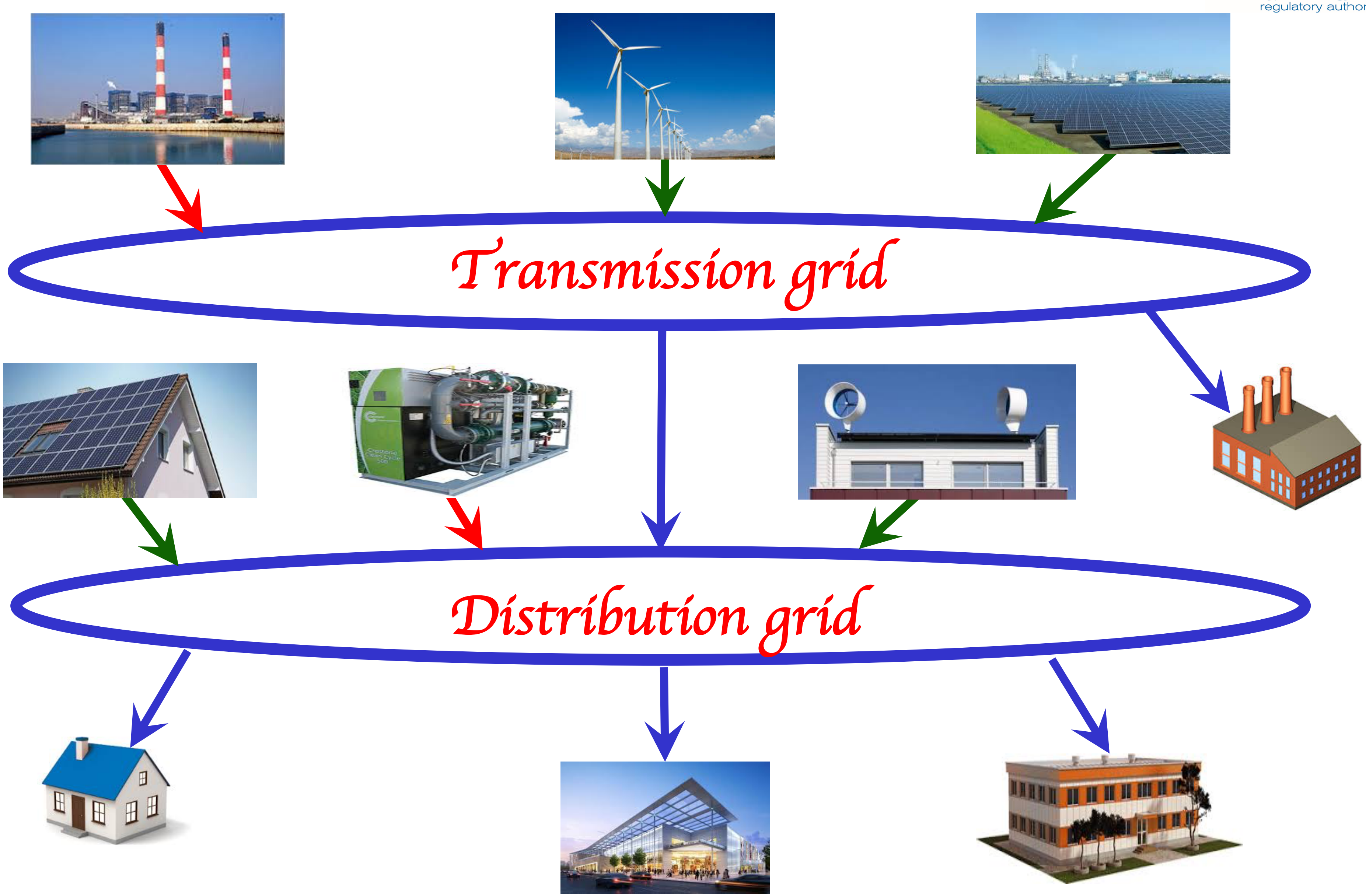
- **Transmission** (monopoly)

- **Distribution** (monopoly)

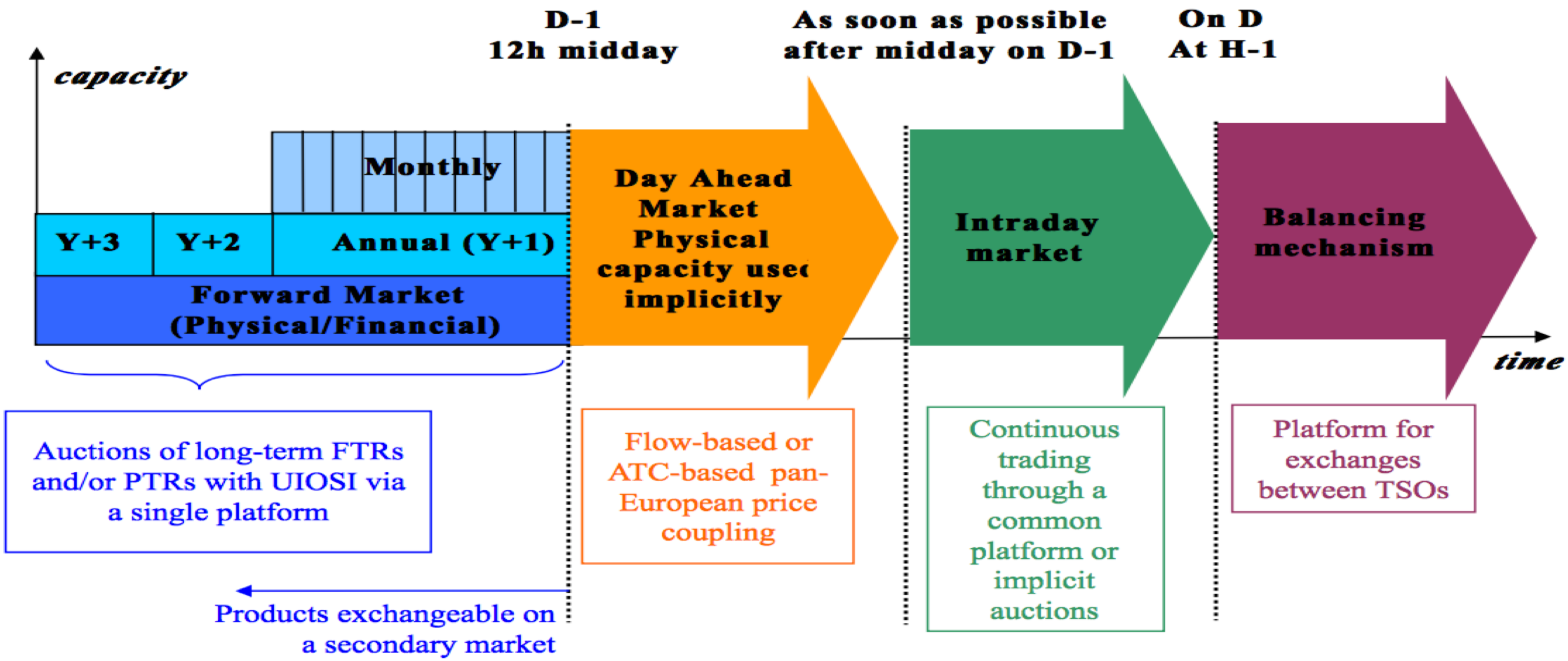
- **Supply** (competition)



Competition *vs* monopoly

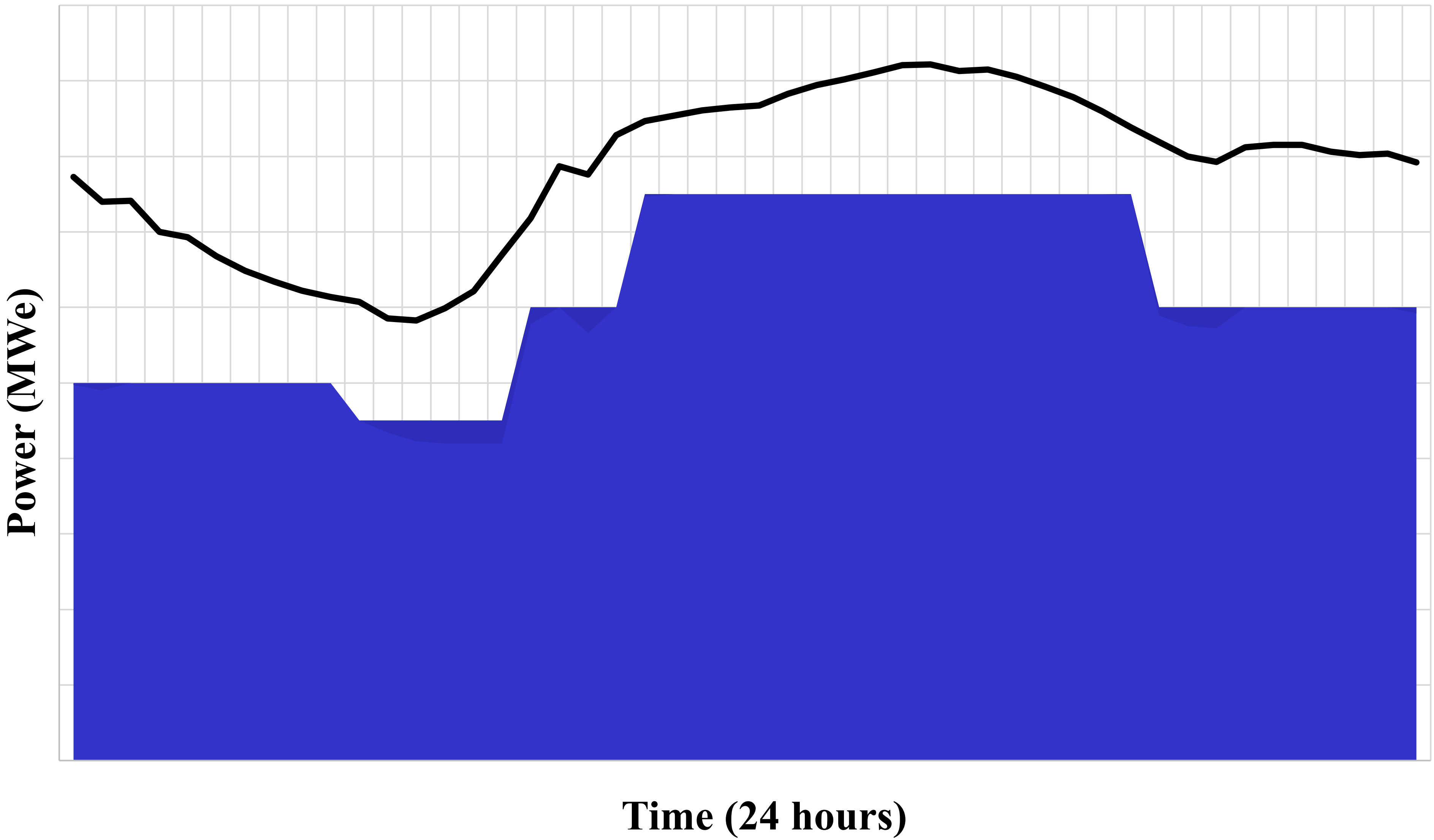


EU electricity market target model



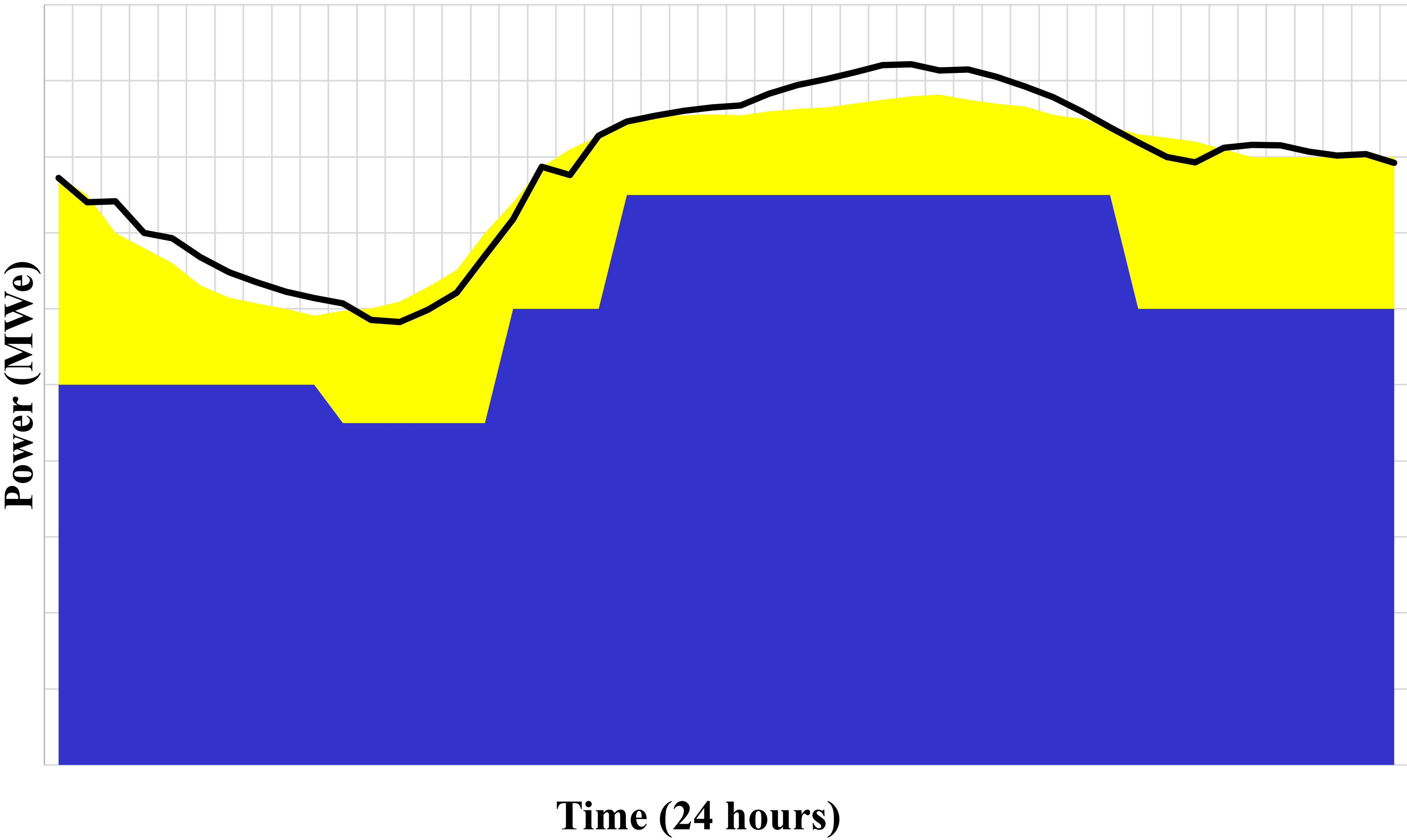
Electricity market operation

- **Forward market**



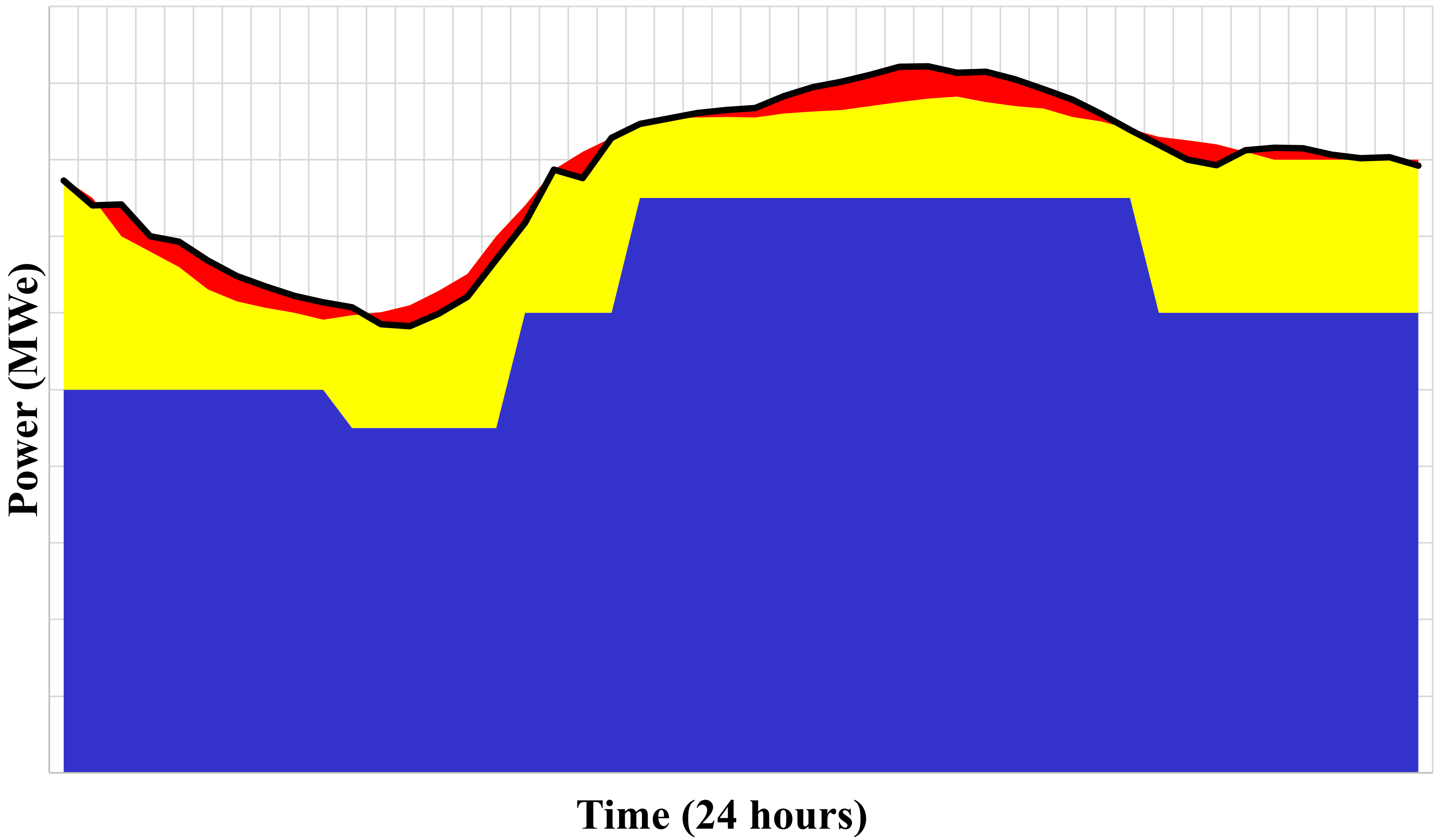
Electricity market operation

- **Forward market + Day ahead market**



Electricity market operation

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



Modeling for optimum large scale integration of RES

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
- Cost or benefit in the cost of electricity
- Price of feed in tariffs
- Green tax

Important factors

- **Fuel avoidance cost:** by increasing RES-E penetration fuel consumption reduced
- **CO_2 avoidance cost:** by increasing RES-E penetration CO_2 emissions reduced
- **Conventional power system operating cost:** by increasing RES-E penetration the conventional power system operating cost is increased due to the increased requirements of conventional reserve capacity

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

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

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

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

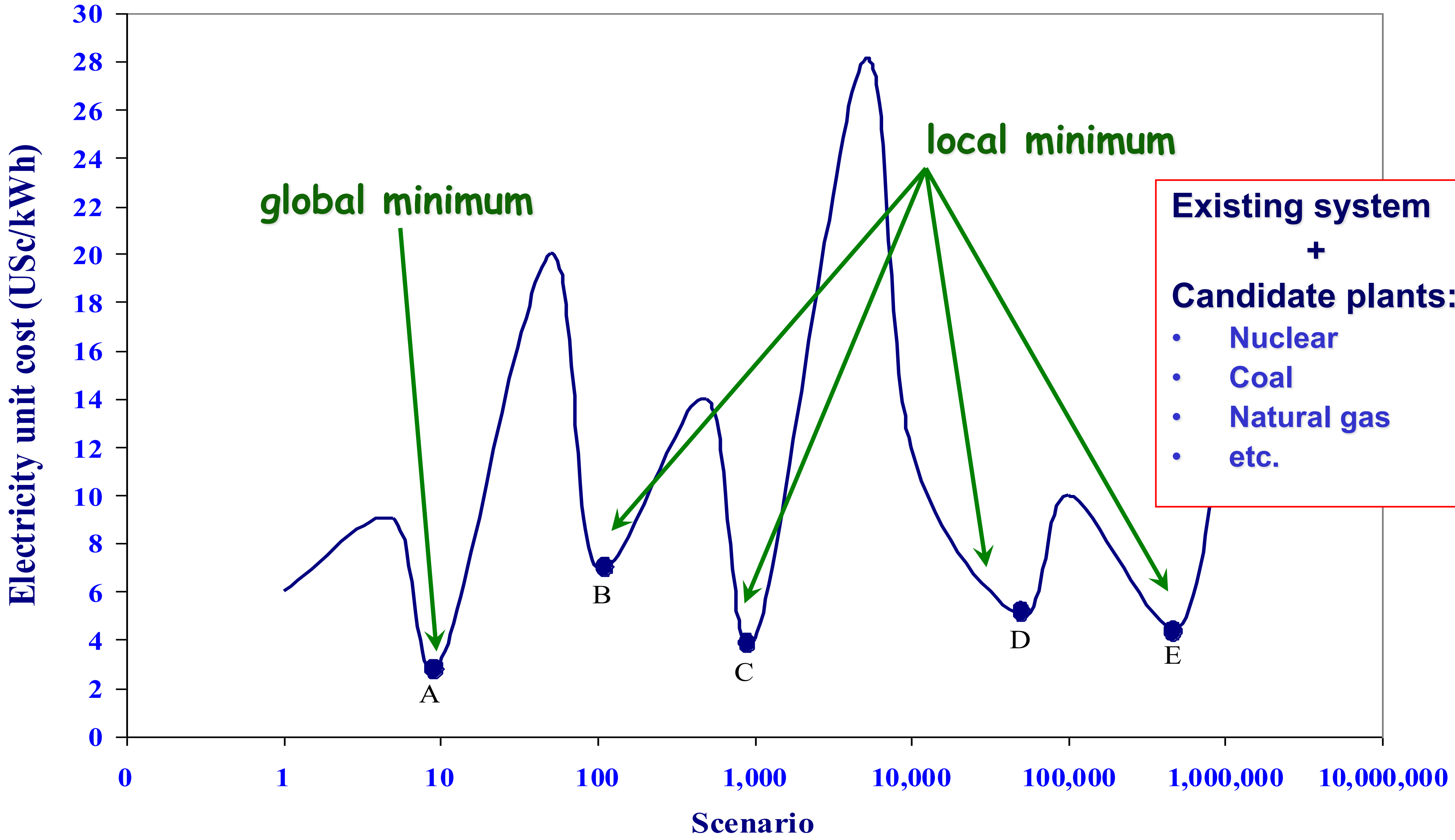
$$R_{S(t)} \le \sum_i r_{s(i,t)} I_{(i,t)} \qquad r_{s(i,t)} = \min\left[10MSR_i , P_{g,\max(i)} - P_{(i,t)}\right]$$

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

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

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

Typical shape of objective function*



Existing system

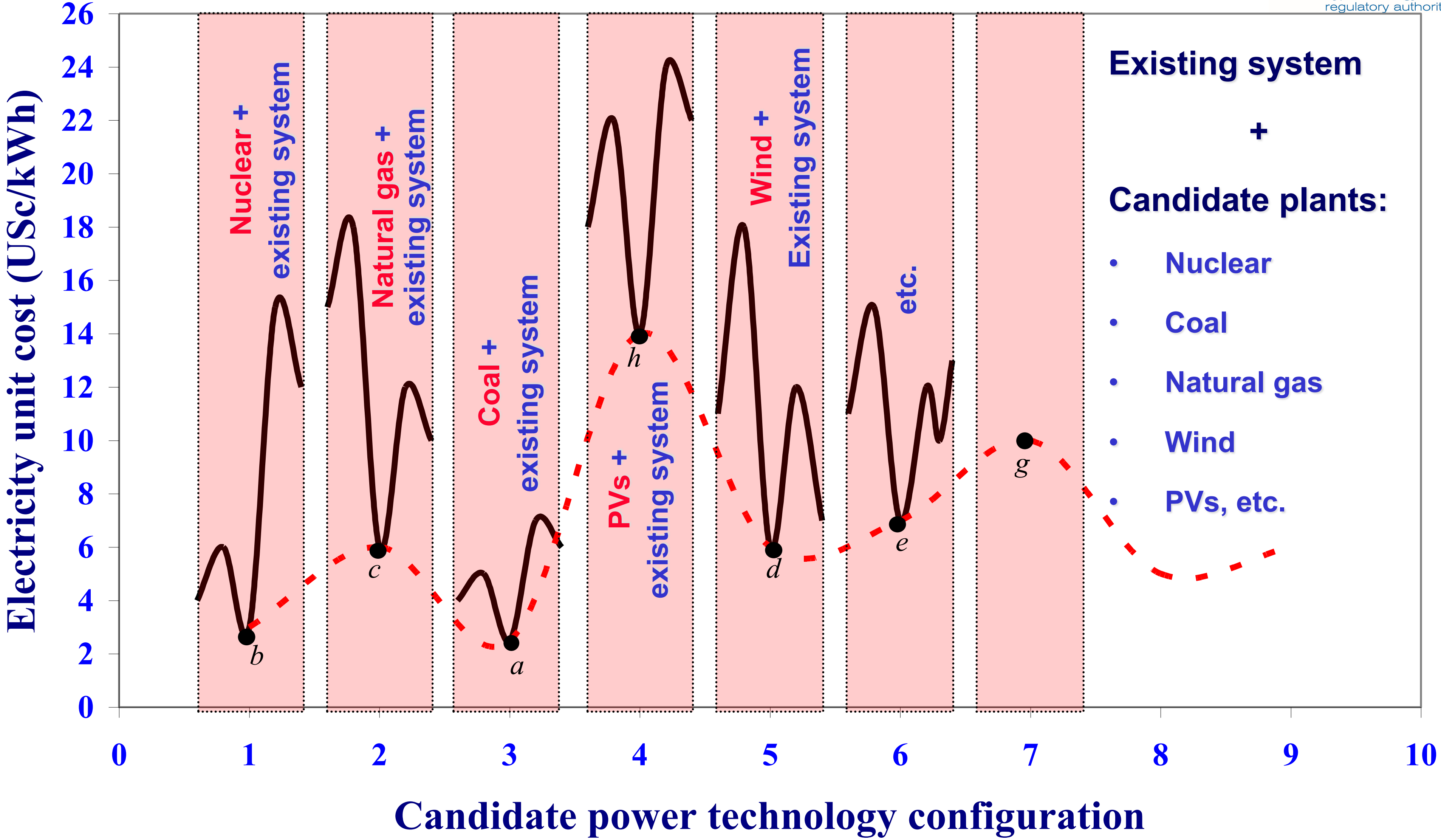
+

Candidate plants:

- Nuclear
- Coal
- Natural gas
- etc.

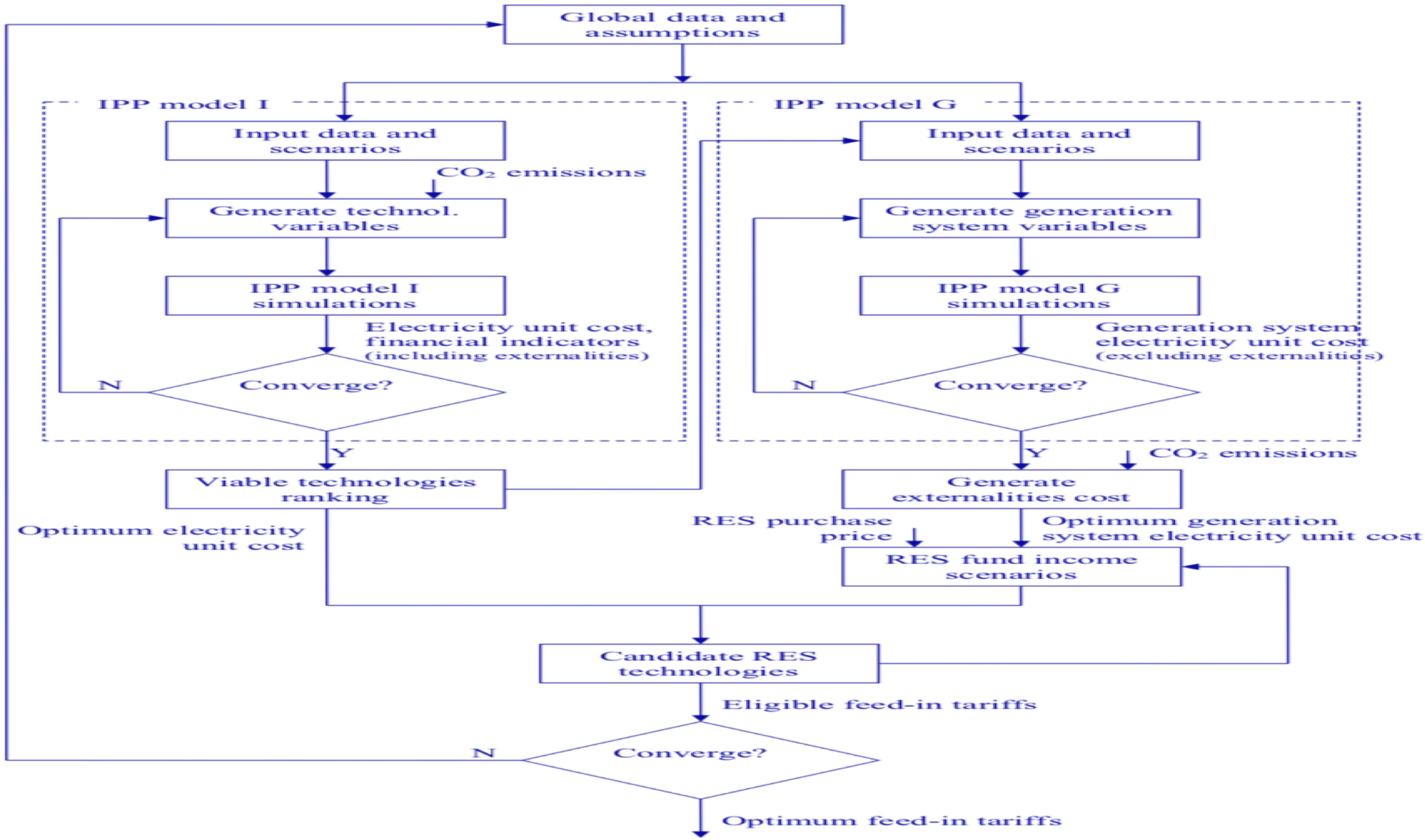
* Poullikkas A., 2009, "A decouple optimization method for power technology selection in competitive markets", *Energy Sources.*

Decouple optimization technique*



* 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*.

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.

Primary objective functions*

- **Capital cost function***

Annual capital cost ($) · Capacity (MW) · Specific capital cost ($/kW) · Loan interest (%) · Inflation (%)

$$\frac{\partial C_{Cj}}{\partial k} = q_j (1+m)^j (1+r)^{j-1} \frac{\partial E}{\partial k} \frac{\partial C_{SCj}}{\partial k}$$

- **Fuel cost function***

Annual fuel cost ($) · Capacity (MW) · Loading factor (%) · Specific fuel cost ($/t) · Efficiency (%) · Calorific value (kJ/kg)

$$\frac{\partial C_{Fj}}{\partial k} = Z_1 \frac{\partial}{\partial k}\left(\frac{E \times LF_j \times F_j}{\eta \times CV}\right)$$

- **Fixed O&M cost function***

Annual fixed O&M cost ($) · Loading factor (%) · Monthly specific fixed O&M cost ($/kW) · Inflation (%)

$$\frac{\partial C_{OMFj}}{\partial k} = Z_2 (1+r)^{j-1} \frac{\partial E}{\partial k} \frac{\partial O_{MF}}{\partial k}$$

- **Variable O&M cost function***

Annual variable O&M cost ($) · Capacity (MW) · Loading factor (%) · Variable specific O&M cost ($/kWh) · Inflation (%)

$$\frac{\partial C_{OMVj}}{\partial k} = Z_3 (1+r)^{j-1} \frac{\partial E}{\partial k} \frac{\partial LF_j}{\partial k} \frac{\partial O_{MV}}{\partial k}$$

* Poullikkas A., 2001, "A technology selection algorithm for independent power producers", *The Electricity Journal*.

Environmental indicator functions*

- SO_2, NO_X and dust environmental indicator function

Environmental indicator (g/kWh)

Emission limit value (Nm^3/kg)

Exhaust gases specific volume (Nm^3/kg)

$$\frac{\partial U_{Wj}}{\partial k} = \frac{\frac{\partial FI_j}{\partial k}\frac{\partial S_{Wj}}{\partial k}\frac{\partial G}{\partial k}}{1000}$$

Fuel consumption indicator (kg/kWh)

$$\frac{\partial FI_j}{\partial k} = \frac{\partial}{\partial k}\left(\frac{360}{\eta \times CV}\right)$$

- CO_2 environmental indicator function*

Environmental indicator (g/kWh)

Fuel carbon content (%)

Oxidation factor (%)

$$\frac{\partial U_{CO_2 j}}{\partial k} = \frac{440}{12}\frac{\partial FI_j}{\partial k}\frac{\partial X}{\partial k}\frac{\partial X_o}{\partial k}$$

Fuel consumption indicator (kg/kWh)

$$\frac{\partial FI_j}{\partial k} = \frac{\partial}{\partial k}\left(\frac{360}{\eta \times CV}\right)$$

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

CCS cost functions*

- CO_2 capture cost function

$$CCS_{capture} = \frac{\frac{\partial c}{\partial k} - \frac{\partial c}{\partial (k-1)}}{\frac{\partial \phi}{\partial k}\frac{\partial U_{CO_2}}{\partial k}}$$

- $CCS_{capture}$: CO_2 capture cost (US$/tonne CO_2)
- $\frac{\partial c}{\partial k}$: Electricity unit cost of candidate technology with CCS (USc/kWh)
- $\frac{\partial c}{\partial (k-1)}$: Electricity unit cost of candidate technology without CCS (USc/kWh)
- $\frac{\partial \phi}{\partial k}$: CO_2 capture efficiency (%)
- $\frac{\partial U_{CO_2}}{\partial k}$: CO_2 emissions of candidate technology with CCS (g/kWh)

- CO_2 avoidance cost function

$$CCS_{avoidance} = \frac{\frac{\partial c}{\partial k} - \frac{\partial c}{\partial (k-1)}}{\frac{\partial U_{CO_2}}{\partial (k-1)} - \left[\frac{\partial U_{CO_2}}{\partial k}\left(1 - \frac{\partial \phi}{\partial k}\right)\right]}$$

- $CCS_{avoidance}$: CO_2 avoidance cost (US$/tonne CO_2)
- $\frac{\partial c}{\partial k}$: Electricity unit cost of candidate technology with CCS (USc/kWh)
- $\frac{\partial c}{\partial (k-1)}$: Electricity unit cost of candidate technology without CCS (USc/kWh)
- $\frac{\partial U_{CO_2}}{\partial (k-1)}$: CO_2 emissions of candidate technology without CCS (g/kWh)
- $\frac{\partial U_{CO_2}}{\partial k}$: CO_2 emissions of candidate technology with CCS (g/kWh)
- $\frac{\partial \phi}{\partial k}$: CO_2 capture efficiency (%)

* Poullikkas A., Zueter A.F., Dirar M.H., , 2015, "Prospective scenarios for the adoption of sustainable power generation technologies in United Arab Emirates", *International Journal of Sustainable Energy*

* Hadjipaschalis I., Christou C., Poullikkas A., 2007, "Assessment of future sustainable power technologies with carbon capture and storage", *International Journal of Emerging Electric Power Systems.*

RES cost functions*

ρυθμιστική αρχή ενέργειας κύπρου
cyprus energy regulatory authority

Wind functions*

$$\frac{\partial P}{\partial k} = \sum_{j=1}^{N} \left[\frac{\partial c_p}{\partial k} \frac{\partial n_m}{\partial k} \frac{\partial n_e}{\partial k} \frac{P_w}{\partial k} \right]$$

- Production (kWh)
- Coefficient of performance (%)
- Efficiency (%)
- Wind potential (kW))
- Efficiency (%)

PV functions**

$$\frac{\partial P}{\partial k} = \sum_{j=1}^{N} \left[\frac{\partial I_j}{\partial k} \frac{\partial A}{\partial k} \frac{\partial n}{\partial k} \right]$$

- Production (kWh)
- Solar potential (kWh/m²)
- Efficiency (%)
- Area (m²)

CSP functions***

$$\frac{\partial P}{\partial k} = \sum_{j=1}^{N} \left[\frac{\partial I_j}{\partial k} \frac{\partial A}{\partial k} \frac{\partial n_a}{\partial k} \frac{\partial n_s}{\partial k} \right]$$

- Production (kWh)
- Solar potential (kWh/m²)
- Efficiency (%)
- Area (m²)

* Al-Tajer Y., Poullikkas A., 2015, "Parametric analysis for the implementation of wind power in United Arab Emirates", *Renewable and Sustainable Energy Reviews*

** Poullikkas A., 2013, "A comparative assessment of net metering and feed-in tariff schemes for residential PV systems", *Sustainable Energy Technologies and Assessments*

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

Minimisation procedure*

Set of equations*

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

- 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*.

Sustainable energy strategies for UAE

Main objective

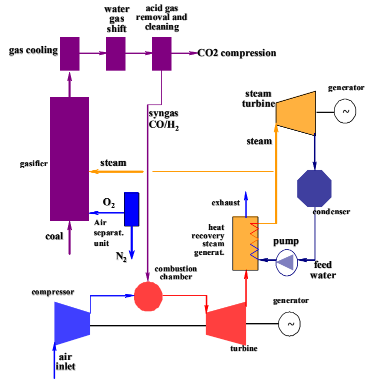
Investigate the viability of

sustainable technologies

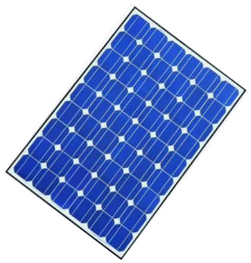
for power generation in UAE

Sustainable power generation technologies considered

- **250MWe natural gas combined cycle technology with**
  - **post-combustion CCS**
  - **pre-combustion CCS**

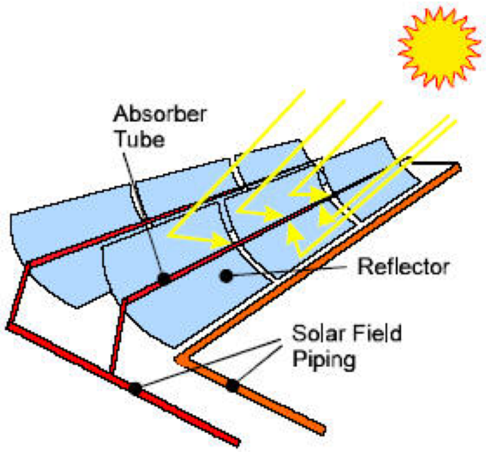


- **50MWp PV systems**

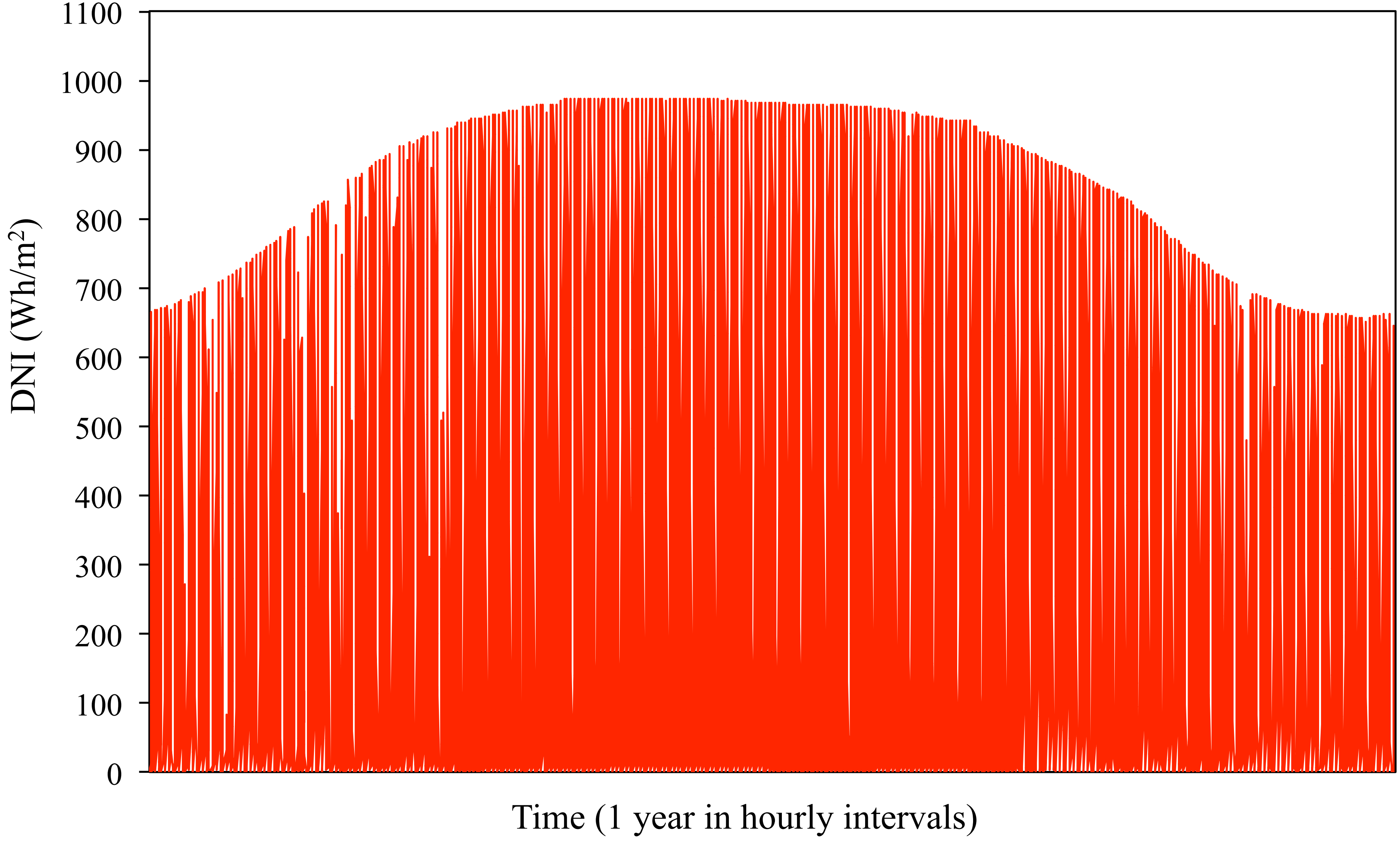


- **50MW wind parks**

- **50MWe parabolic trough CSP technology with**
  - **no thermal storage**
  - **4.5h thermal storage**
  - **9.5h thermal storage**
  - **14.5h thermal storage**
  - **24/7 operation**

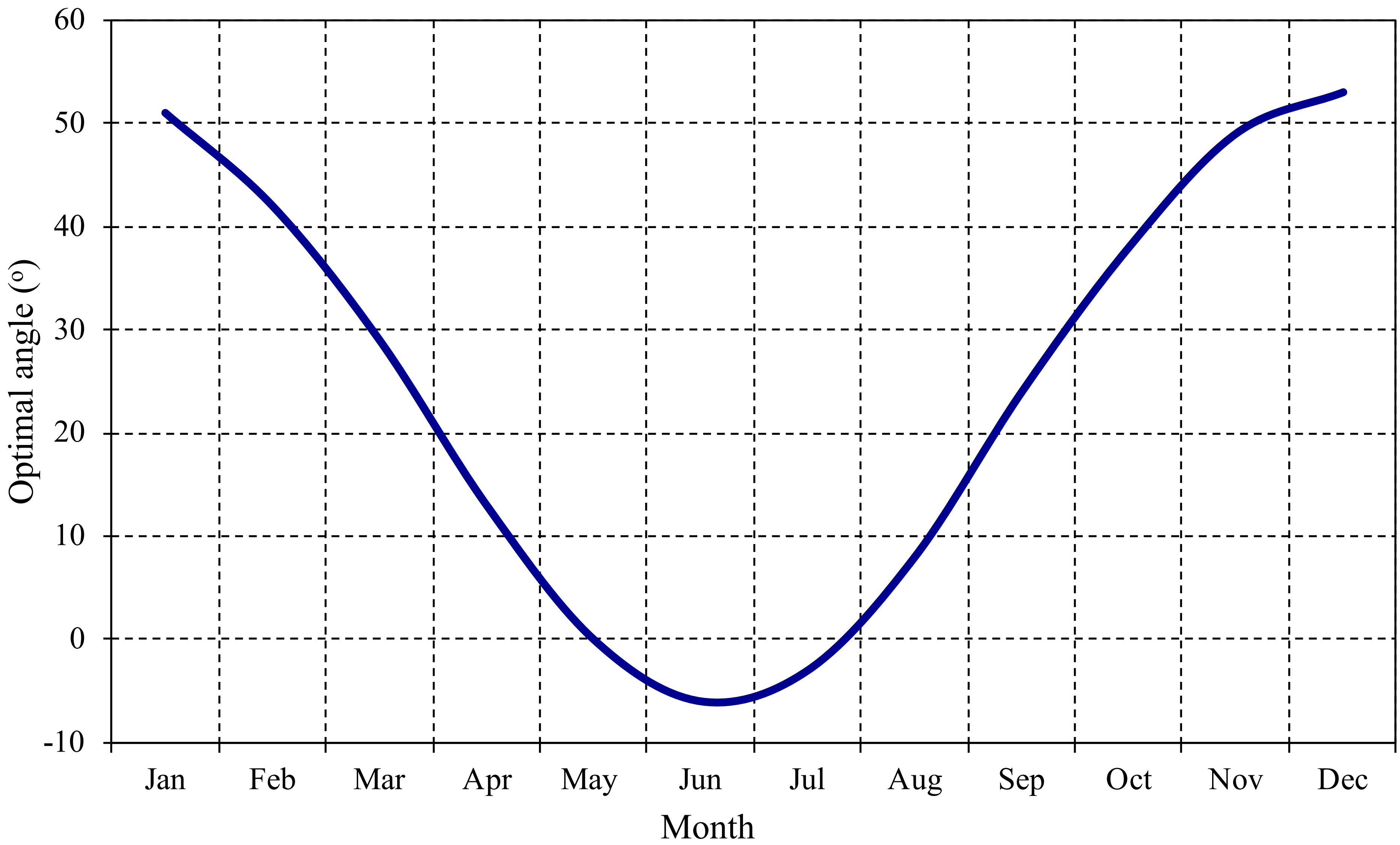


Annual solar potential* (2106kWh/m²)



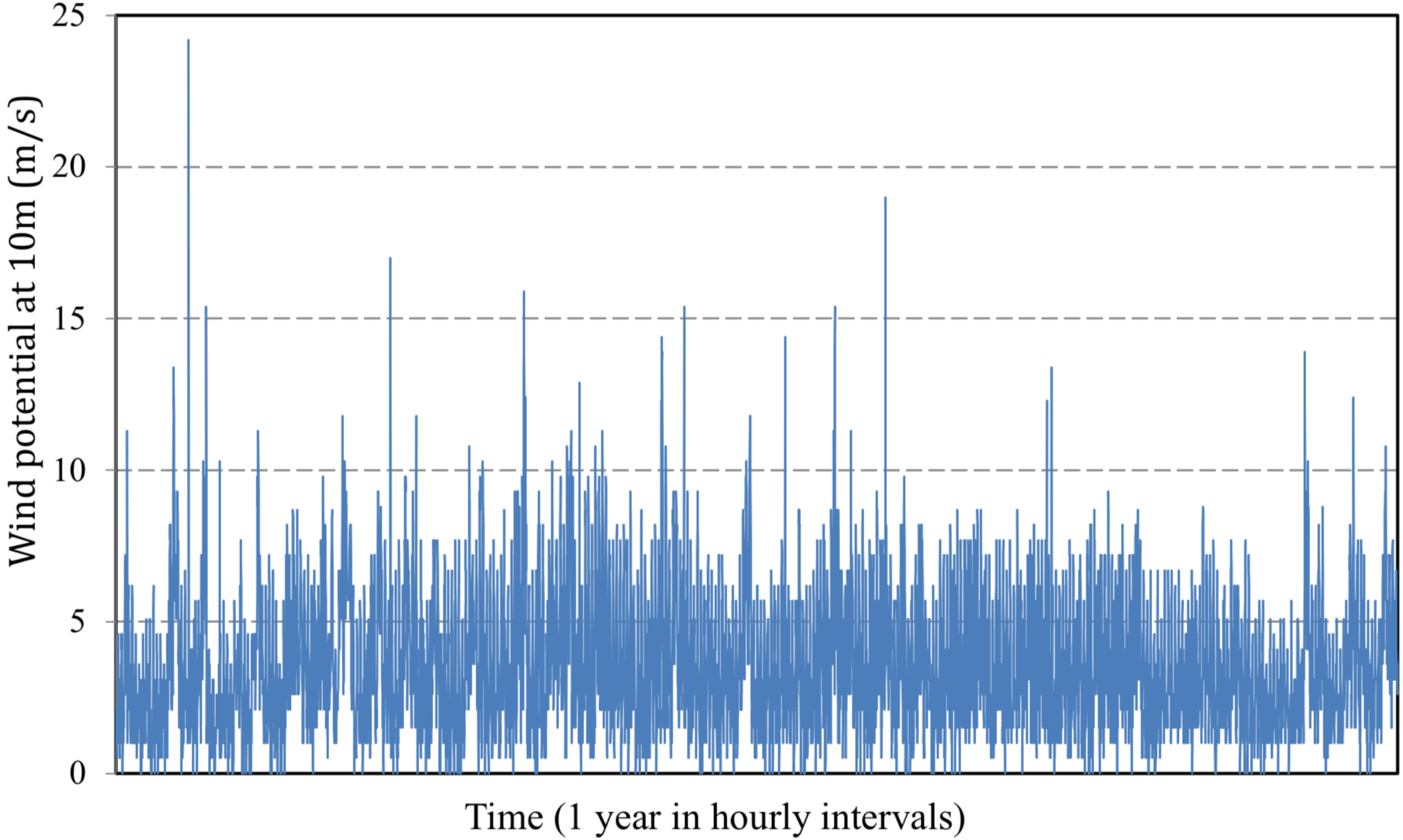
* **Poullikkas A., Gadalla M., 2013, "Assessment of solar electricity production in United Arab Emirates", *International Journal of Sustainable Energy***

Monthly optimal solar angle*



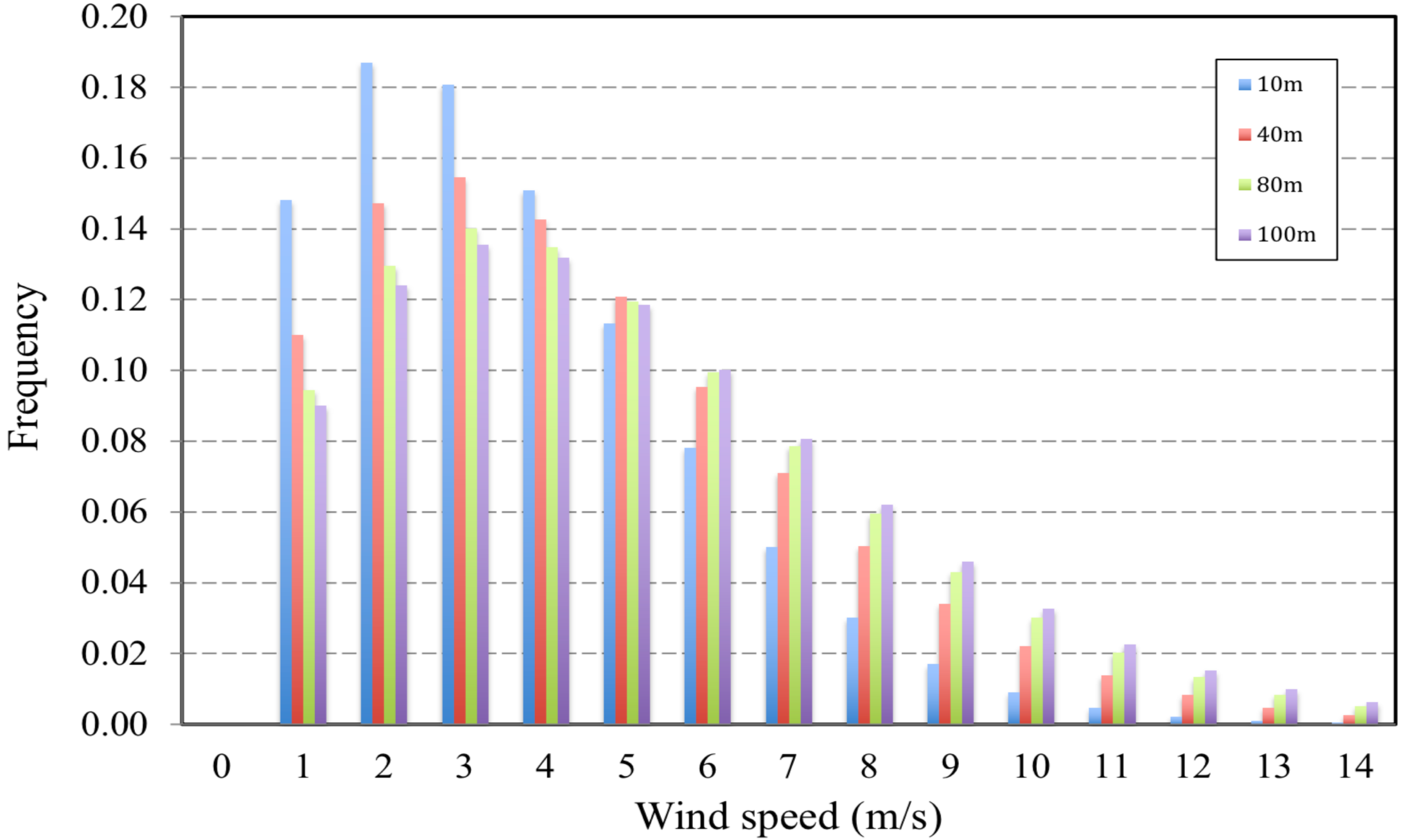
* **Poullikkas A., Gadalla M., 2013, "Assessment of solar electricity production in United Arab Emirates", *International Journal of Sustainable Energy***

Hourly wind potential for the year of 2011*



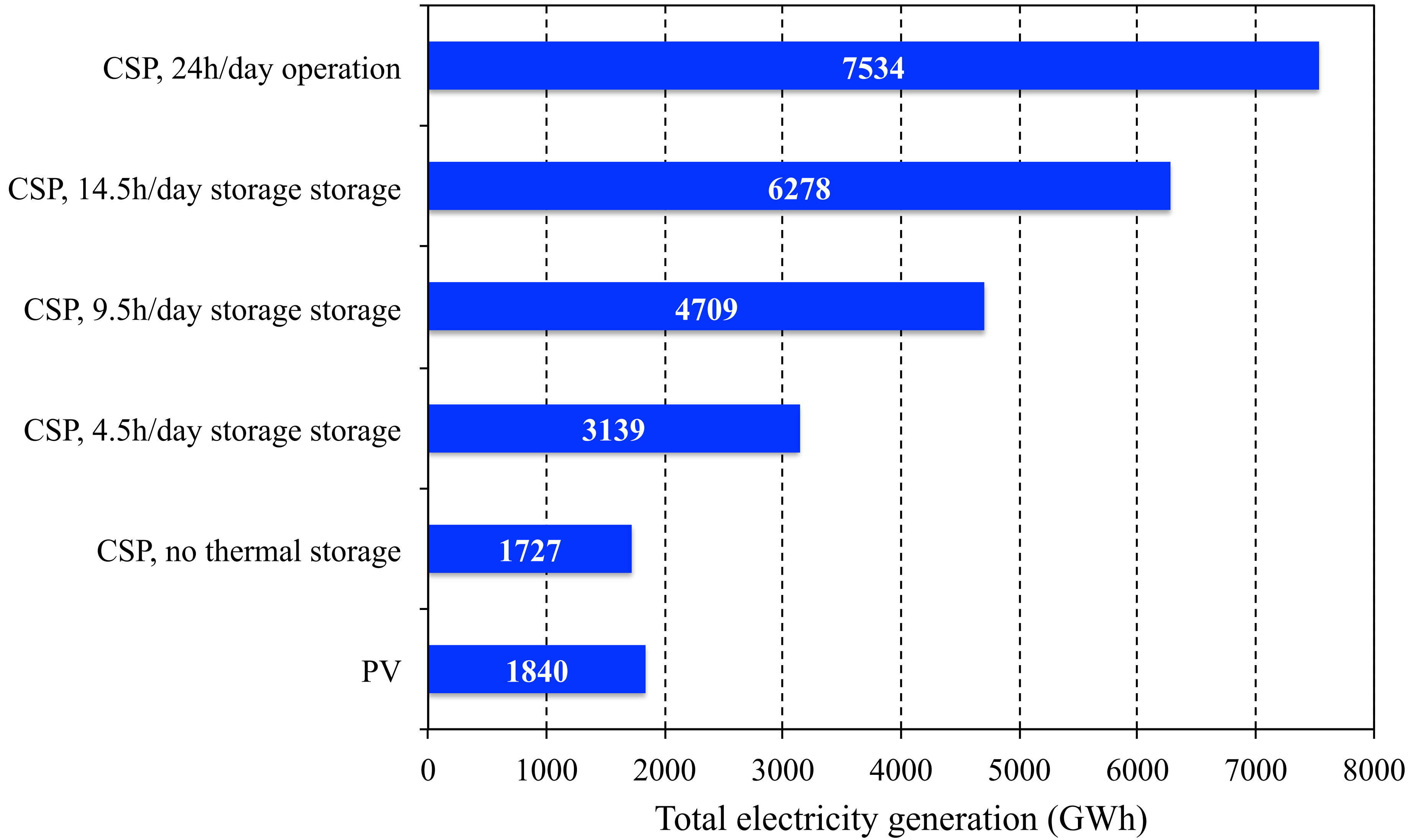
* Al-Tajer Y., Poullikkas A., 2015, "Parametric analysis for the implementation of wind power in United Arab Emirates", *Renewable and Sustainable Energy Reviews*

Weibull curve distribution at different hub heights*



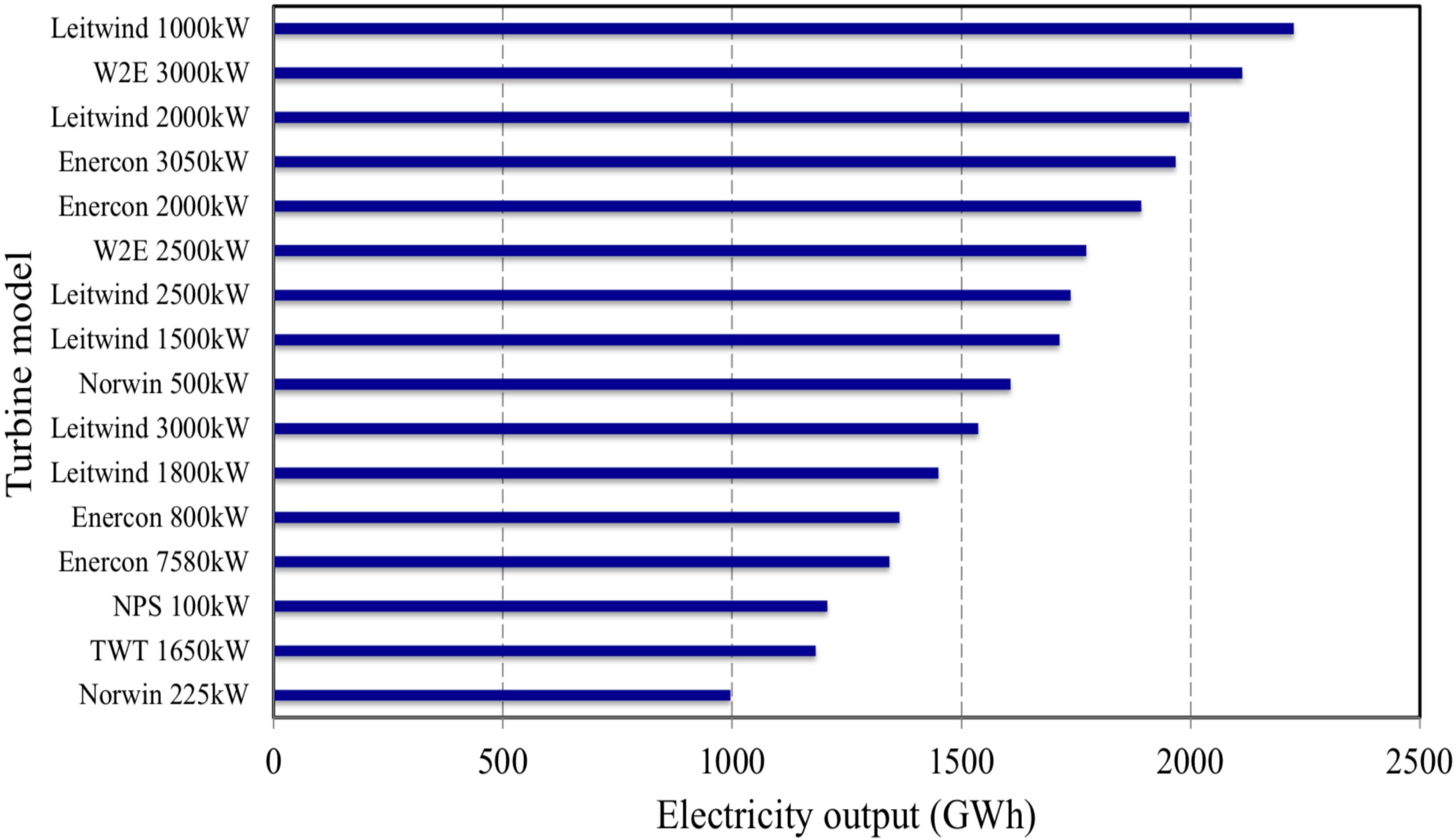
* **Al-Tajer Y., Poullikkas A., 2015, “Parametric analysis for the implementation of wind power in United Arab Emirates”, *Renewable and Sustainable Energy Reviews***

Total electricity generation for 50MW (20y)*



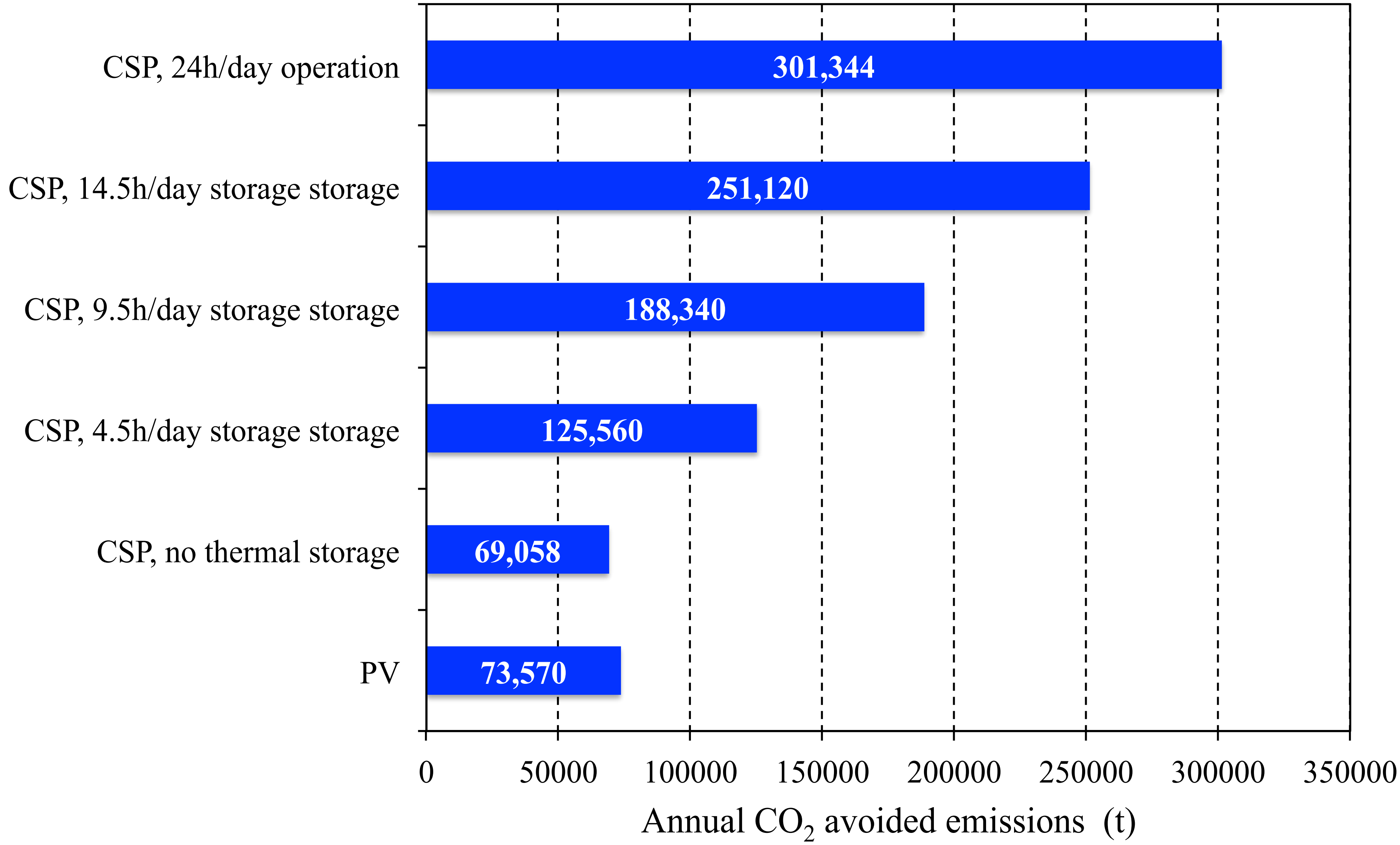
* **Poullikkas A., Gadalla M., 2013, "Assessment of solar electricity production in United Arab Emirates", *International Journal of Sustainable Energy***

Total electricity production for 20 years for 50MW wind parks*



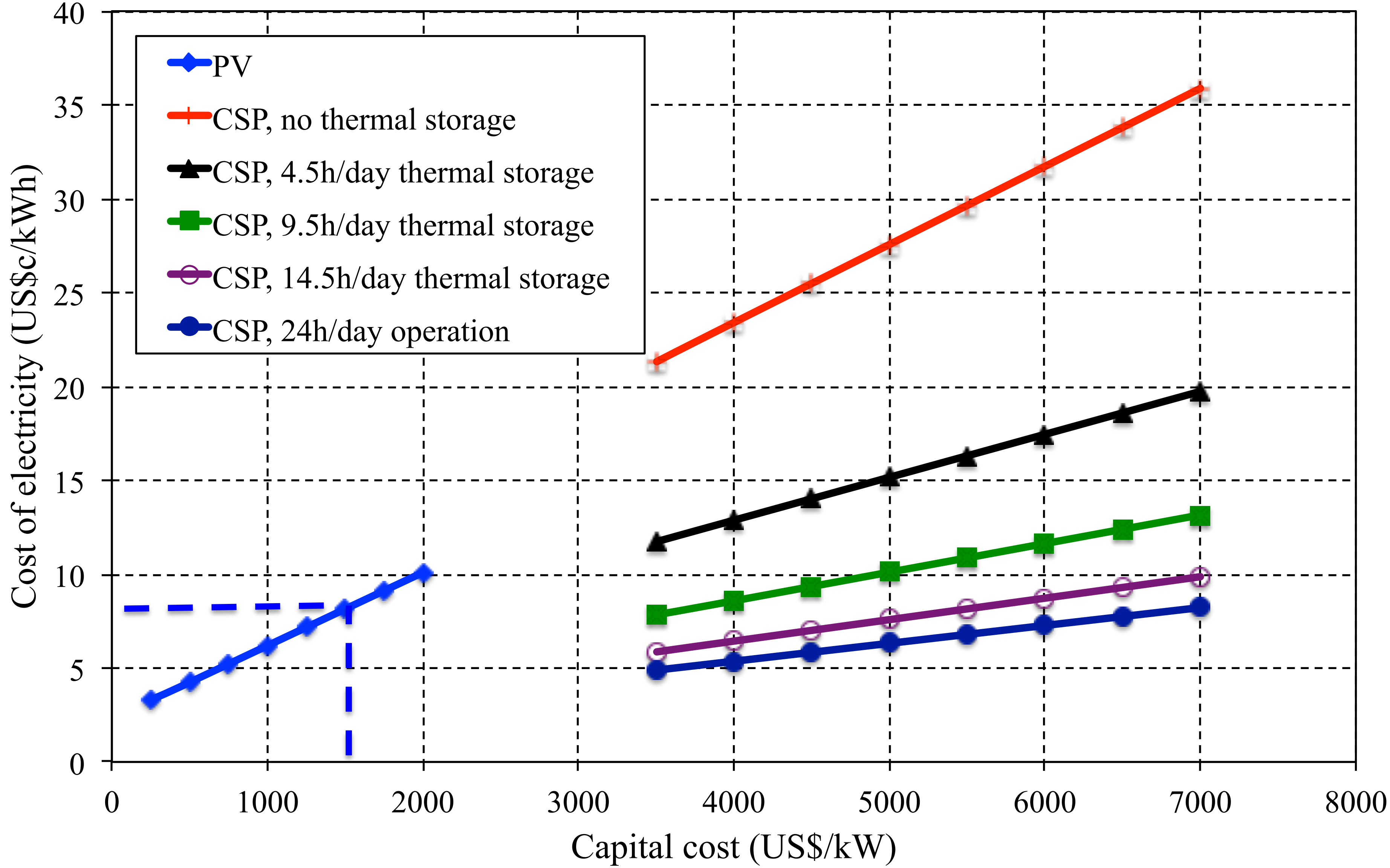
* Al-Tajer Y., Poullikkas A., 2015, "Parametric analysis for the implementation of wind power in United Arab Emirates", *Renewable and Sustainable Energy Reviews*

Annual CO2 avoided emissions*



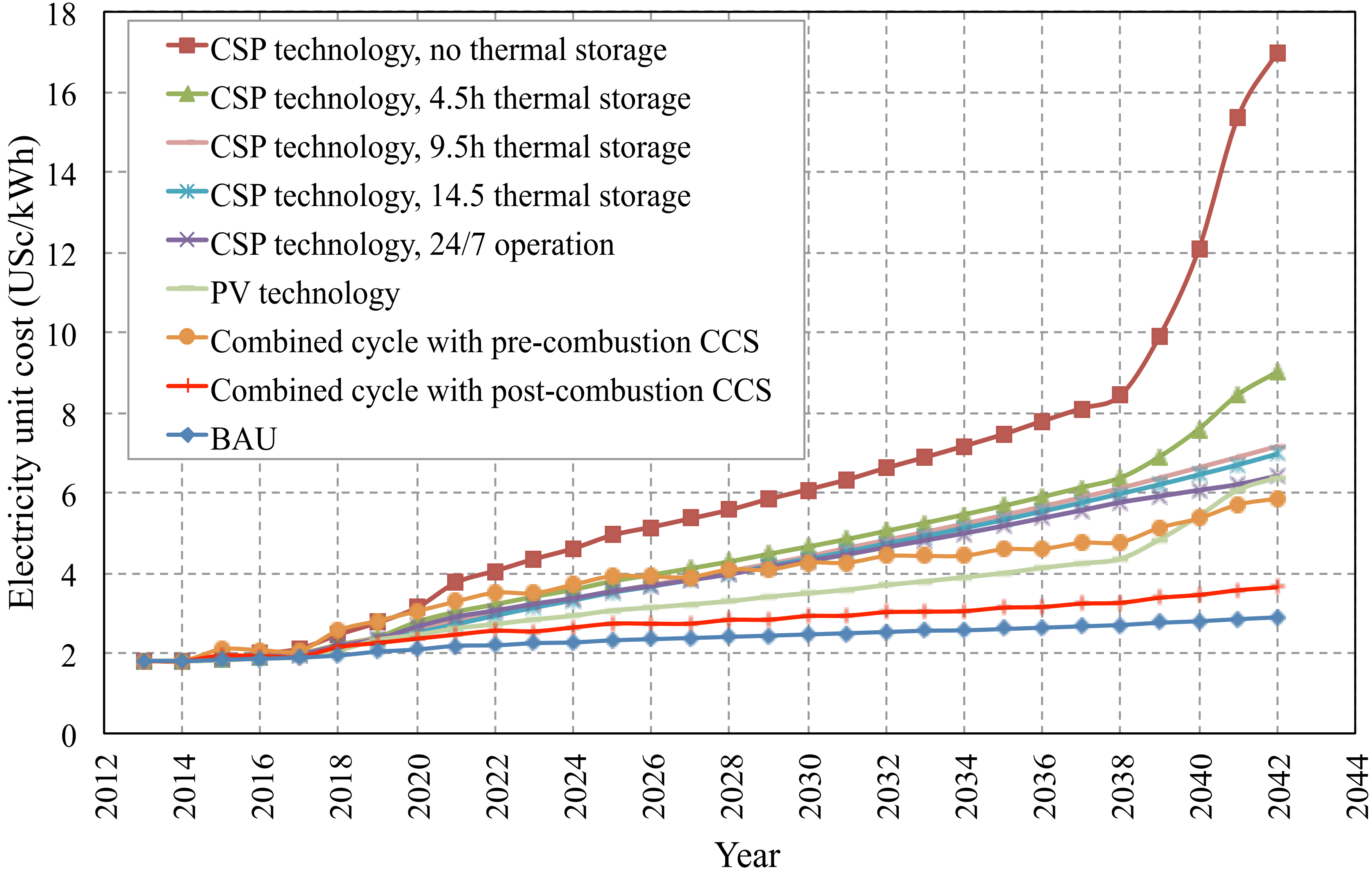
* **Poullikkas A., Gadalla M., 2013, "Assessment of solar electricity production in United Arab Emirates", *International Journal of Sustainable Energy***

Cost of electricity parametric curves*



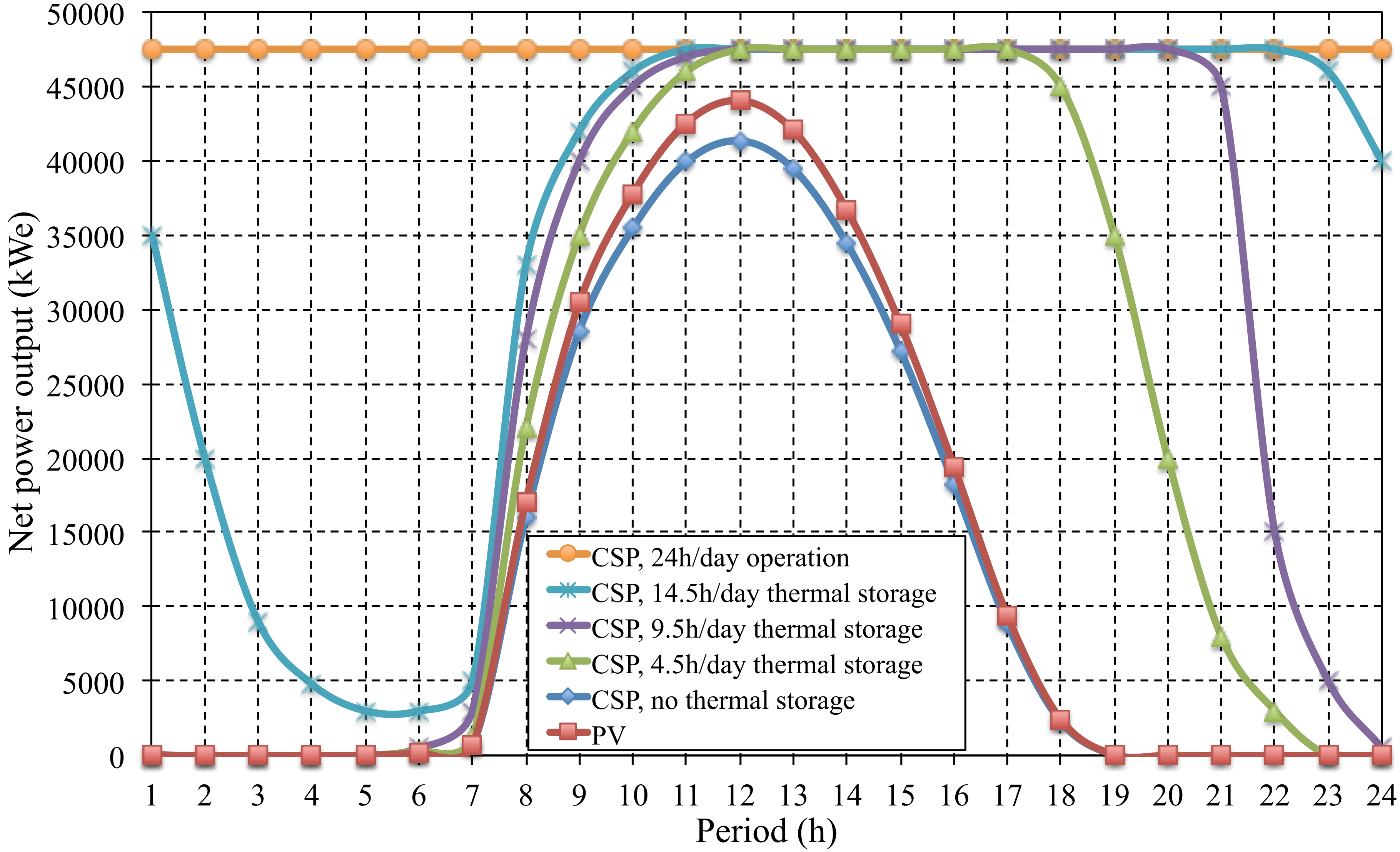
* Poullikkas A., Zueter A.F., Dirar M.H., 2014, "Prospective scenarios for the adoption of sustainable power generation technologies in United Arab Emirates", *International Journal of Sustainable Energy*.

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



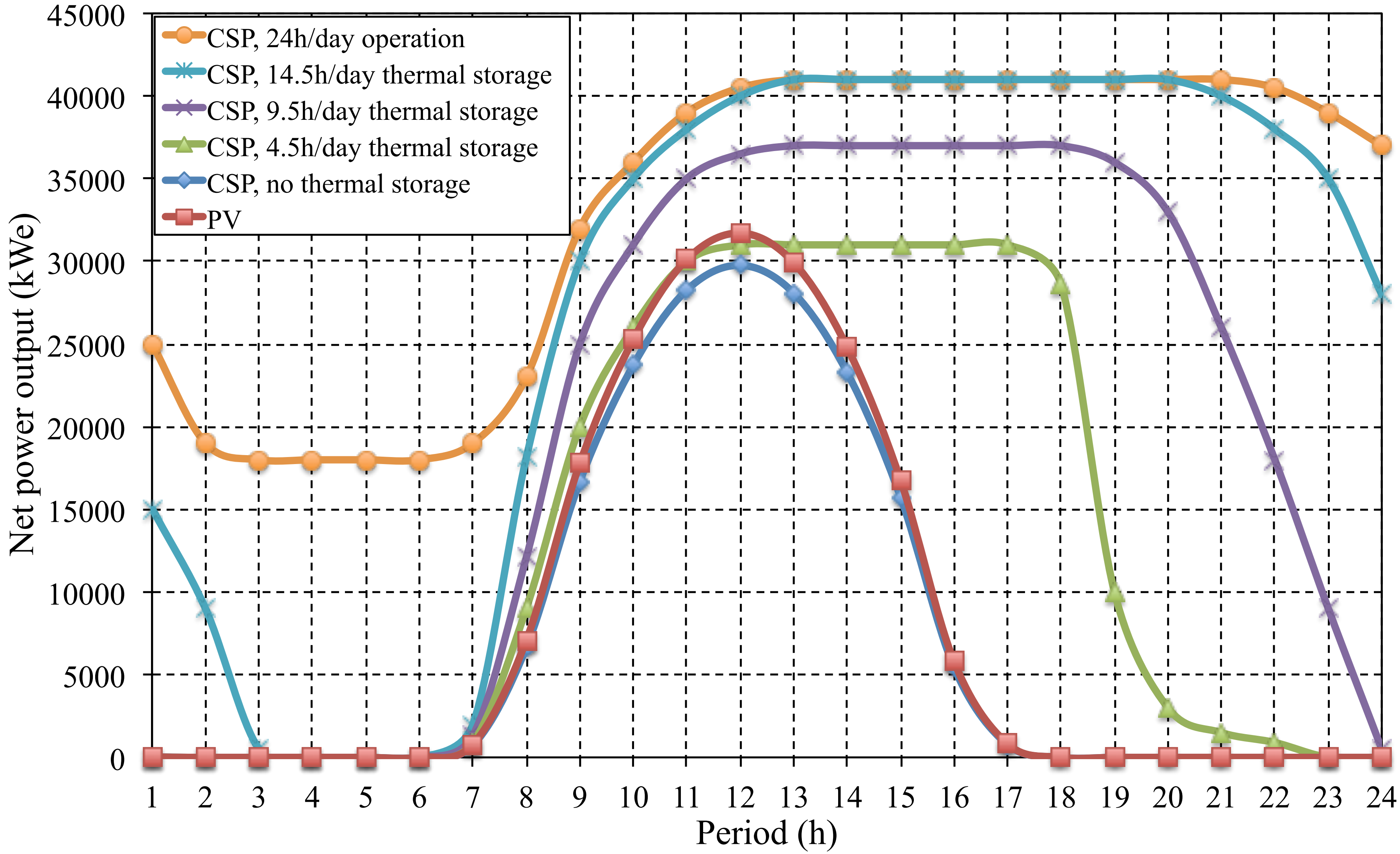
* **Poullikkas A., Zueter A.F., Dirar M.H., 2014, "Prospective scenarios for the adoption of sustainable power generation technologies in United Arab Emirates",** ***International Journal of Sustainable Energy*****.**

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***

Next steps

First steps towards the development of UAE sustainable energy strategy

- **Horizon up to 2060**
- **Integration of sustainable technologies***
- **Use of net-metering for domestic PV systems****
- **Use of auctioning schemes for new power capacity**
- **Use of hydrogen after 2030**
- **Hydrogen production*****
  - **Nuclear power**
  - **Solar technologies**

* Poullikkas A., Zueter A.F., Dirar M.H., , 2015, "Prospective scenarios for the adoption of sustainable power generation technologies in United Arab Emirates", *International Journal of Sustainable Energy*

** Poullikkas A., 2013, "A comparative assessment of net metering and feed-in tariff schemes for residential PV systems", *Sustainable Energy Technologies and Assessments*

***Babu B.S., Orhan M., Poullikkas A., 2013, "Mitigation of Environmental Impact via an Integrated Hydrogen production system based on solar and nuclear energy sources in U.A.E.", *Proceedings of the 4th International Conference on Renewable Energy and Sources and Energy Efficiency*