Τα Μελλοντικά Αειφόρα Ενεργειακά Συστήματα

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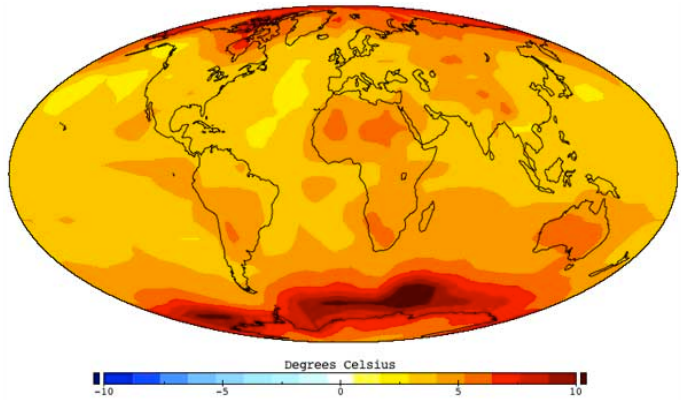
- Long term strategies towards 2050
- Medium term strategies towards 2030
- Short term strategies towards 2020

Long term strategies Towards 2050

Future energy systems

- **Climate change**



- **Third industrial revolution**

- **Future energy economics**

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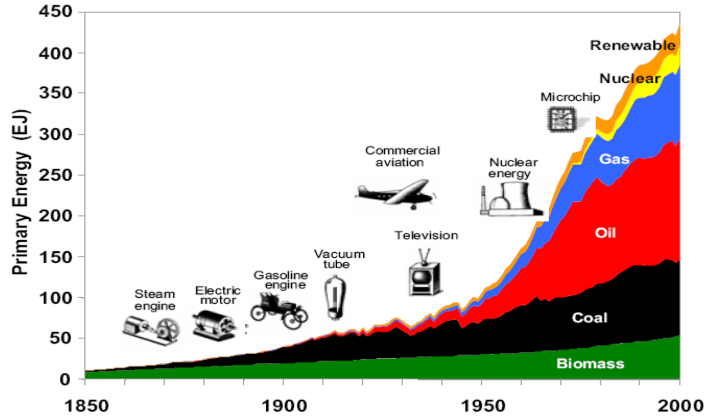
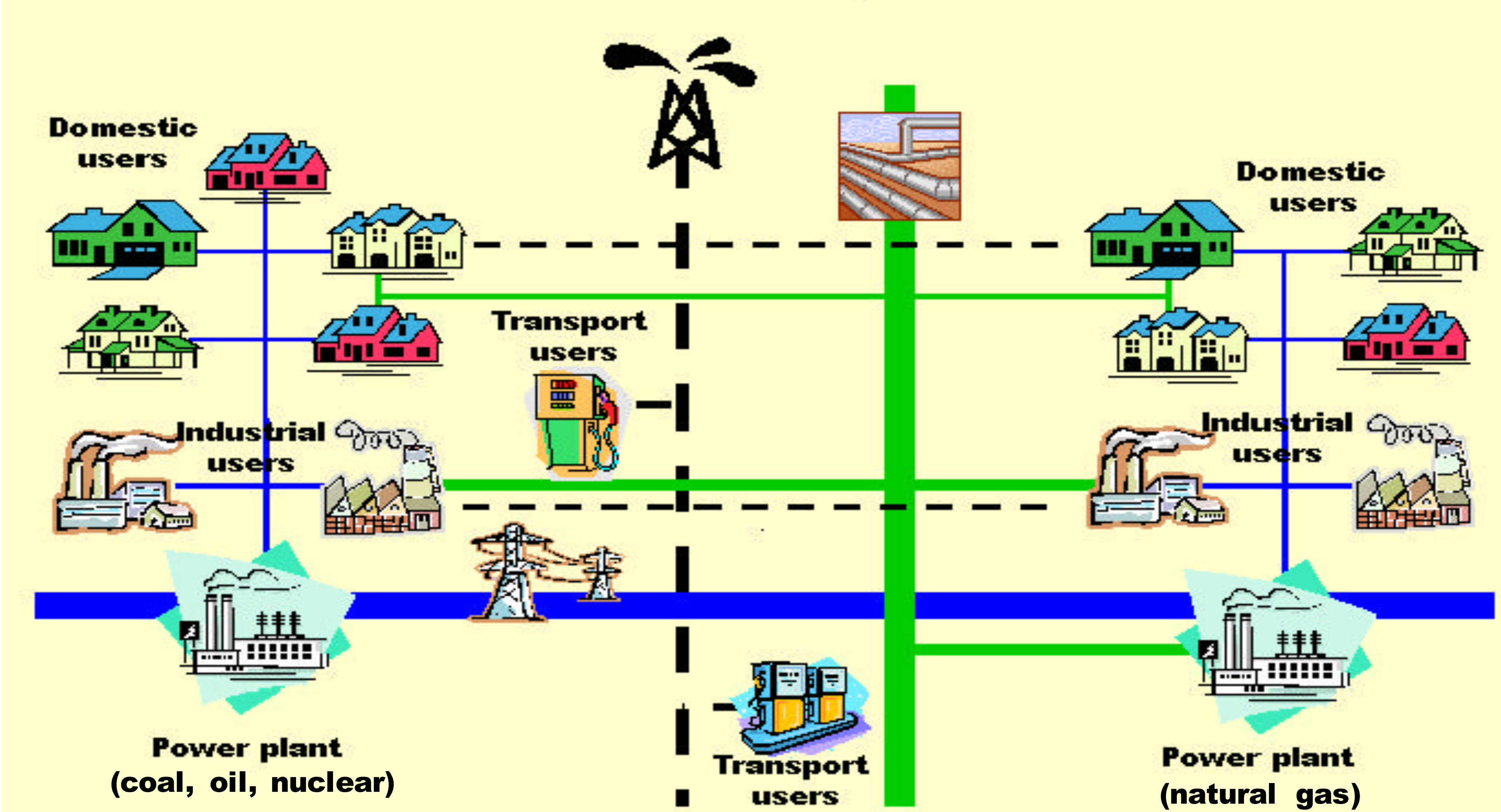
EU energy objectives

- greenhouse gas reduction
- sustainable production and consumption
- security of supply



Future energy systems

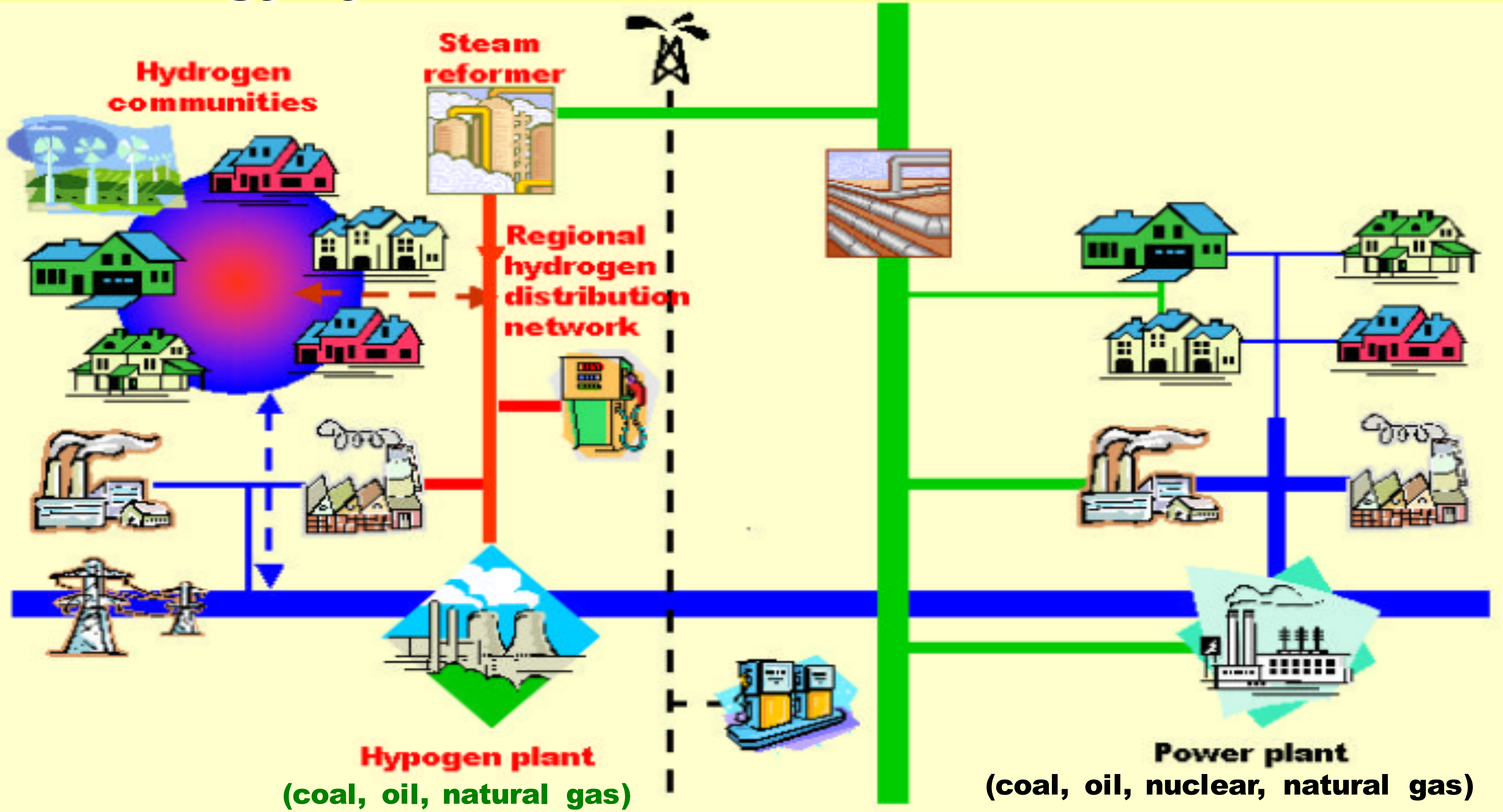
EU energy system today*



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

Future energy systems

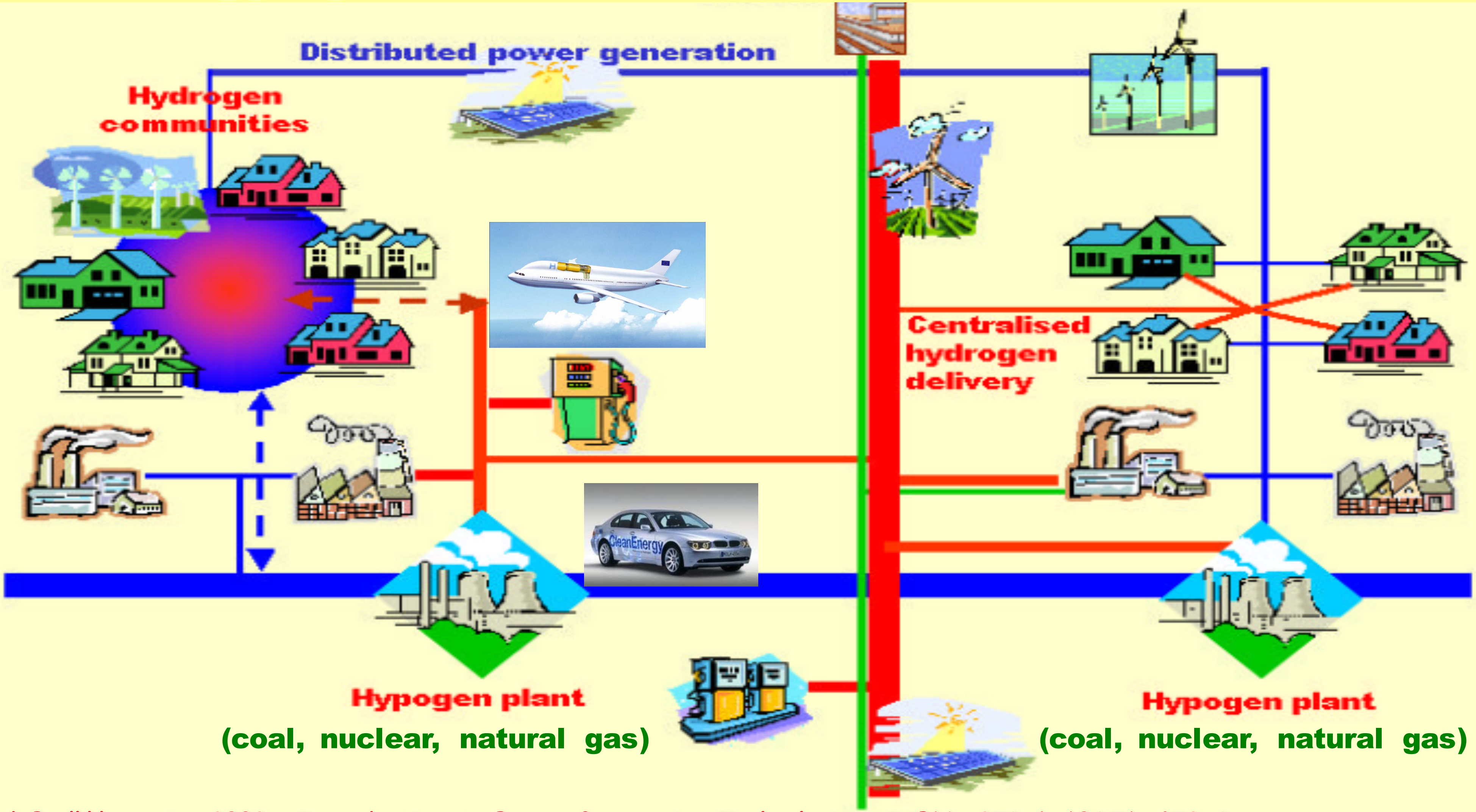
EU energy system in 2020-30*



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

Future energy systems

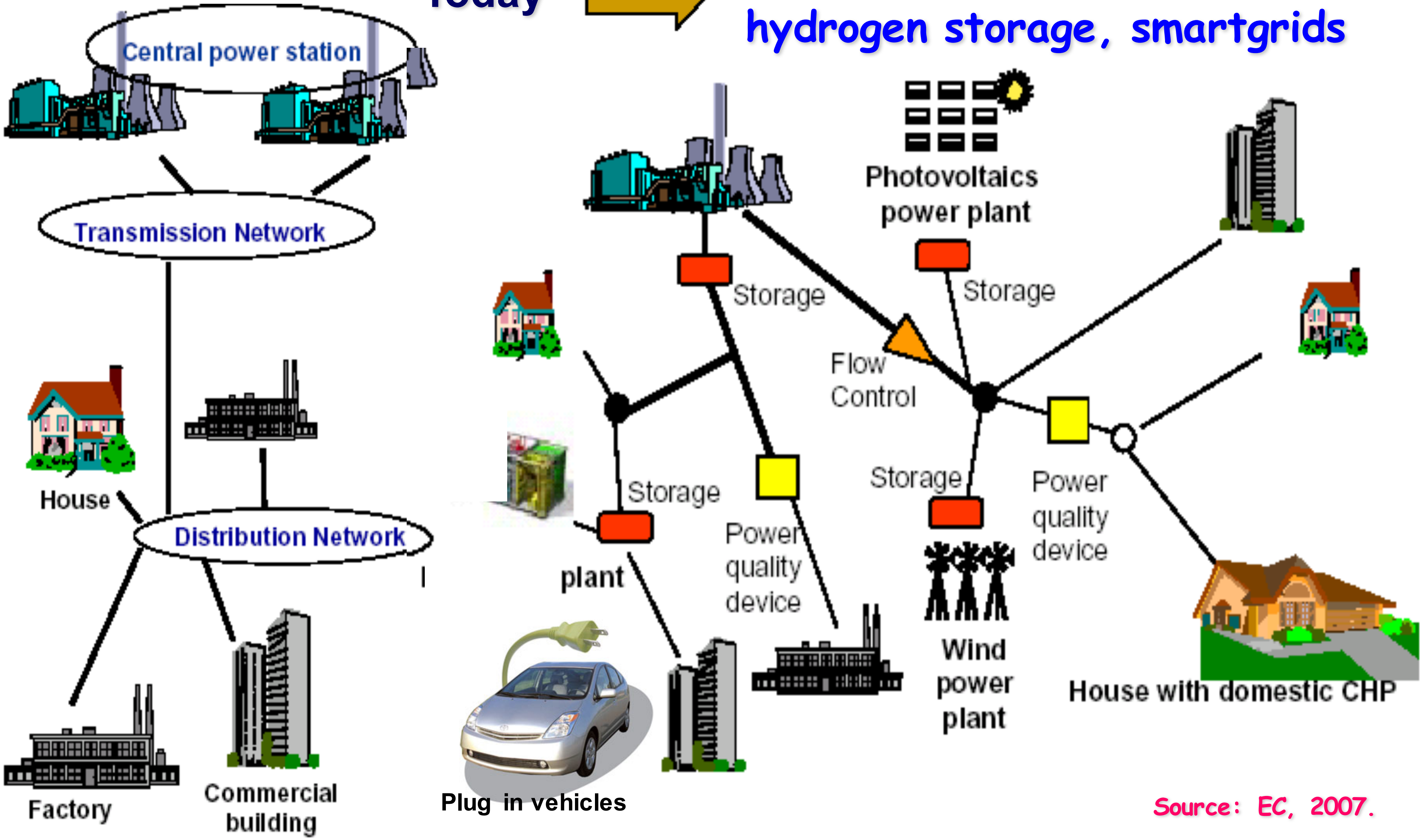
EU energy system in 2040-50*



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

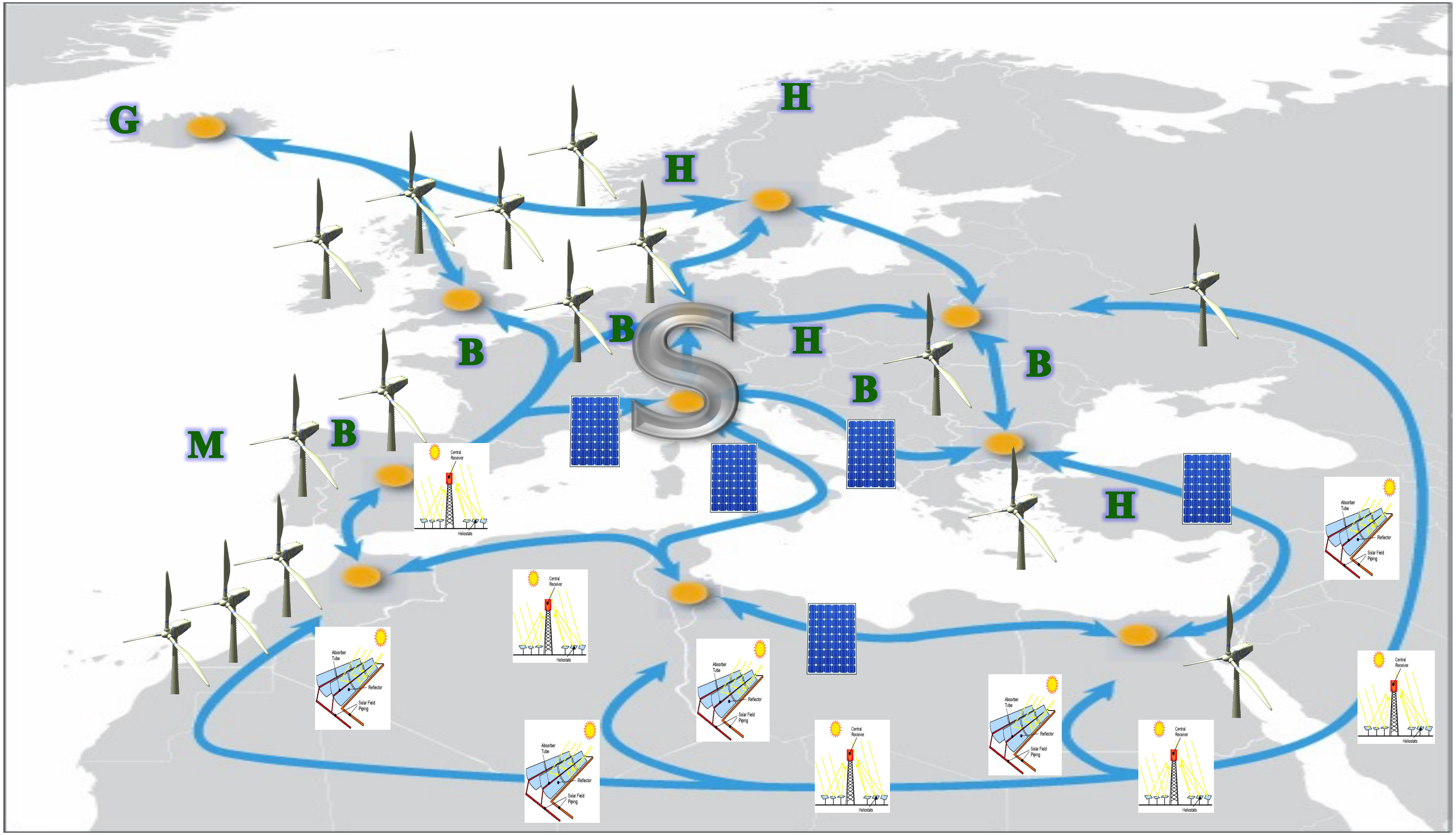
Future PS

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



Source: EC, 2007.

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



Main ingredients of future sustainable electric systems

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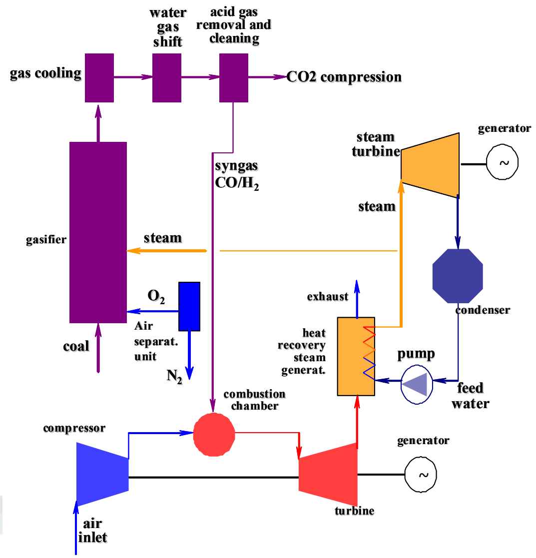
- –Large scale integration of renewable energy sources
- –Distributed generation
- –Carbon capture and storage
- –Smartgrids
- –Electric vehicles
- –Storage devices
- –Hydrogen



Development of new sustainable technologies and infrastructure

Towards hydrogen economy in 2050

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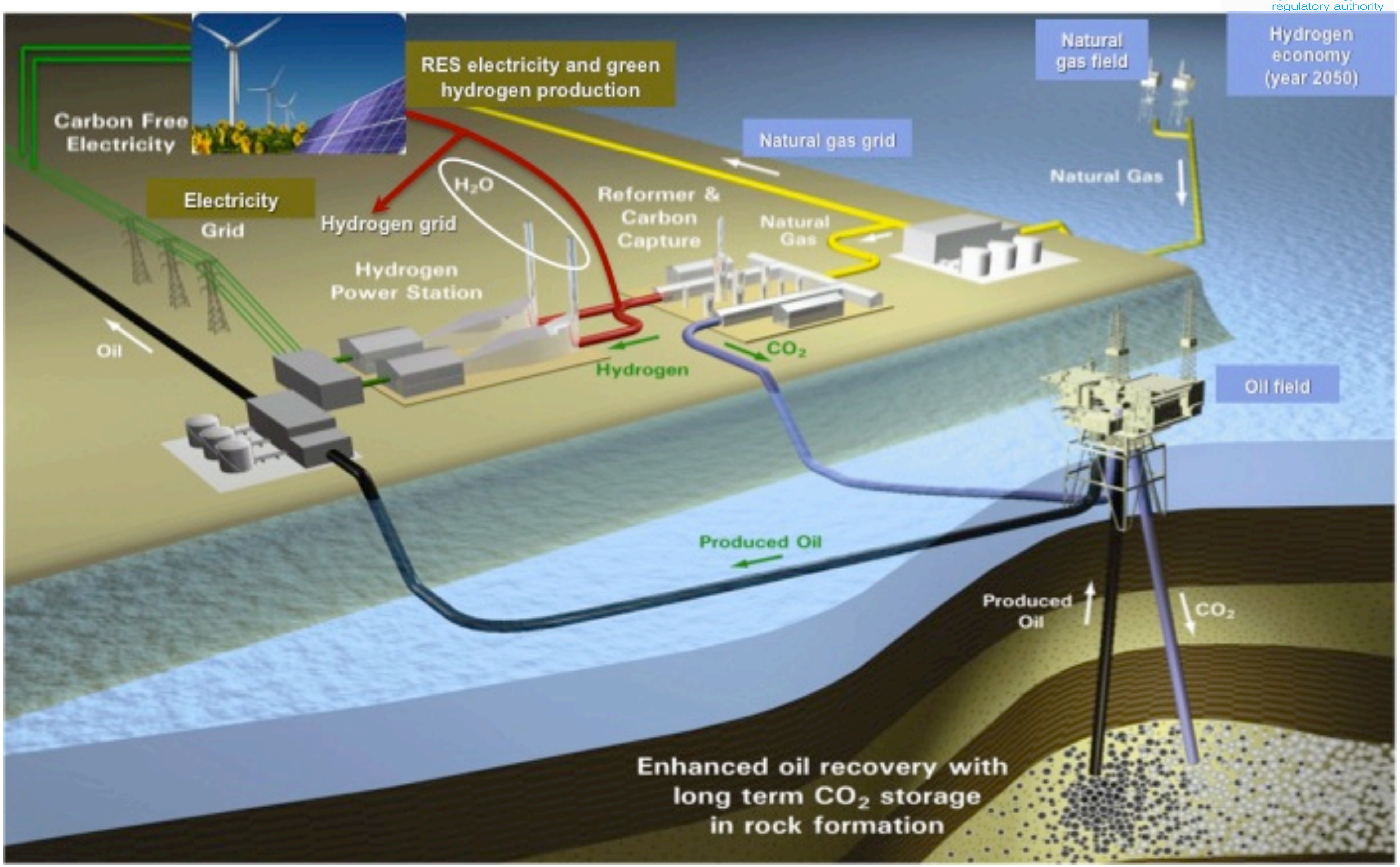


Medium term strategies Towards 2030

Towards Energy Union

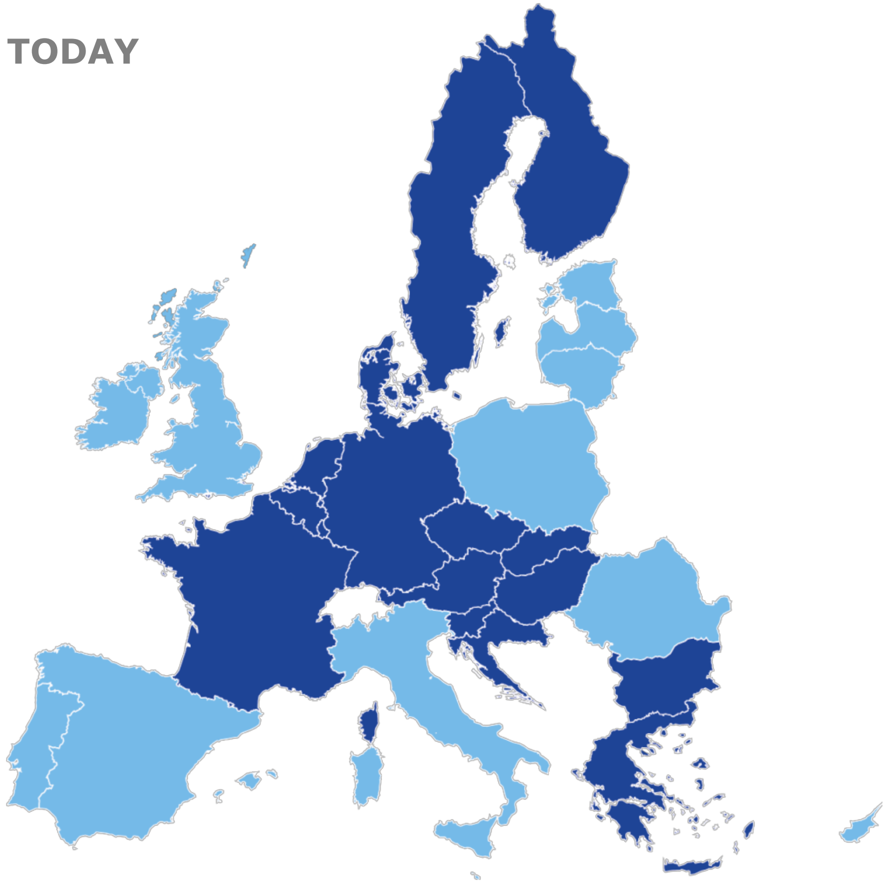
« *I want to reform and reorganise Europe's energy policy in a new European Energy Union.* »

Jean-Claude Juncker

Energy Union

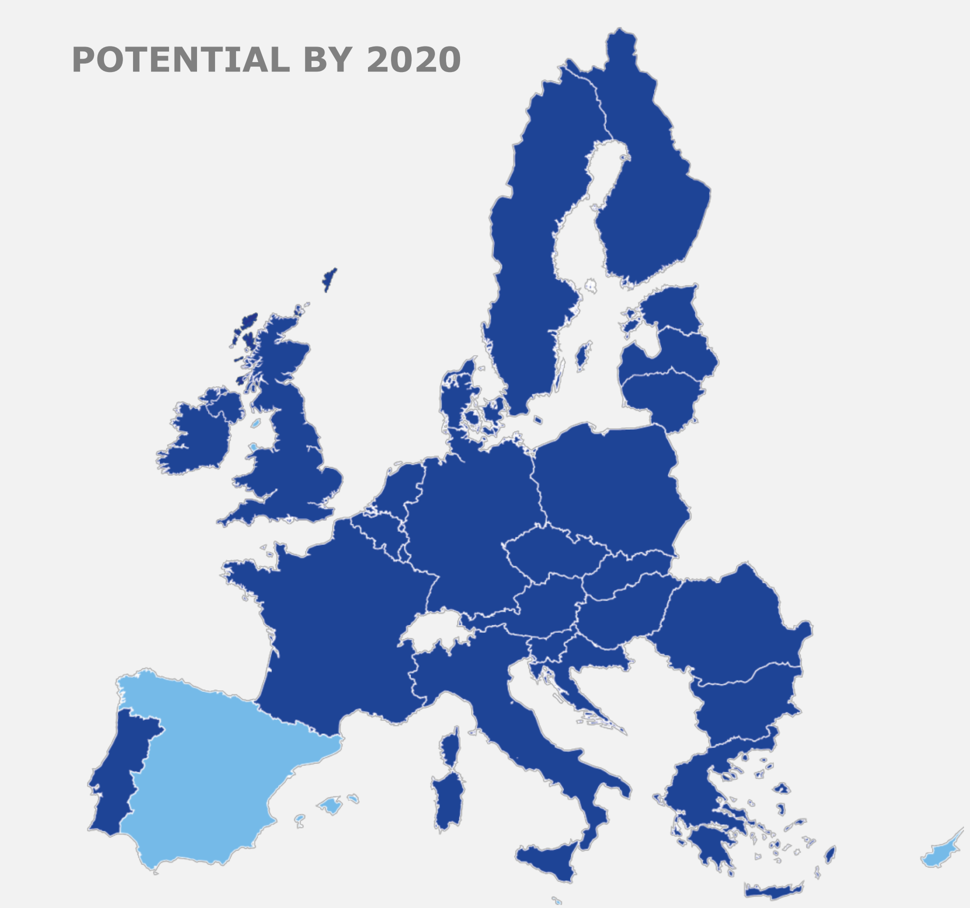
- a binding EU target of at least 40% less greenhouse gas emissions by 2030, compared to 1990
- a binding target of at least 27% of renewable energy use at EU level
- an energy efficiency increase of at least 27%
- the completion of the internal energy market by reaching an electricity interconnection target of 15%
- increase energy security (natural gas South Corridor)

Connecting electricity markets



■ Countries meeting the 10% **interconnection** target

■ Countries not meeting the 10% **interconnection** target



Efforts need to be stepped up for those below the 10% target by 2020, mainly Spain and Cyprus, and in view of achieving the 15% target by 2030.

Importance for Cyprus

- **Great importance for Cyprus**
  - Special attention is made to the more remote and isolated energy systems such as Cyprus
  - EU financing for electric interconnections with the rest of the internal energy market
  - implement critical projects of common interest in the gas sector, such as:
    - the Southern Gas Corridor
    - the promotion of a new gas hub in Southern Europe
- **Action Plan**

Short term strategies Towards 2020

RES-E strategic plan 2010-20 main objective*

- … to assess the optimum (minimum) increase in the cost of electricity of the Cyprus generation system by the integration of the necessary RES-E technologies for Cyprus to achieve its national RES energy target …

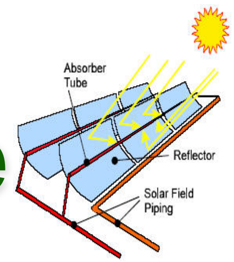
* Poullikkas A., Kourtis G., Hadjipaschalis I., 2011, "A hybrid model for the optimum integration of renewable technologies in power generation systems", *Energy Policy*

RES technologies considered

- **Wind**

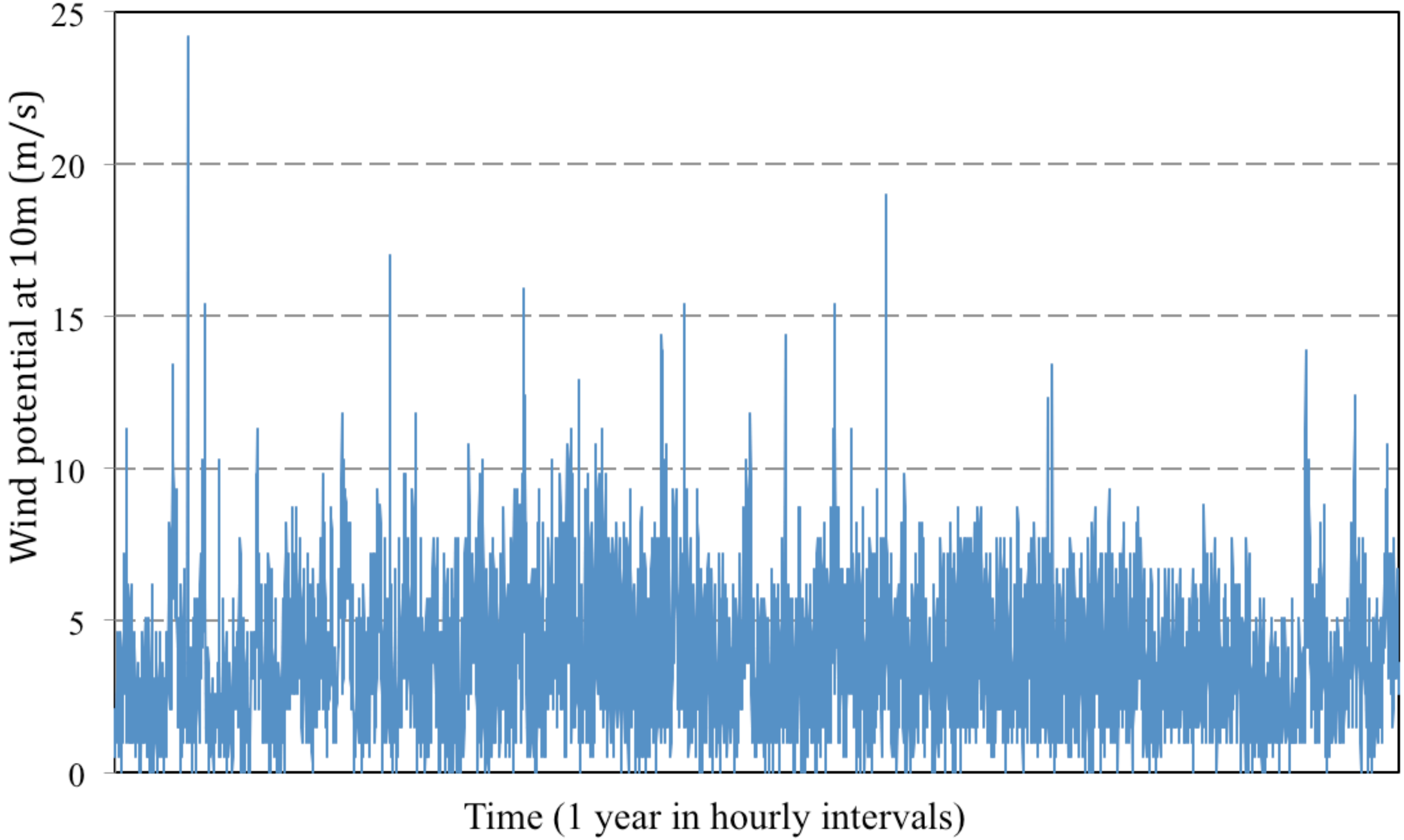
- **PVs**

- **CSP with 6 hours thermal storage**

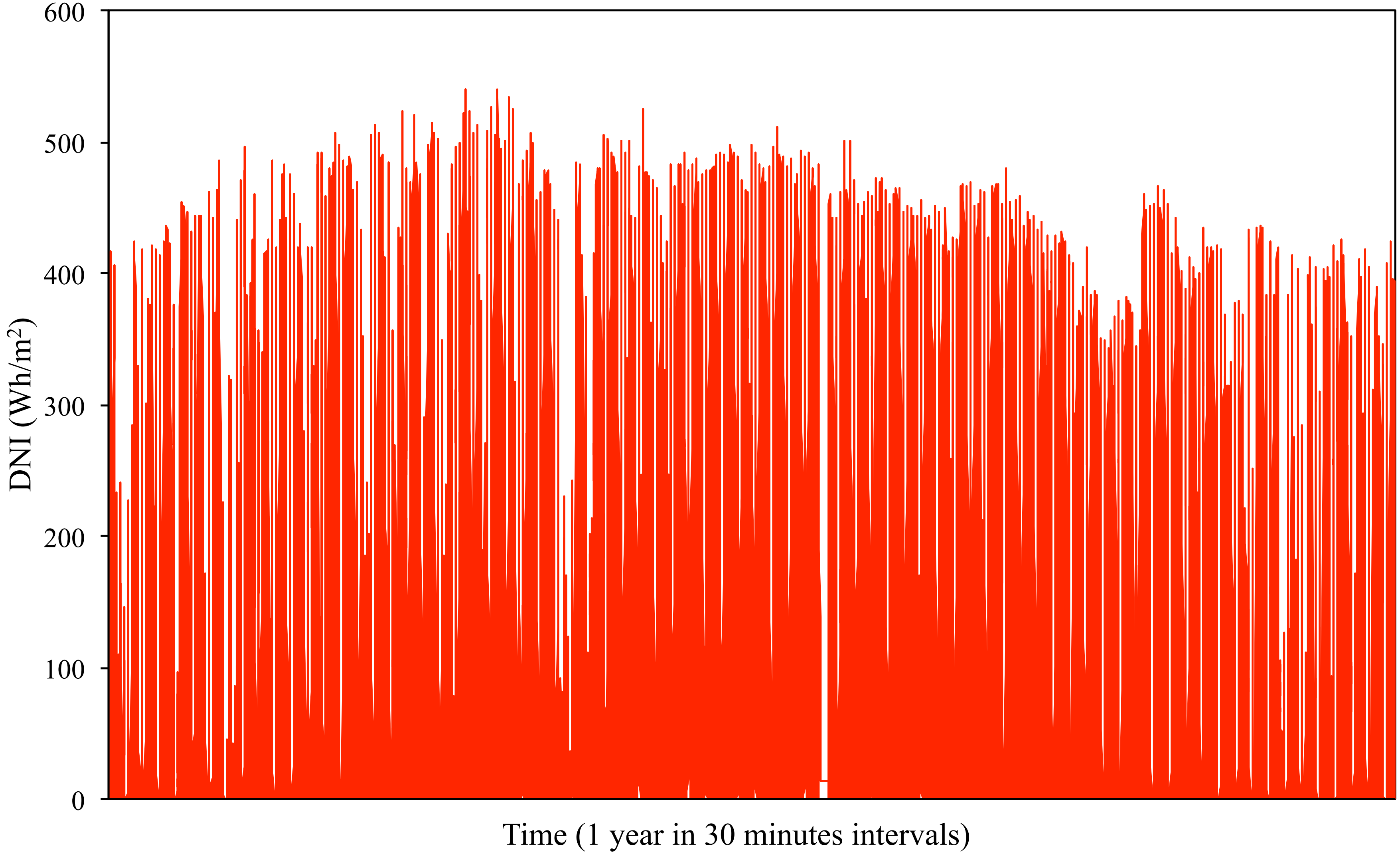


- **Biomass**

Hourly annual wind potential



½ hour annual solar potential



The problem

The need

- **Large scale integration of RES**
  - **e.g., EU RES targets by 2020**

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

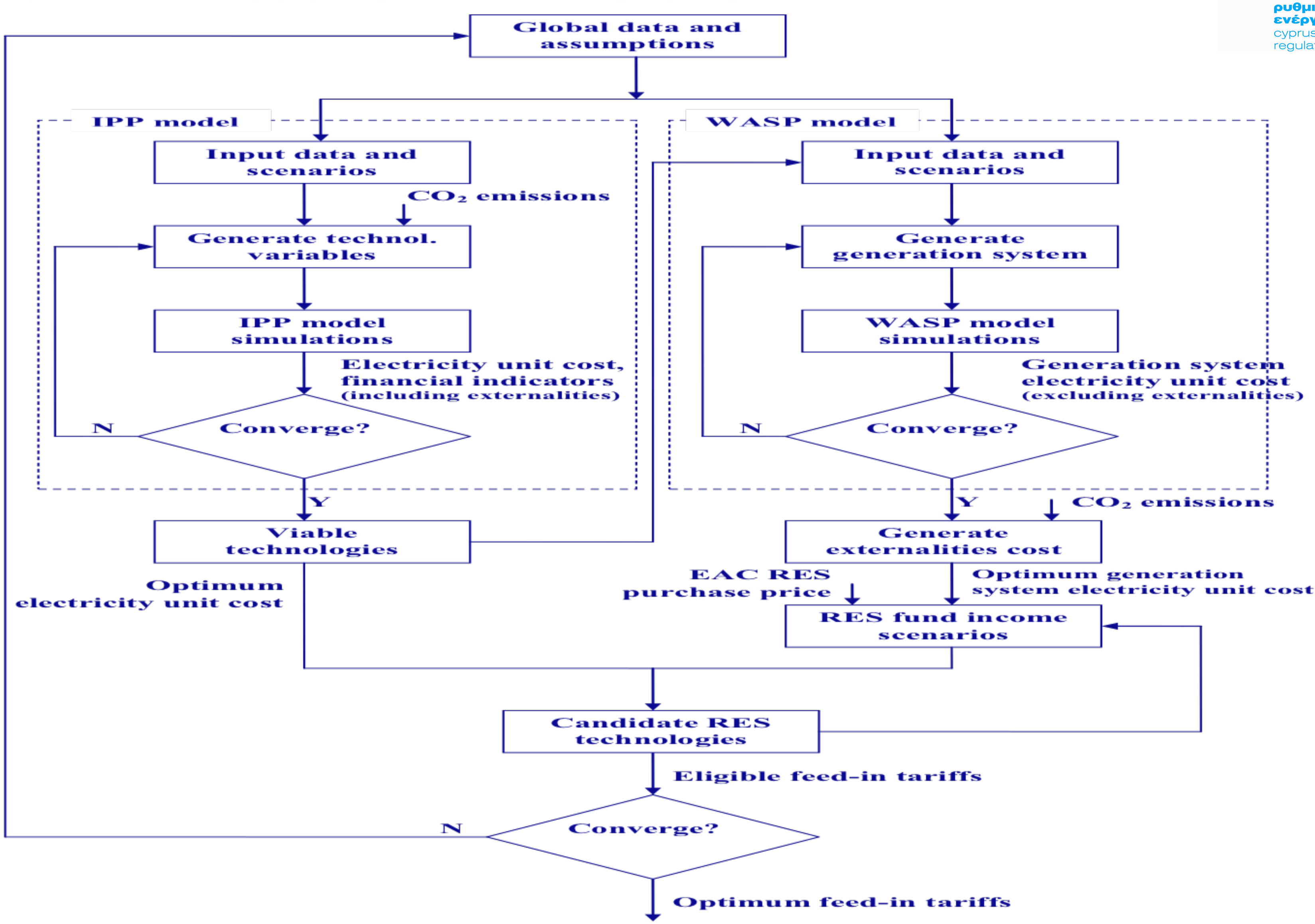
- Use of unit commitment algorithms
- Energy mix
- Cost or benefit in the cost of electricity
- Price of feed in tariffs
- Green tax

Important factors considered

- 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

Optimization model*

Optimization model (hybrid model implementing IPP and WASP models)



* Poullikkas A., Kourtis G., Hadjipaschalis I., 2011, "A hybrid model for the optimum integration of renewable technologies in power generation systems", *Energy Policy* and Poullikkas A., 2009, "A decouple optimization method for power technology selection in competitive markets", *Energy Sources*.

Optimization model

WASP IV (Wien Automatic System Planning)*

- **Find the optimal generation expansion policy for an electric utility system within user-specified constraints**

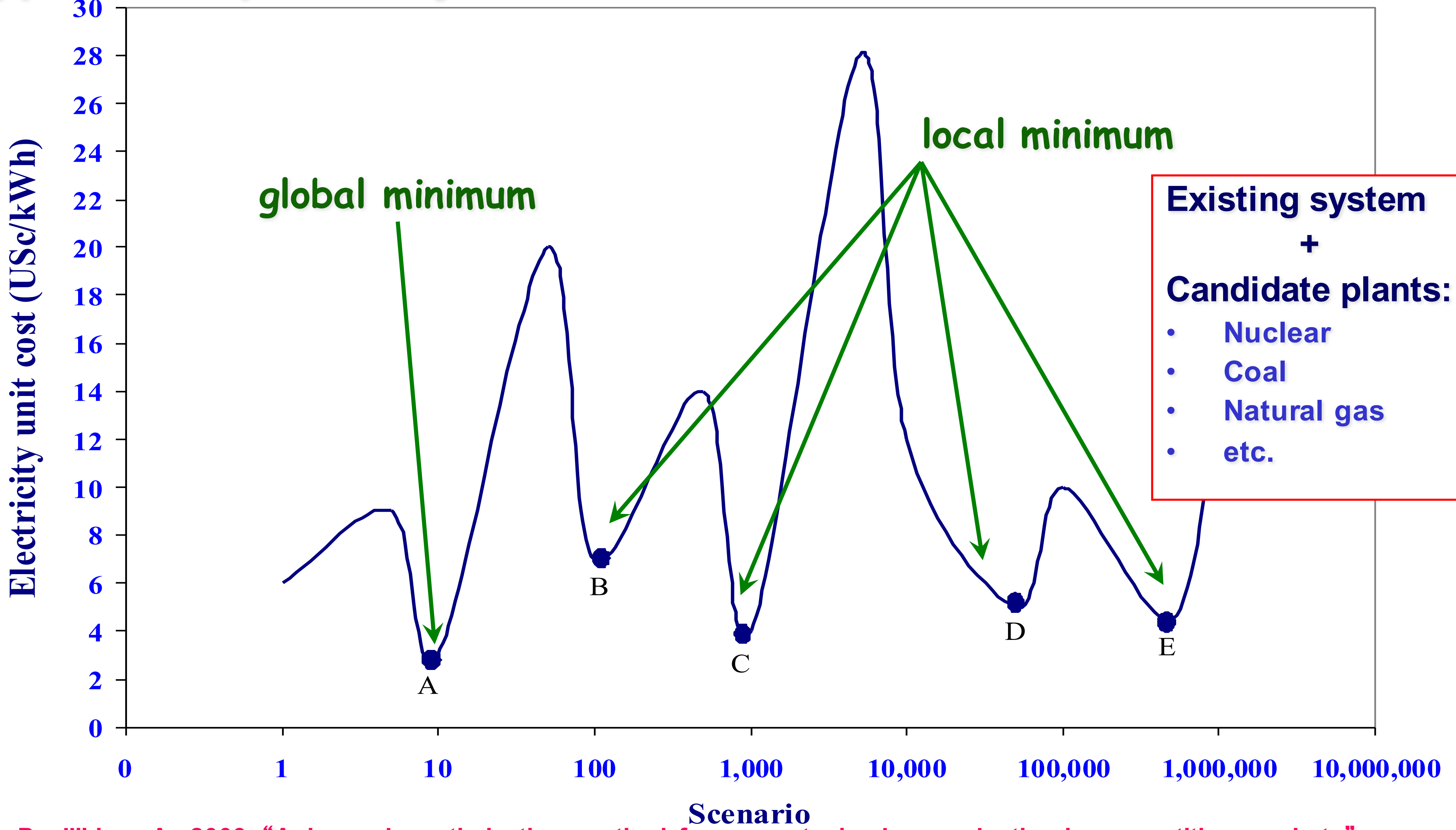
$$B_j = \sum_{t=1}^{T}\left[I_{jt} - S_{jt} + F_{jt} + M_{jt} + \Phi_{jt}\right]$$

  - *Bj :* Objective function attached to the expansion plan *j*
  - *I :* Capital investment costs
  - *S :* Salvage value of investment costs
  - *F :* Fuel Costs
  - *M :* Non-fuel operation and maintenance costs
  - Φ : Cost of energy not served
  - *t :* time in years (1, 2, …., *T*)
  - *T :* length of the study period
- **Optimum solution:** $\min B_j$

* Poullikkas A., Kellas A., "The use of sustainable combined cycle technologies in Cyprus: A case study for the use of LOTHECO cycle", Renewable and Sustainable Energy Reviews, 2004.

Optimization model

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*.

Optimization model

I.P.P. ALGORITHMv2.1 *

(Software for power technology selection in competitive electricity markets)

1. Technical, economic and environmental analysis
2. Evaluation of candidate power technologies:

   Capital cost

   Fuel consumption and cost

   Operation and maintenance cost

   RES potential

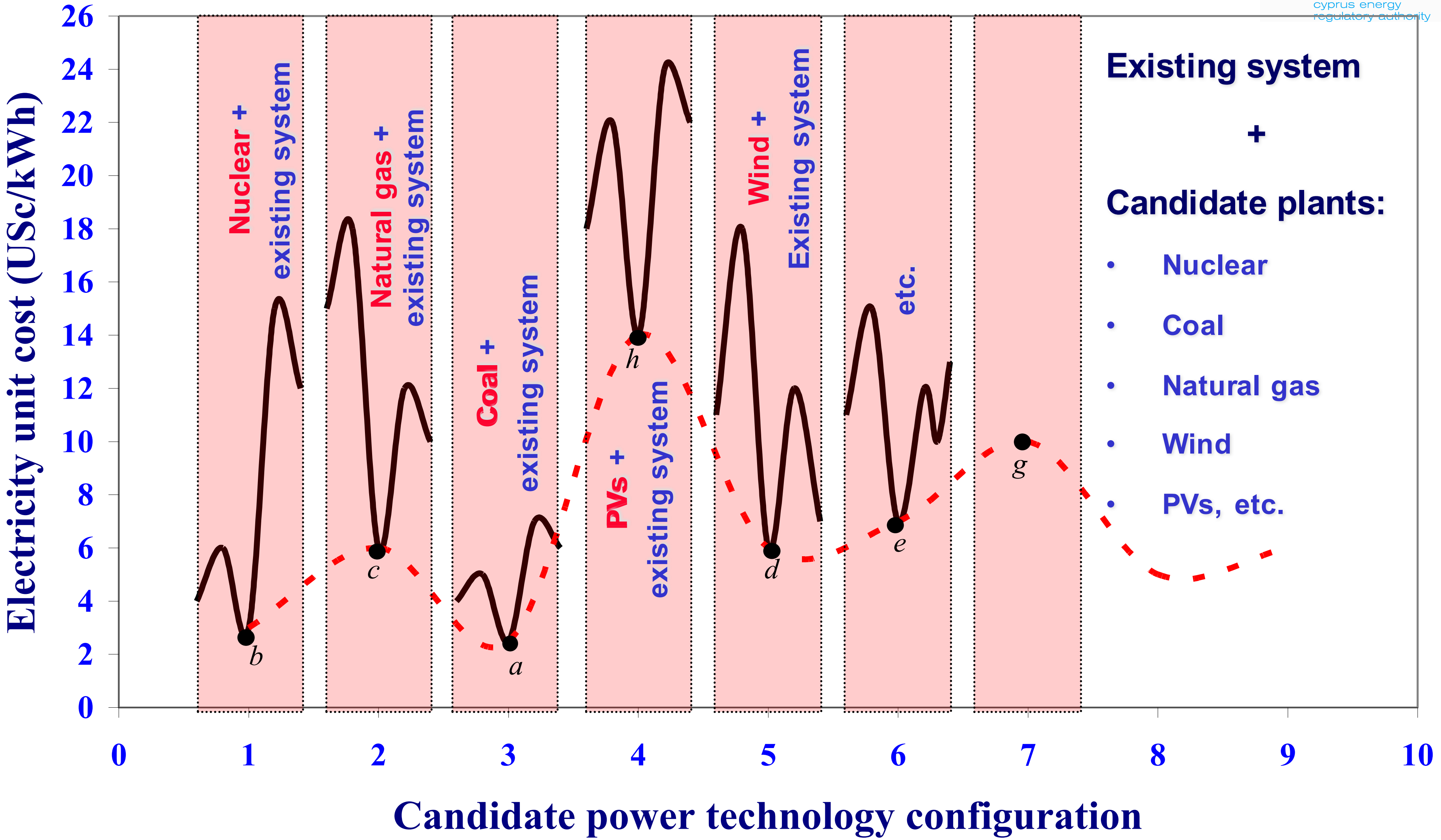
   Life expectancy etc.

3. Least cost power generation configuration

(decouple optimization technique)

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

Decouple optimization technique*



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

Decouple optimization technique*

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.

Decouple optimization technique*

- **Capital cost function***

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

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

- **Fuel cost function***

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

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

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

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

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

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

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

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

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

Decouple optimization technique*

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Environmental indicator functions

- **SO_2, NO_X and dust environmental indicator function***

Environmental indicator (g/kWh)

Emission limit value (Nm³/kg)

Exhaust gases specific volume (Nm³/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*.

Decouple optimization technique*

CCS cost functions

- **CO_2 capture cost function***

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

CO_2 capture cost (US$/tonne CO_2)

Electricity unit cost of candidate technology with CCS (USc/kWh)

Electricity unit cost of candidate technology without CCS (USc/kWh)

CO_2 capture efficiency (%)

CO_2 emissions of candidate technology with CCS (g/kWh)

- **CO_2 avoidance cost function***

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

CO_2 avoidance cost (US$/tonne CO_2)

Electricity unit cost of candidate technology with CCS (USc/kWh)

Electricity unit cost of candidate technology without CCS (USc/kWh)

CO_2 emissions of candidate technology without CCS (g/kWh)

CO_2 emissions of candidate technology with CCS (g/kWh)

CO_2 capture efficiency (%)

* 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*.

Decouple optimization technique*

Wind functions*

Production (kWh)

Coefficient of performance (%)

Efficiency (%)

Wind potential (kW))

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

Efficiency (%)

PV functions**

Production (kWh)

Solar potential (kWh/m²)

Efficiency (%)

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

Area (m²)

CSP functions***

Production (kWh)

Solar potential (kWh/m²)

Efficiency (%)

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

Area (m²)

* Poullikkas A., 2007, "Implementation of distributed generation technologies in isolated power systems", *Renewable and Sustainable Energy Reviews*

** Poullikkas A., 2009, "Parametric cost-benefit analysis for the installation of photovoltaic parks in the island of Cyprus", *Energy Policy*

*** Poullikkas A., 2009, "Economic analysis of power generation from parabolic trough solar thermal plants for the Mediterranean region – A case study for the island of Cyprus", *Renewable and Sustainable Energy Reviews*

Decouple optimization technique*

Set of equations*

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

Candidate technology 1 + existing system

Candidate technology 2 + existing system

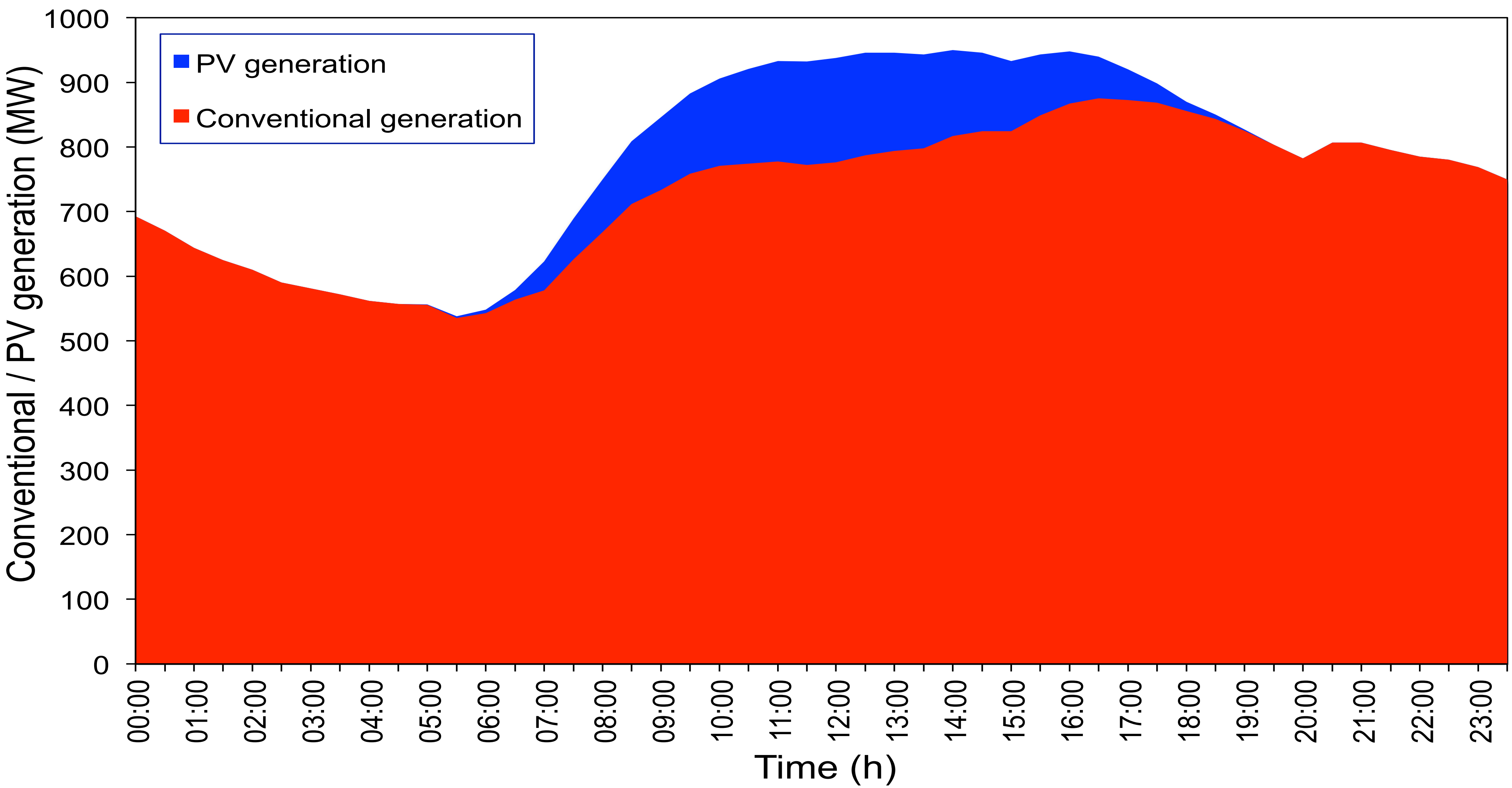
Candidate technology 3 + existing system

Candidate technology 4 + existing system

Candidate technology k + existing system

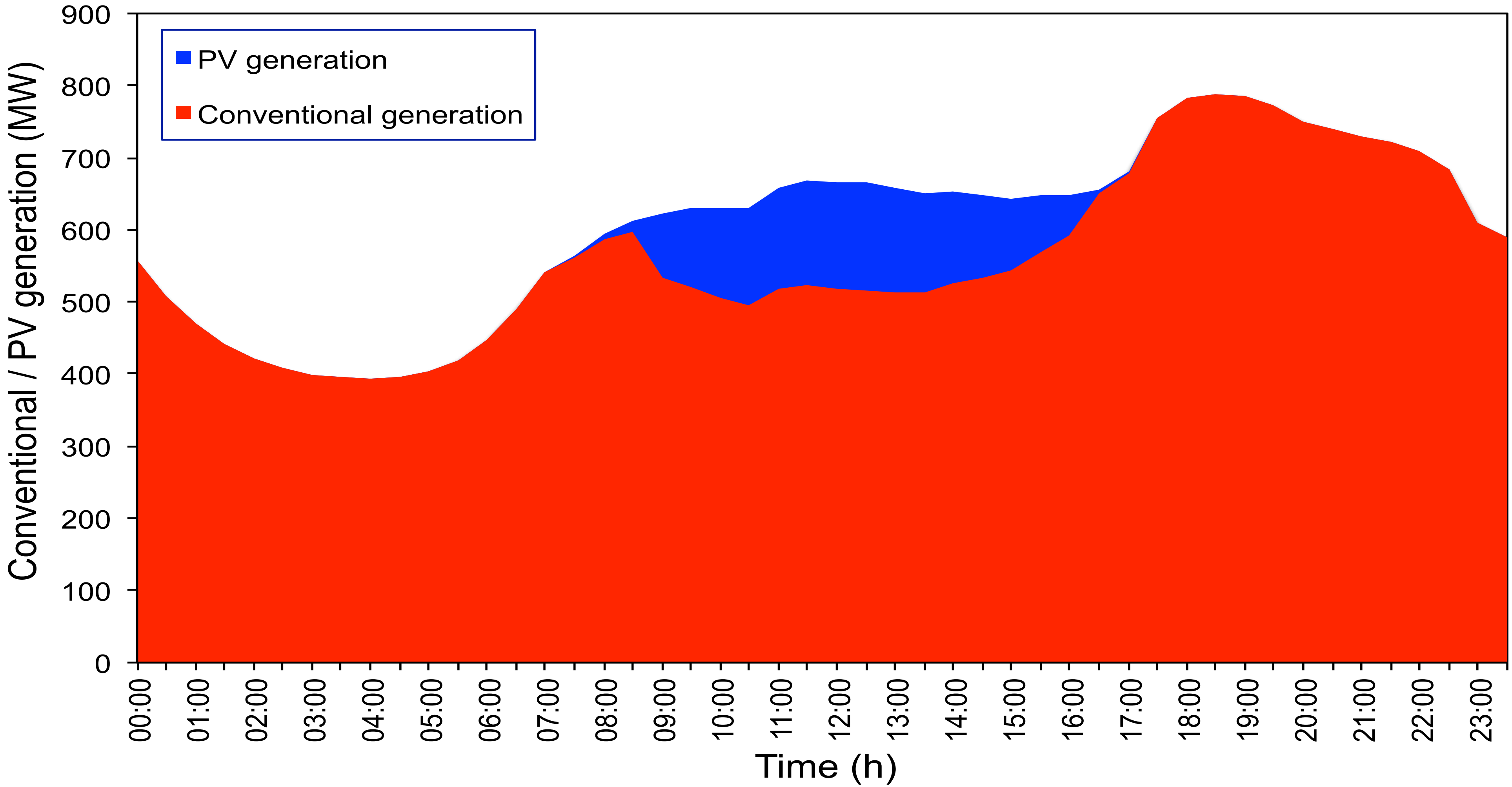
* Poullikkas A., 2009, "A decouple optimization method for power technology selection in competitive markets", *Energy Sources*.

Example of PV generation during Summer time*



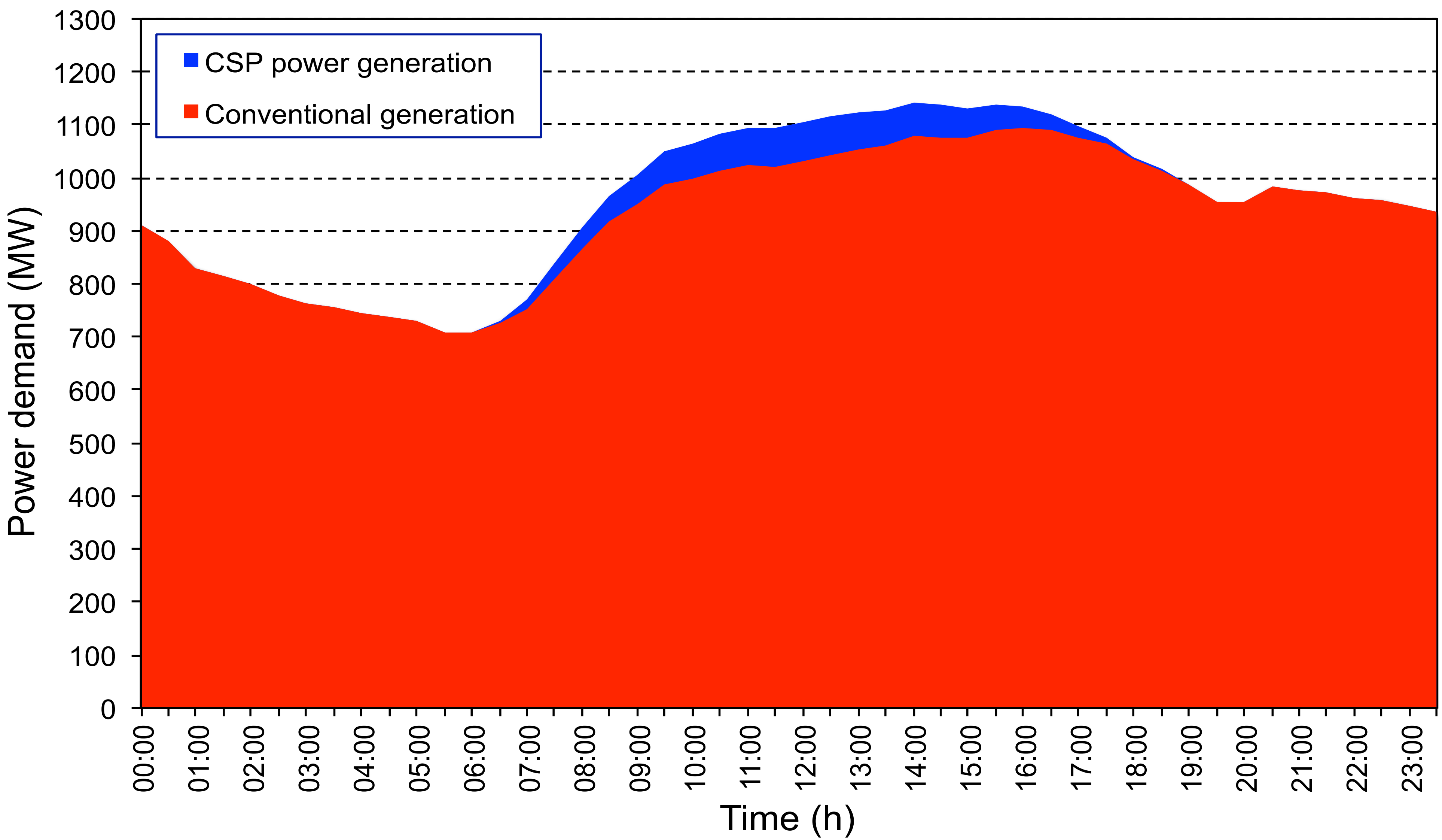
* **Poullikkas A., 2009, "Parametric cost-benefit analysis for the installation of photovoltaic parks in the island of Cyprus", *Energy Policy***

Example of PV generation during Winter time*

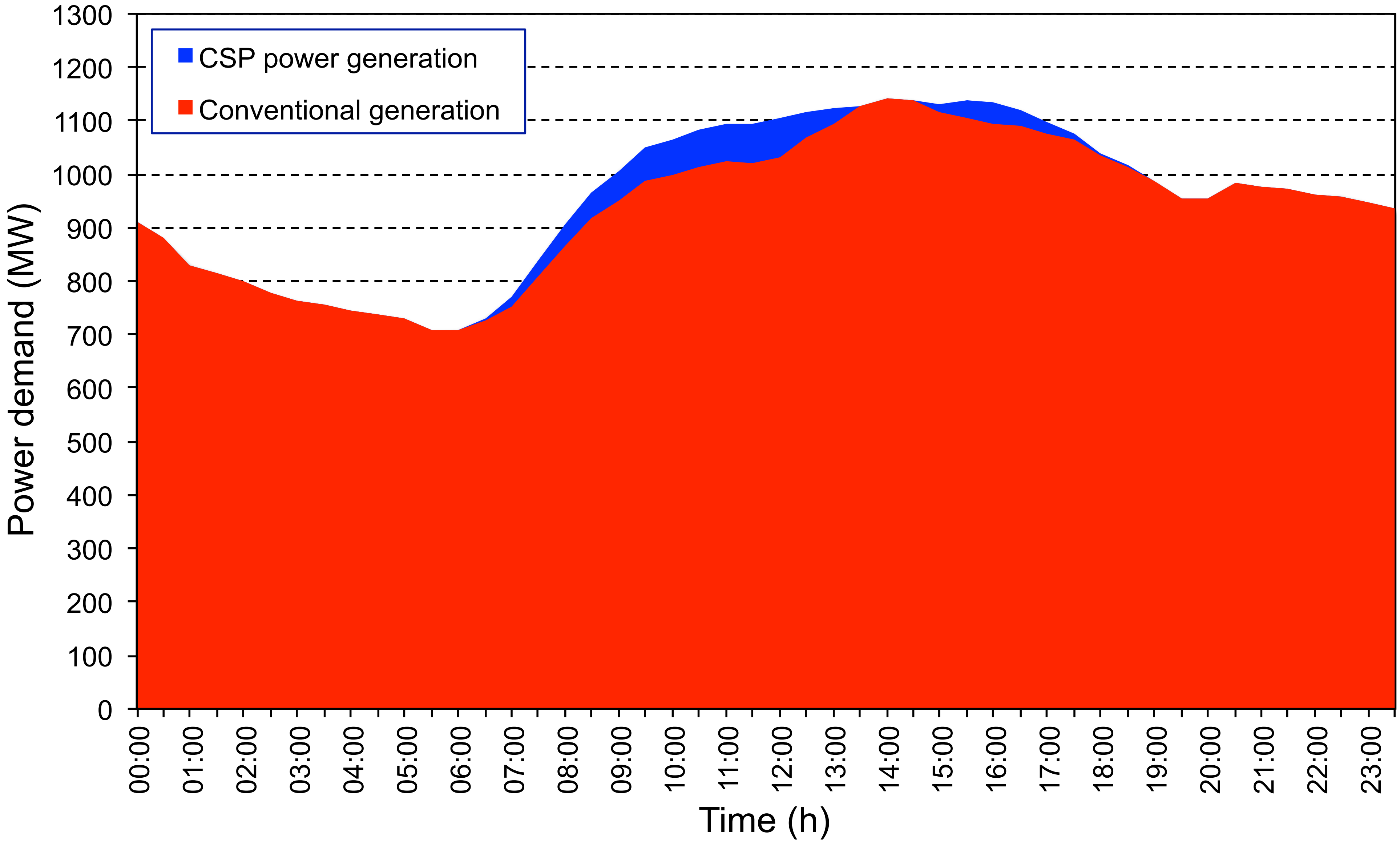


* Poullikkas A., 2009, "Parametric cost-benefit analysis for the installation of photovoltaic parks in the island of Cyprus", *Energy Policy*

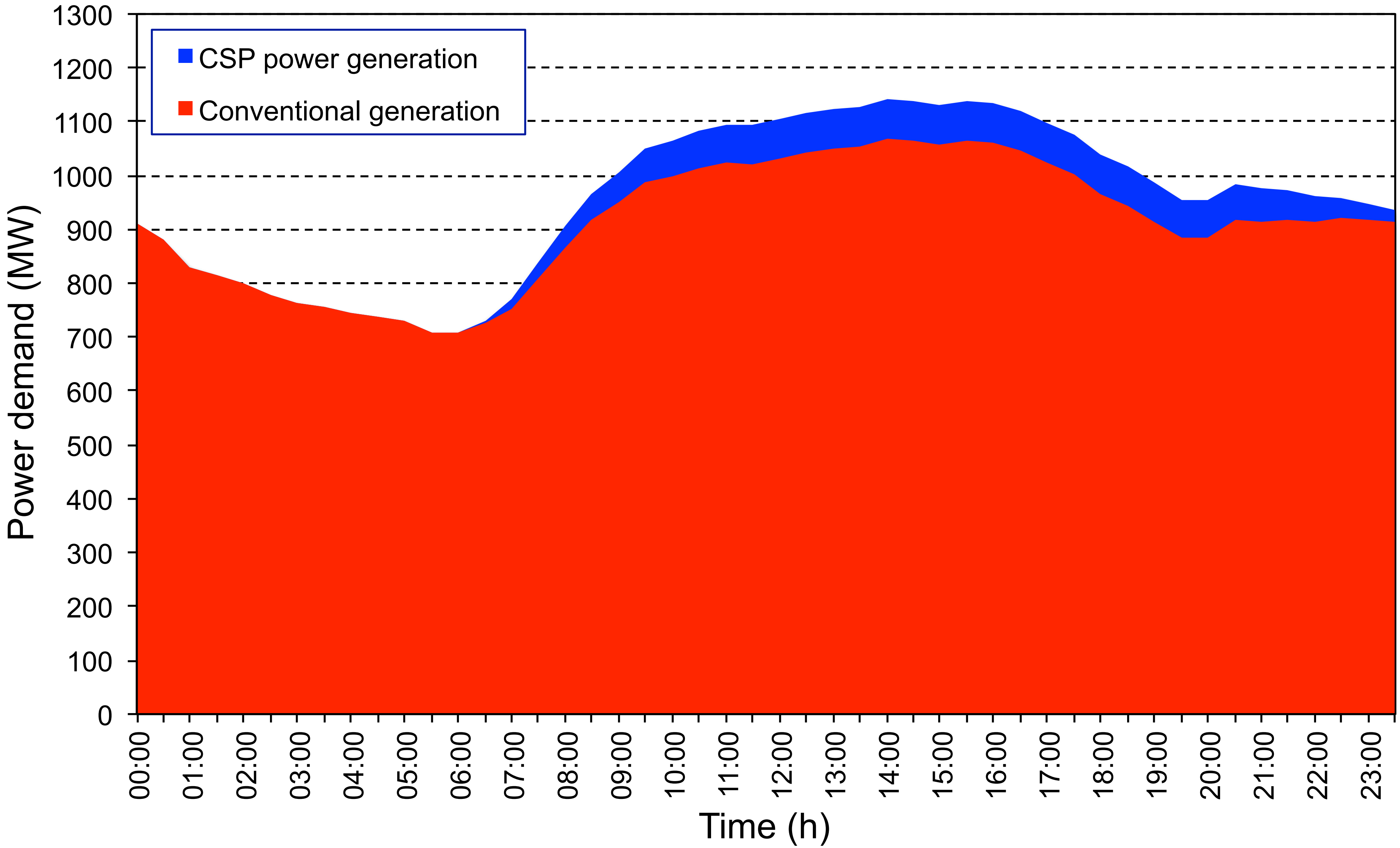
Example of 75MW CSP generation during peak load (no storage, normal conditions)



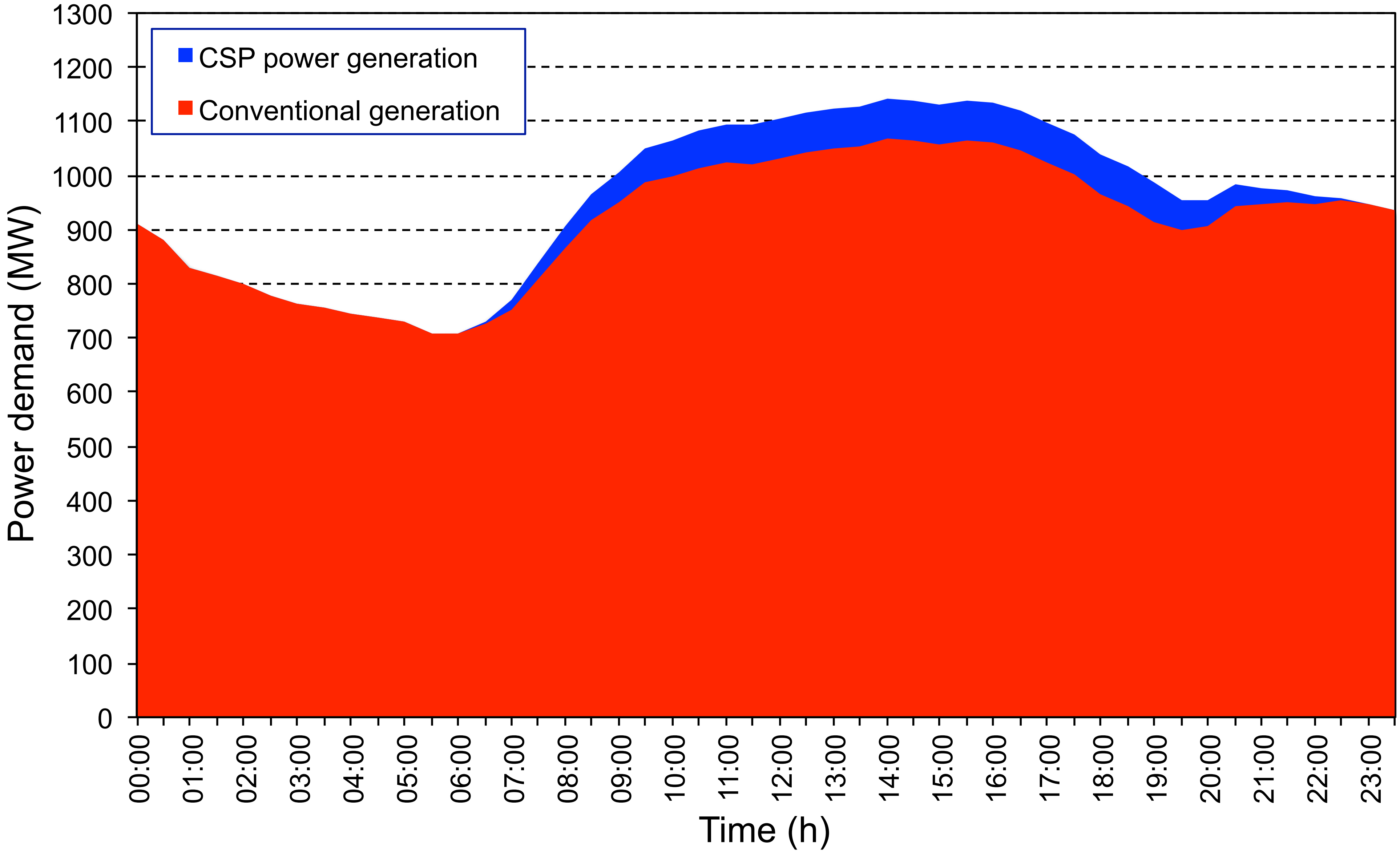
Example of 75MW CSP generation during peak load (no storage, with clouds)



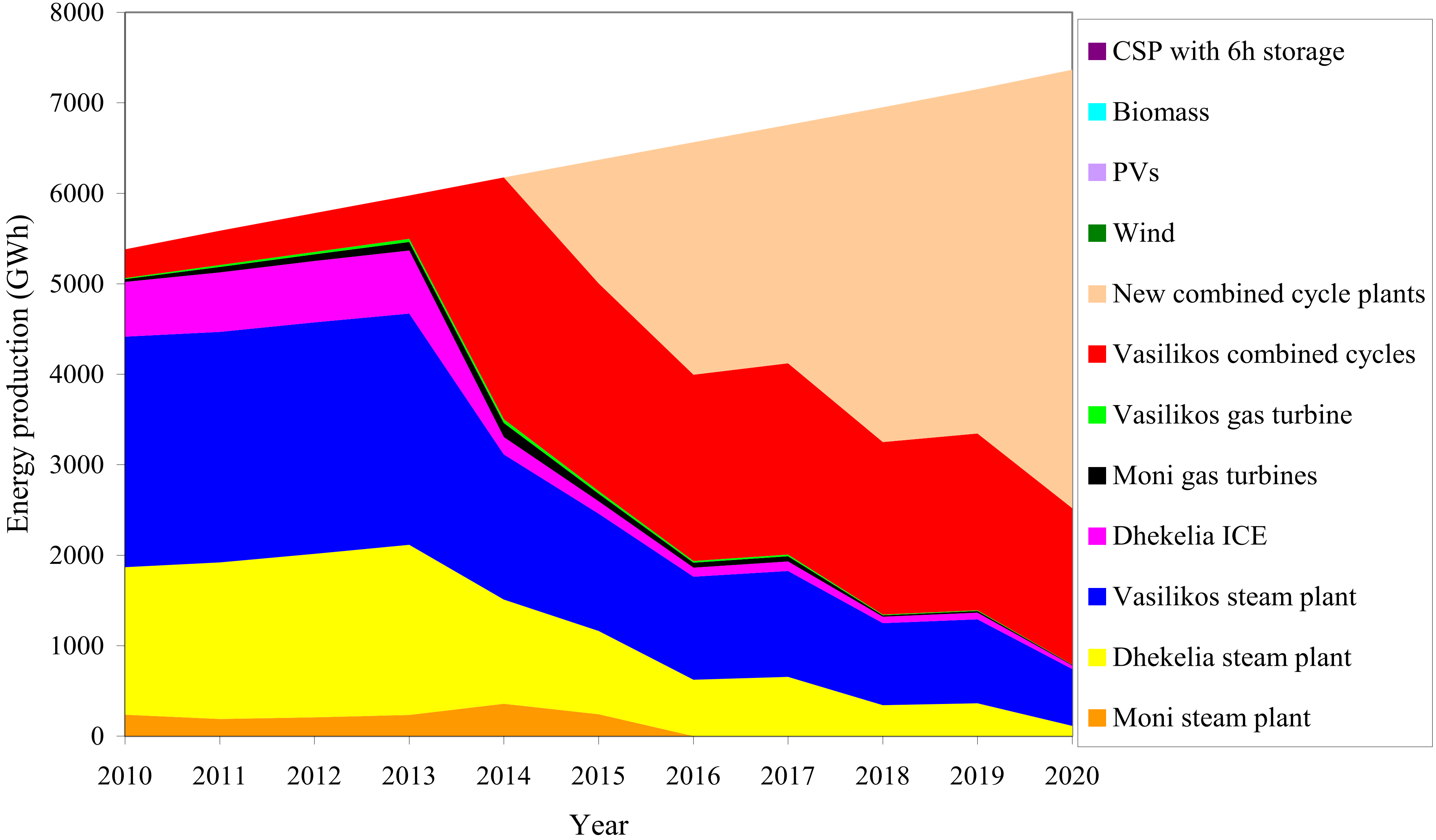
Example of 75MW CSP generation during peak load (6h storage, normal conditions)



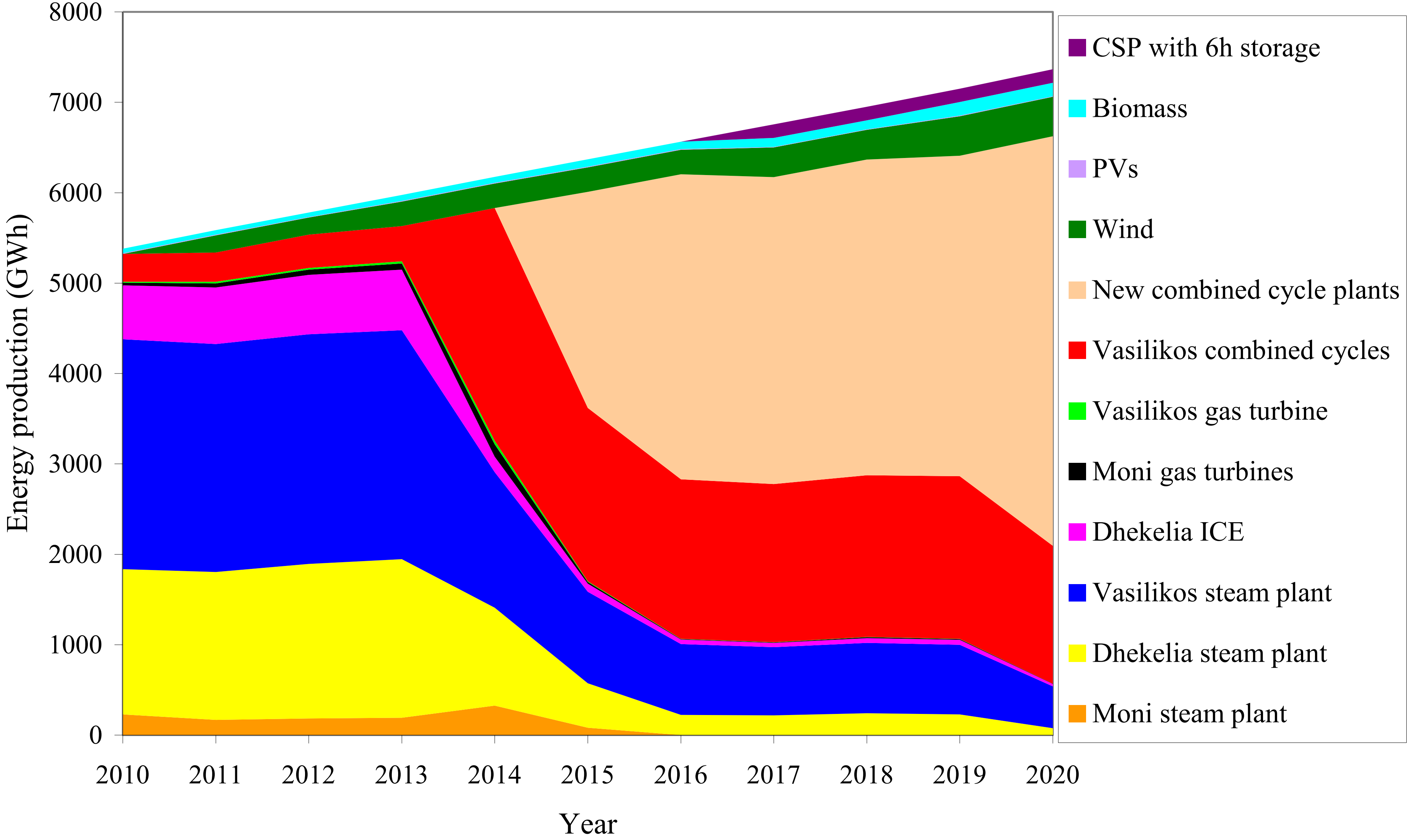
Example of 75MW CSP generation during peak load (6h storage, with clouds)



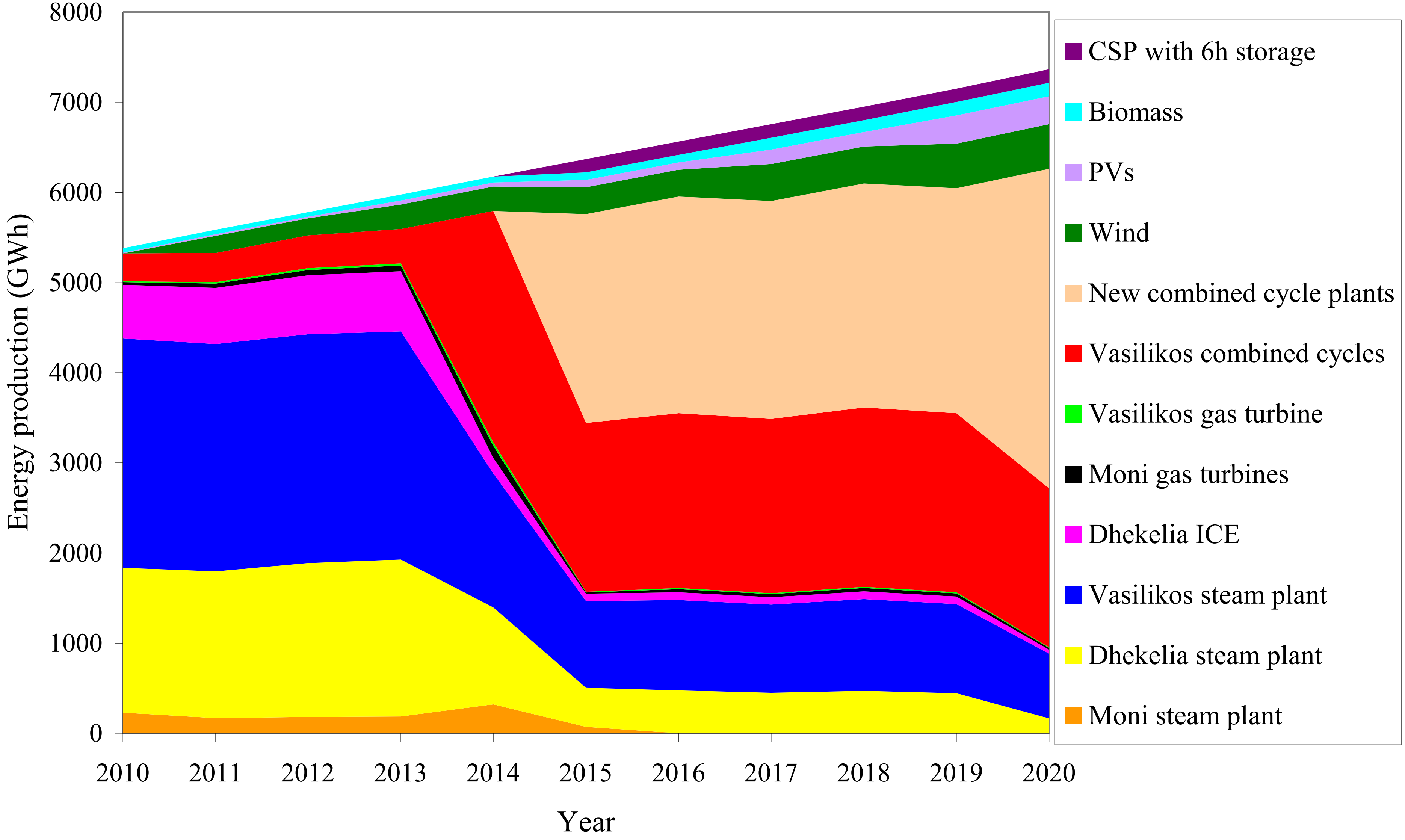
Power generation system energy mix with BAU



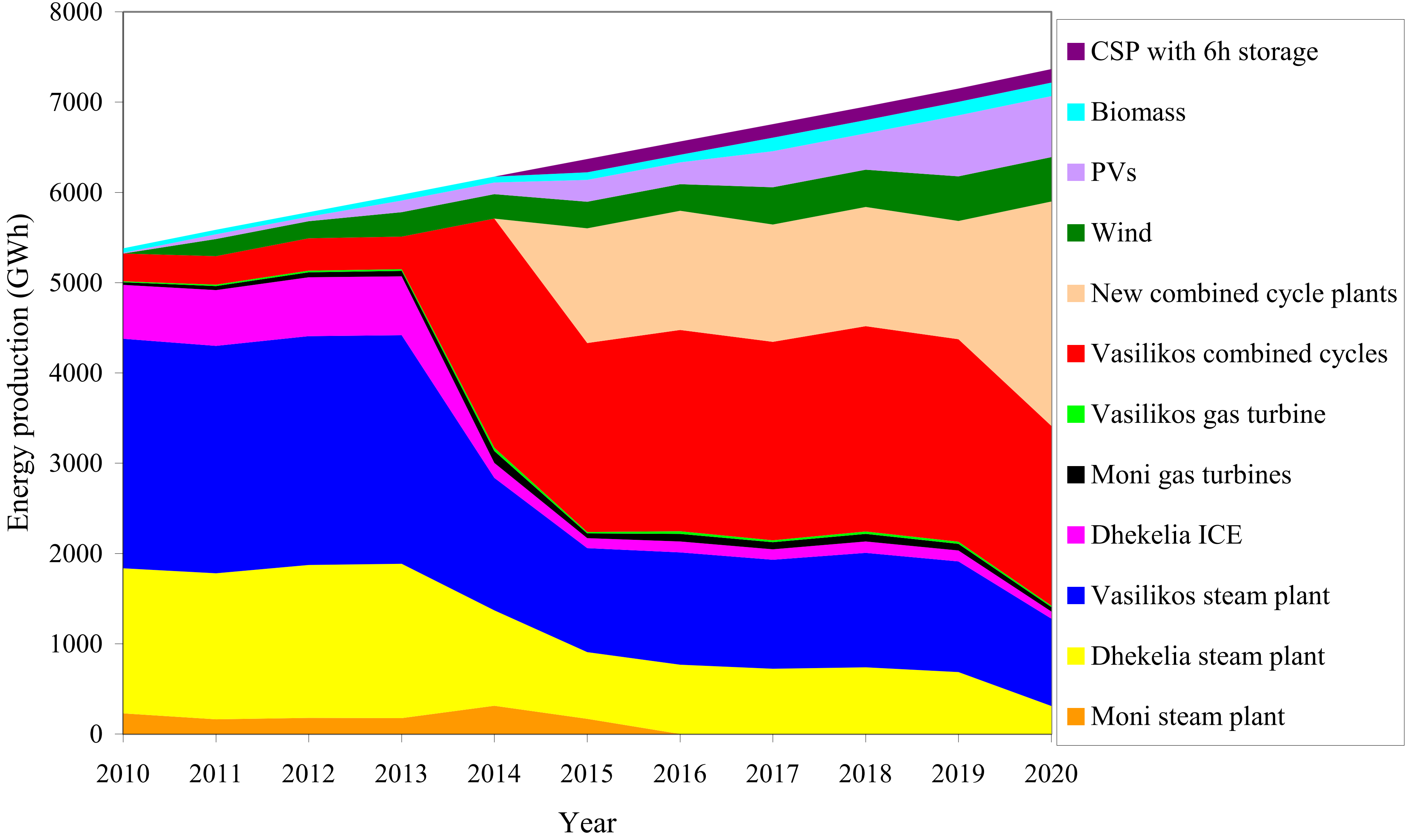
Power generation system energy mix with 10% RES-E penetration



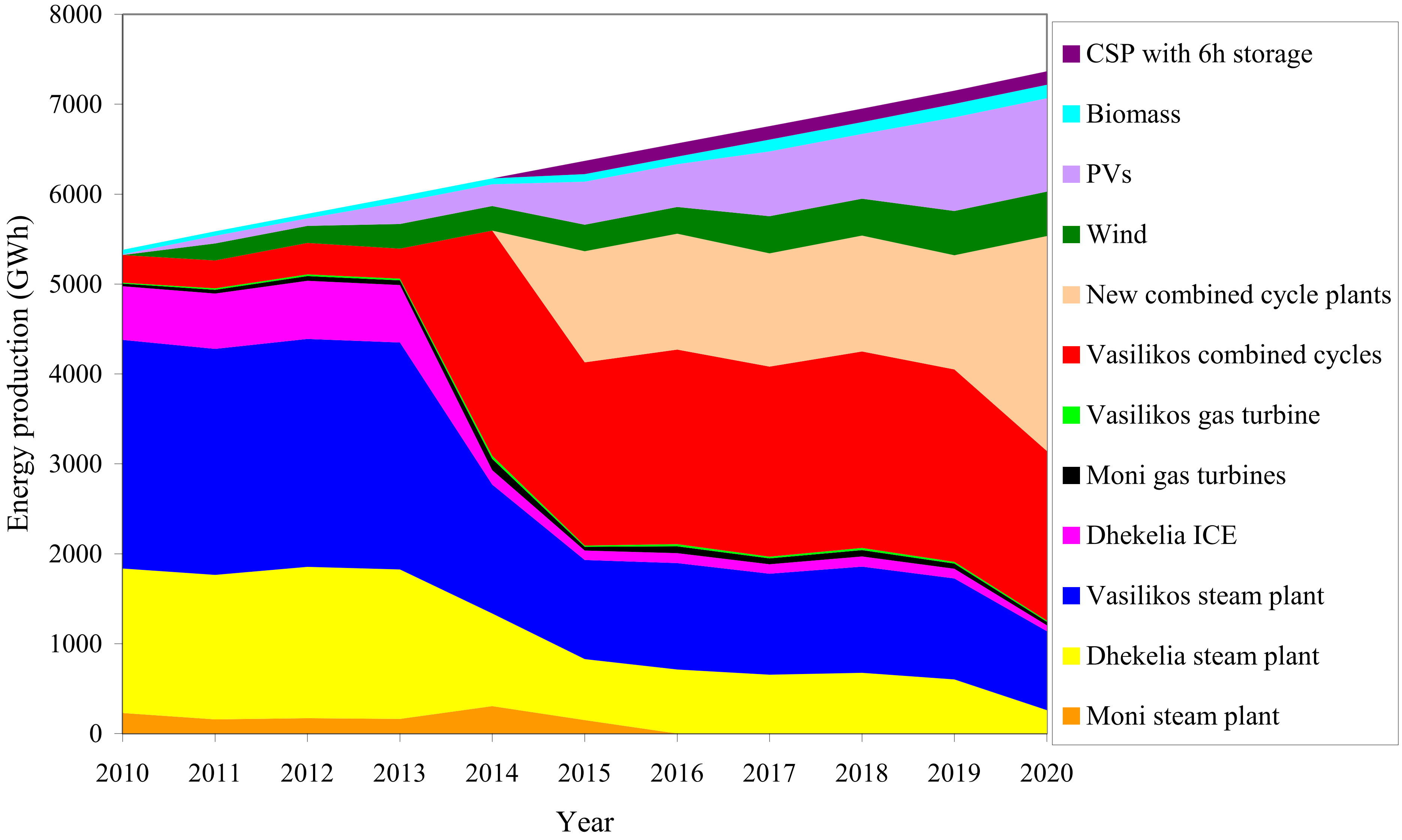
Power generation system energy mix with 15% RES-E penetration



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



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



RES-E strategic plan 2010-20

- RES-E penetration at 16% by 2020
- Important measures
  - Shifting from FiT mechanism, which is independent of electricity market prices, to a more market based mechanism
  - Introduction of the net-metering scheme
  - Use of competitive auctioning processes for RES-E capacity