IEEE SOSE 2012
7th INTERNATIONAL CONFERENCE
ON SYSTEM OF SYSTEMS
ENGINEERING

The shift of Morocco to renewable energies: toward a complex system-of-systems perspective

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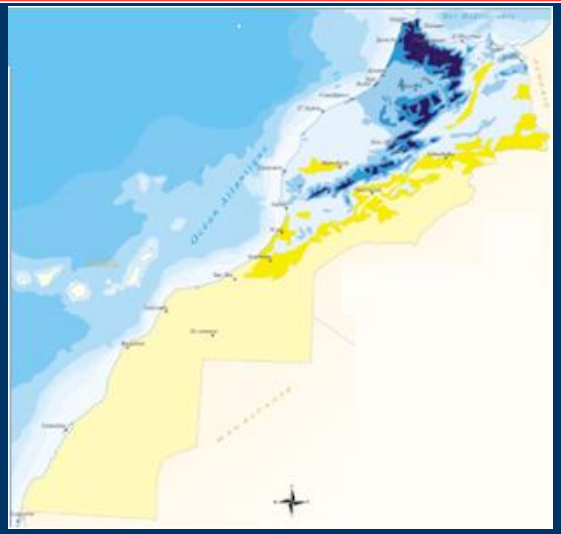
TEER

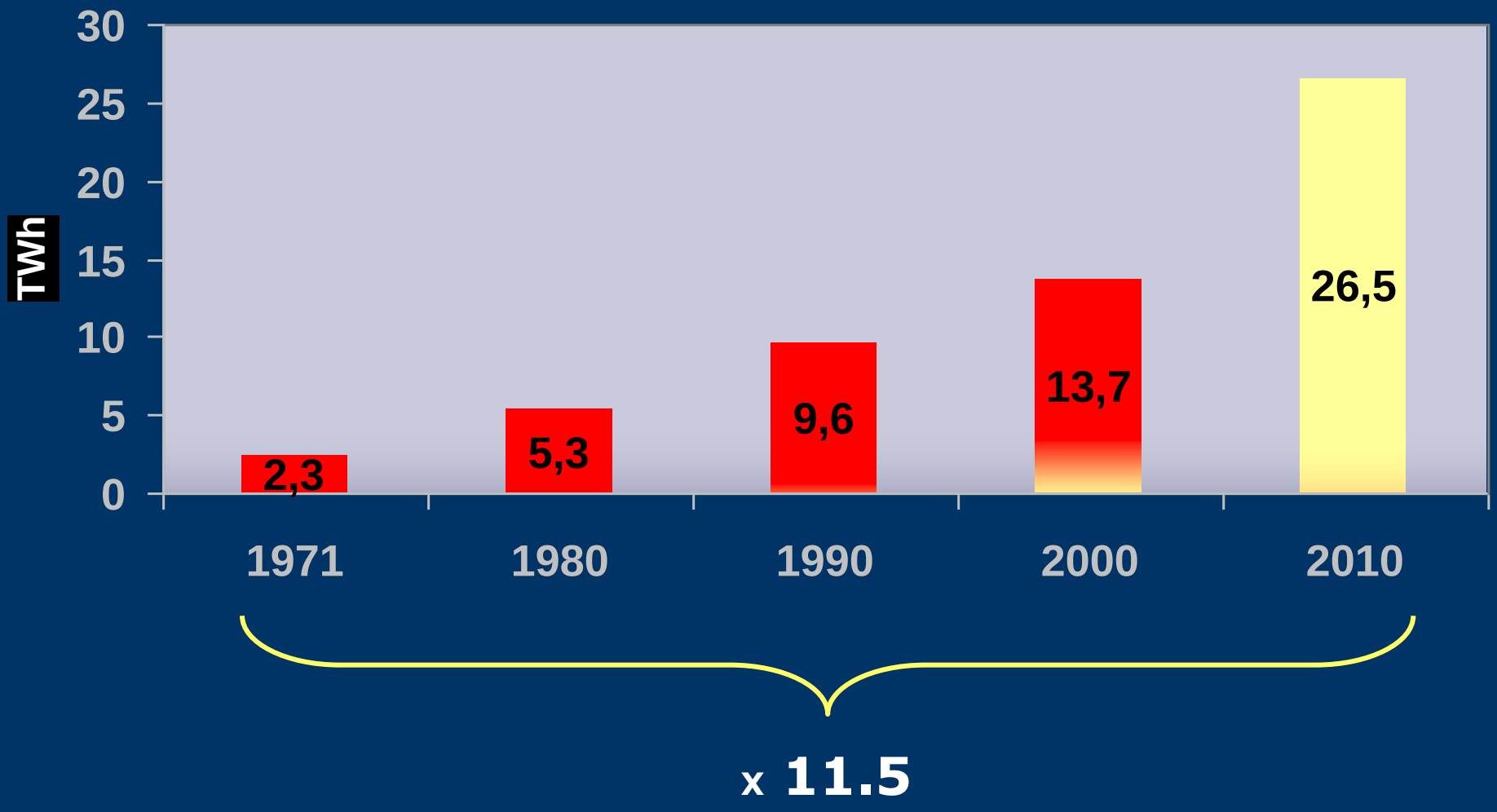
Unité des Technologies et Économie des Énergies Renouvelables

SOME DATA CONCERNING MOROCCO

• Population	: ≈ 32 Million (2010)
• Area	: ≈ 710,850 km^2
• GDP/Capita	: ≈ 2800 $ (2010)
• Main energy source	: Imported petroleum (60%)
• Comm. Primary energy consumption	: ≈ 15.5 Million TOE (2011)
• Electricity consumption	: ≈ 29 TWh (2011)
• Share of GDP dedicated to research	: ≈ 0.8 % (2011)



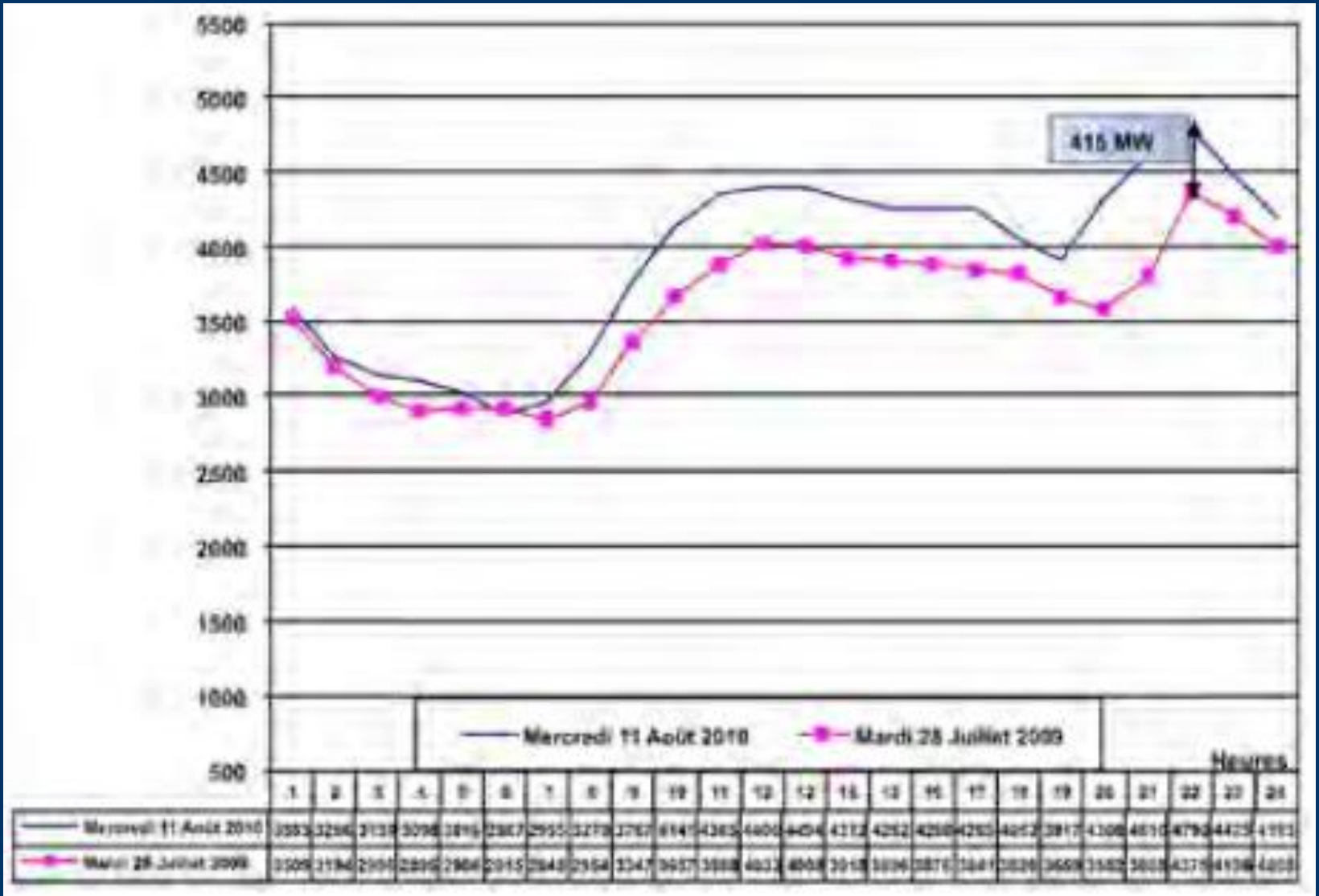
Evolution of the electricity consumption (TWh)

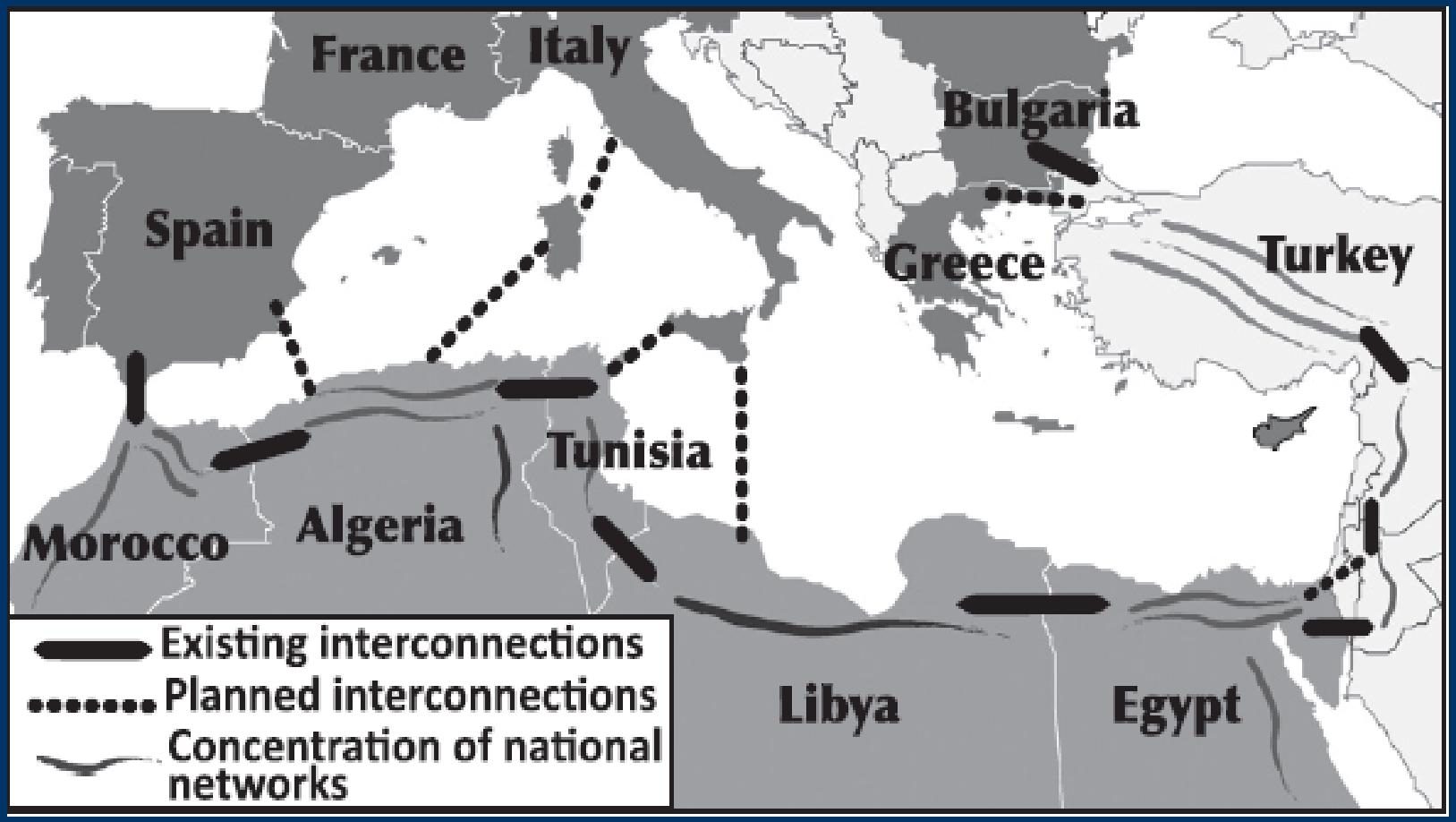


Major drivers of energy demand in Morocco

- Economic growth
- Improvement in living standards
- Increasing freshwater demand

Daily electricity load curve

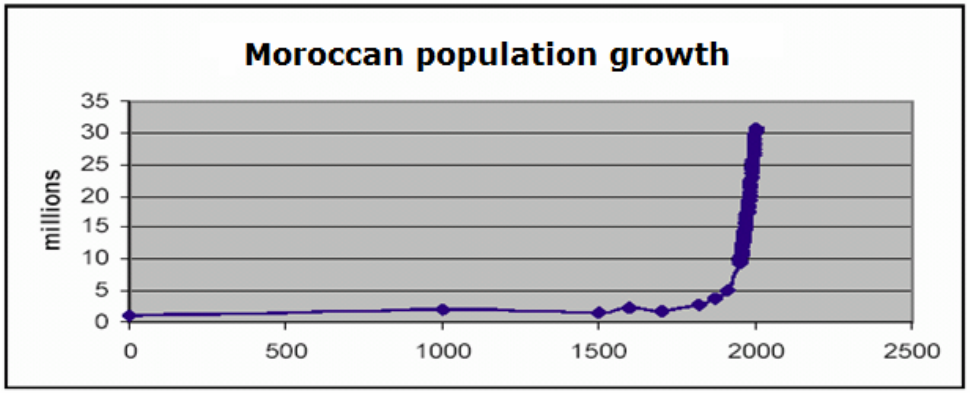




(Source: OME, 2006)

Morocco

Population			Energy		
1971	→	15,4 millions	1971	→	2,47 MTEP
2009	→	~ 31 millions	2009	→	15 MTEP



Source : P. Gérard, ENIM, 2005

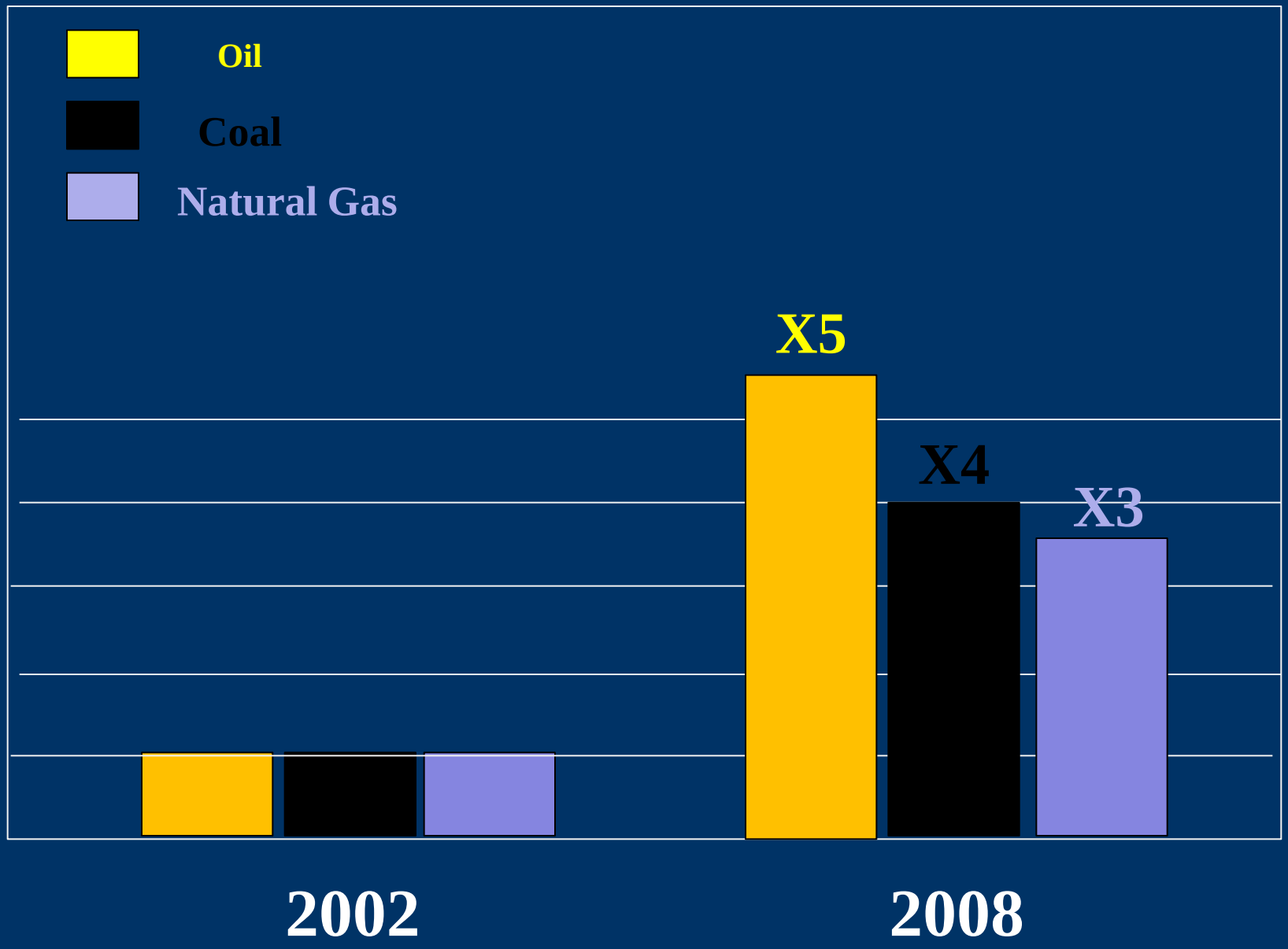
Energy dependancy

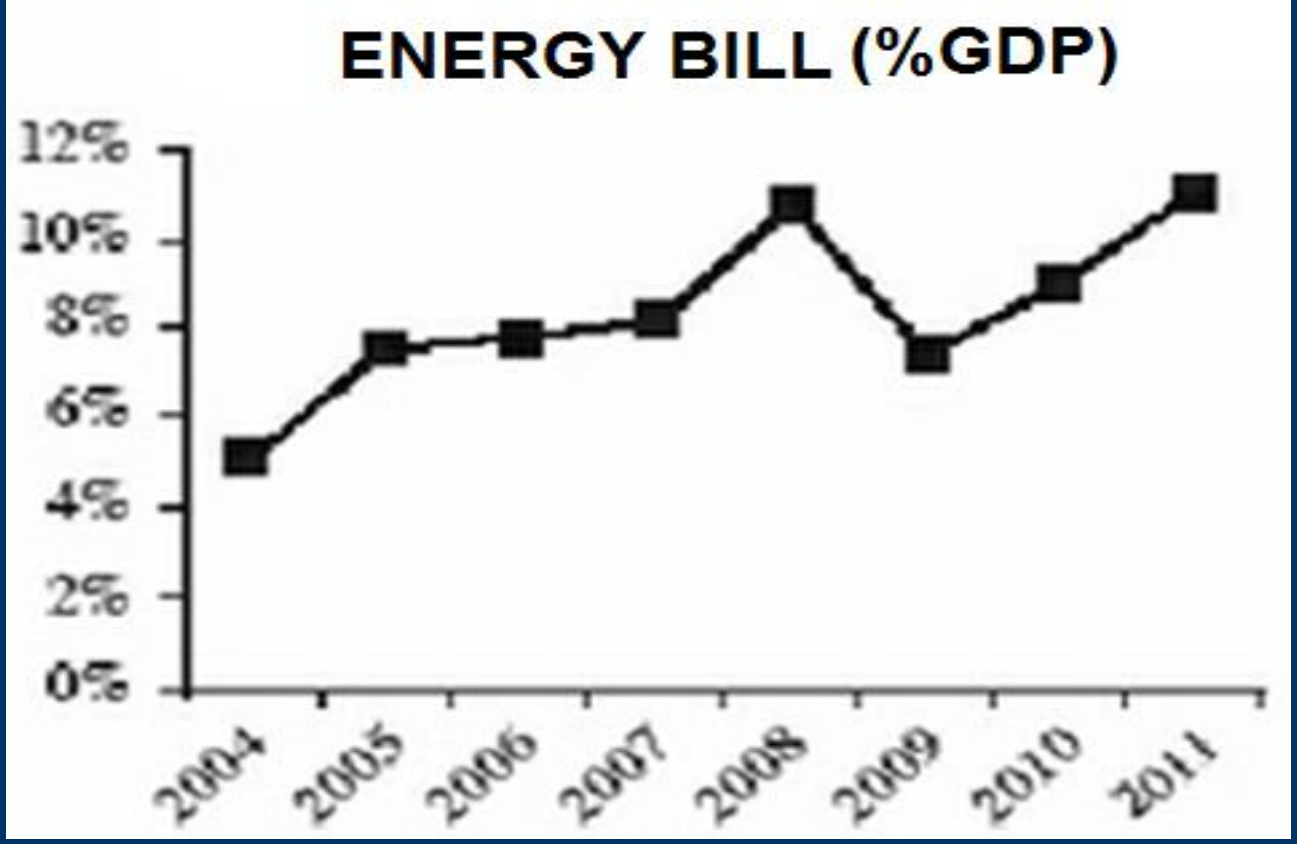
~ 97%

Energy bill

~6.4 M € (2008)
~4.9 M € (2009)
~6.2 M € (2010)

Fossil resources prices





Energy dependancy

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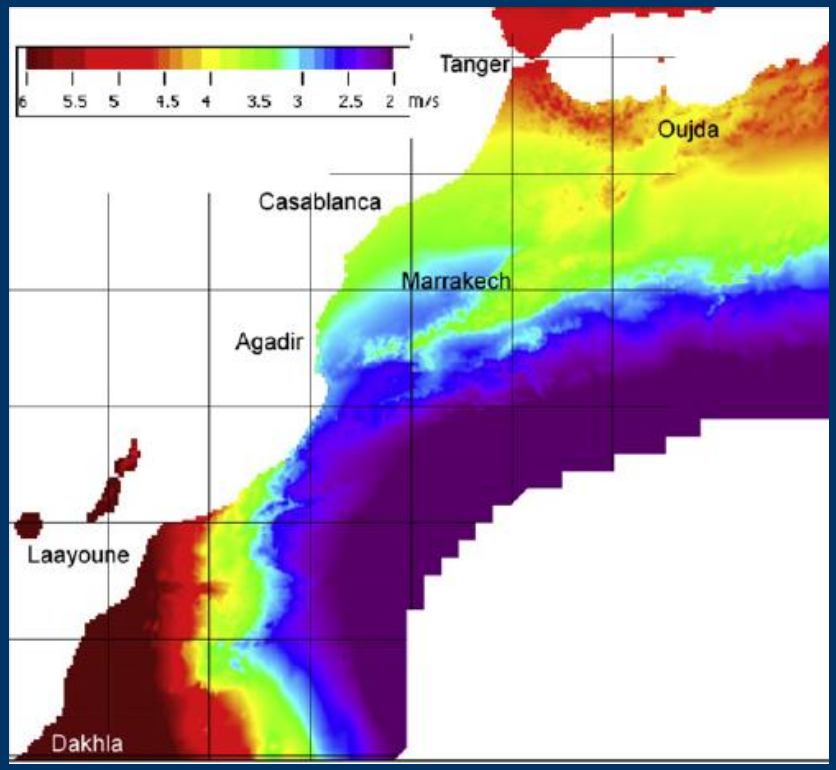
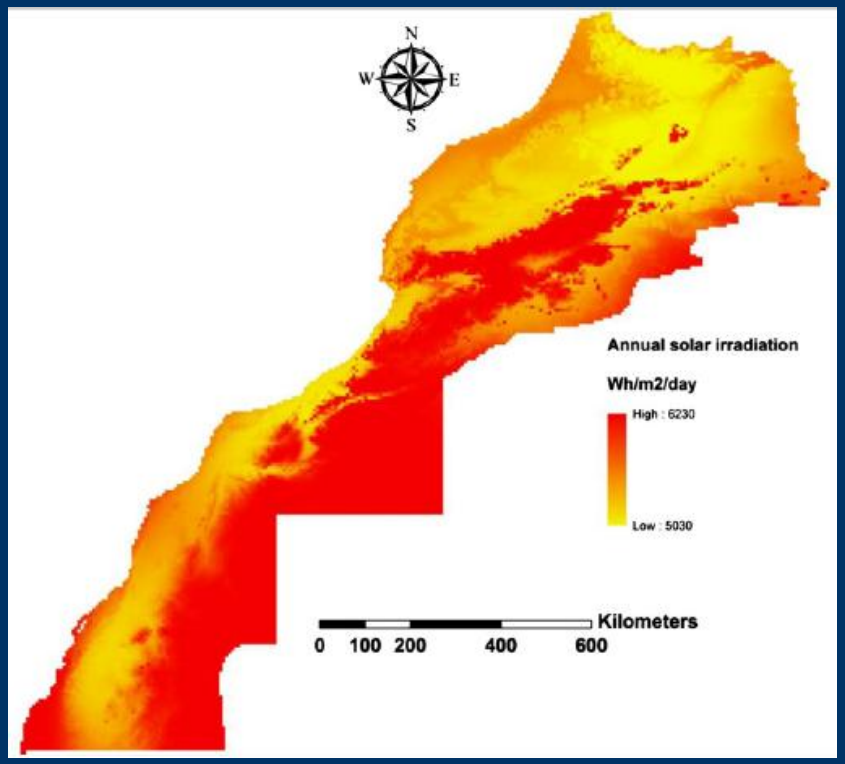
Wind potential



(Source: Ouammi and al, 2010)

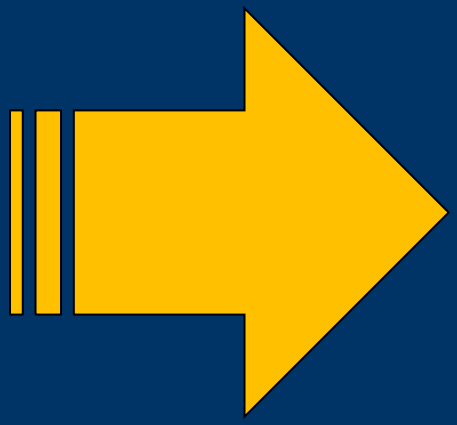
Solar potential

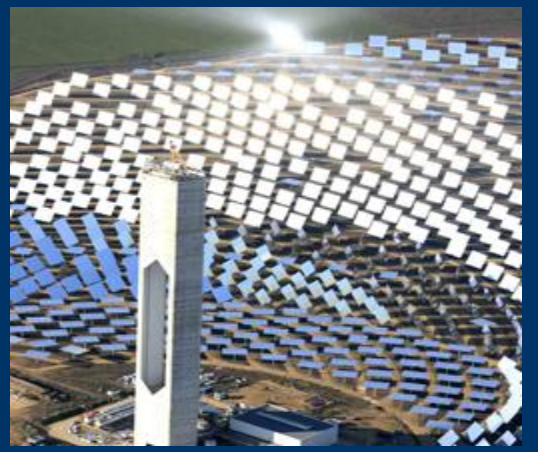


(Source: Ouammi and al, 2012)

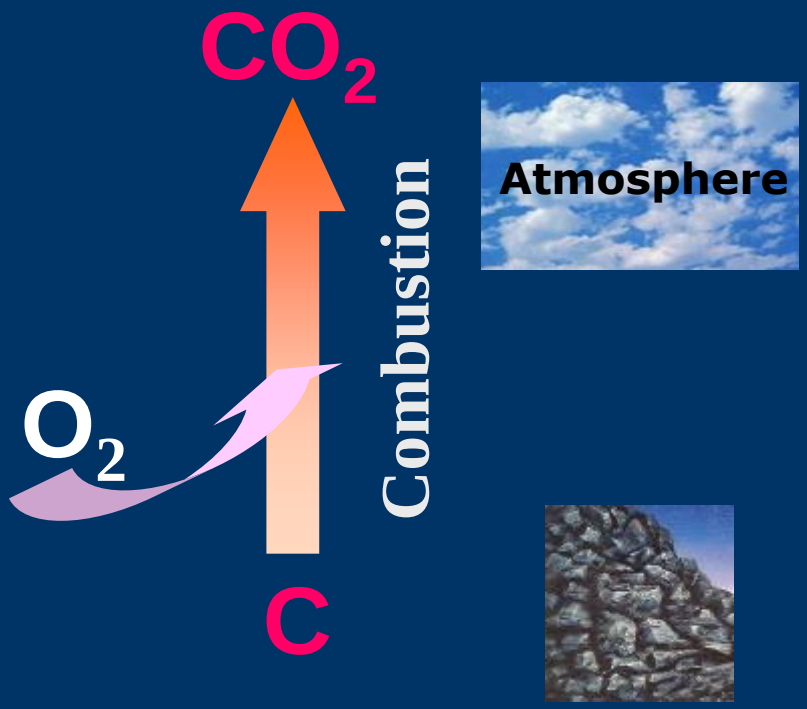
Inevitable paradigm shift:
Towards sustainability of the energy system

FOSSIL FUELS

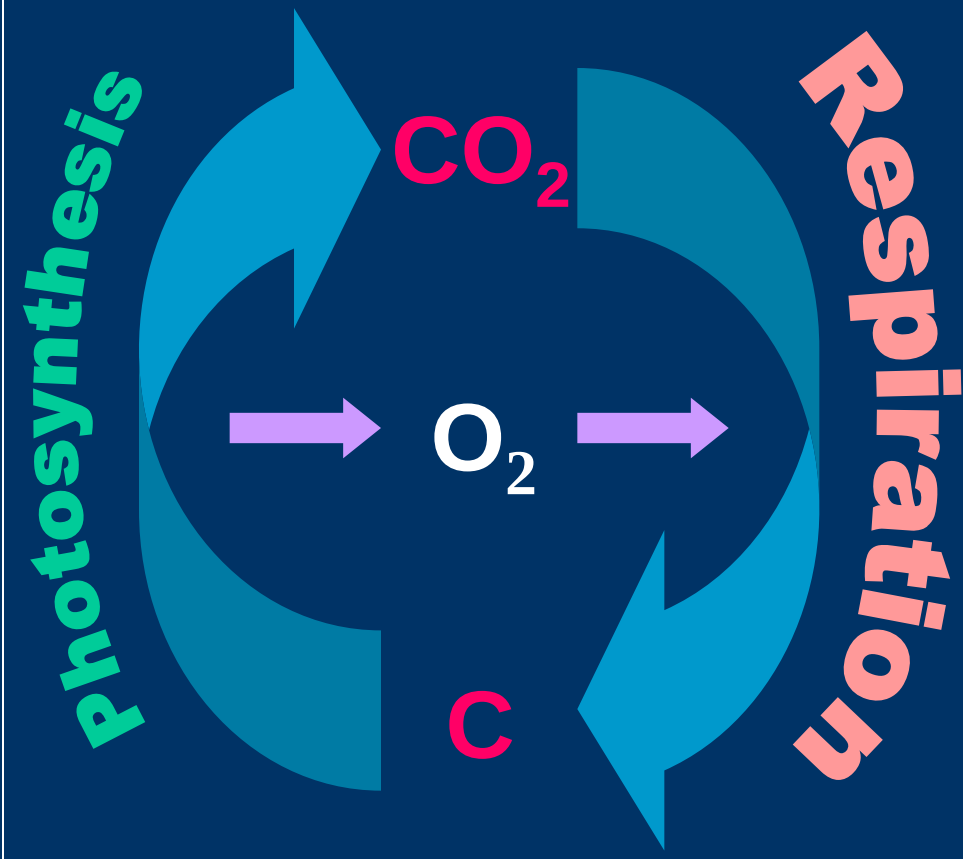




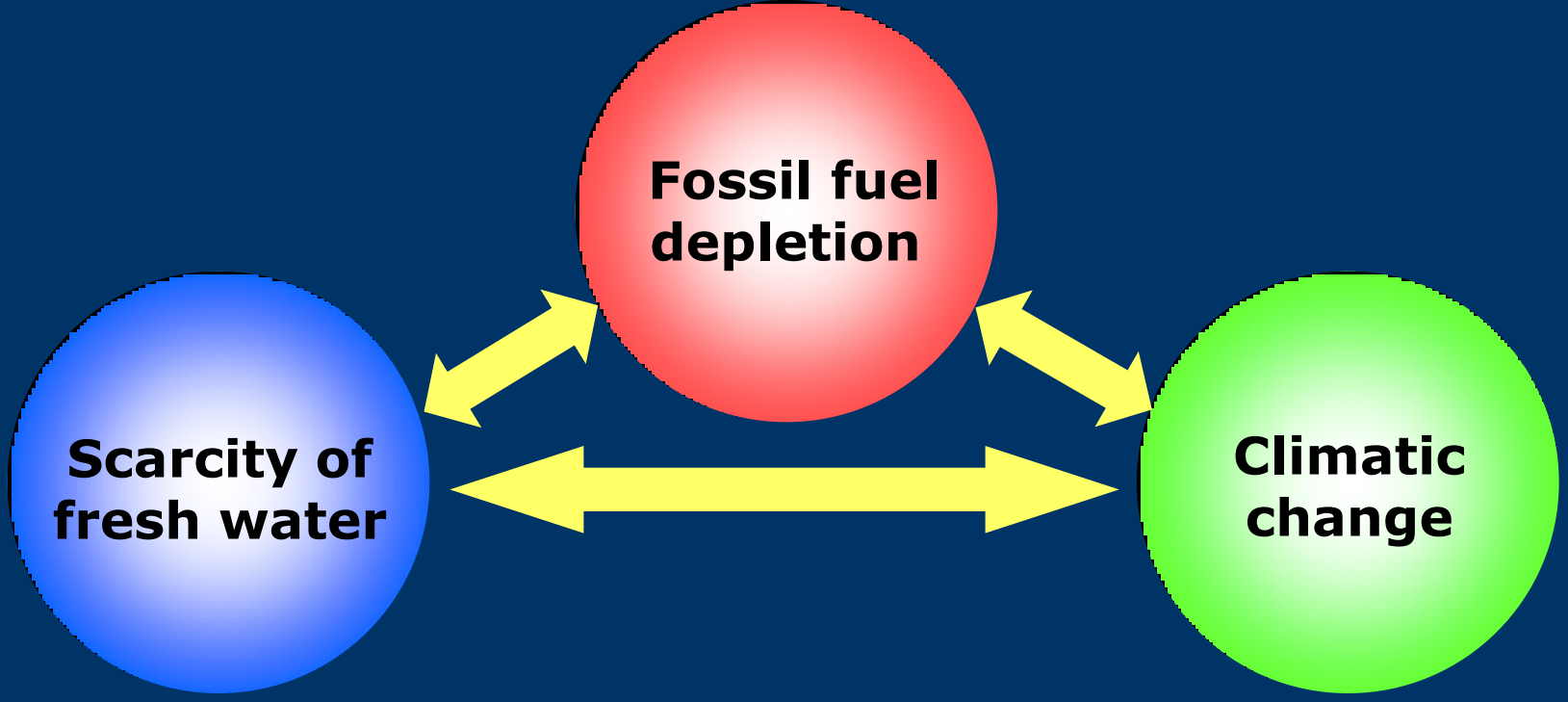
RENEWABLE ENERGIES



Non-closed current energy cycle



Closed life cycle



Major threats

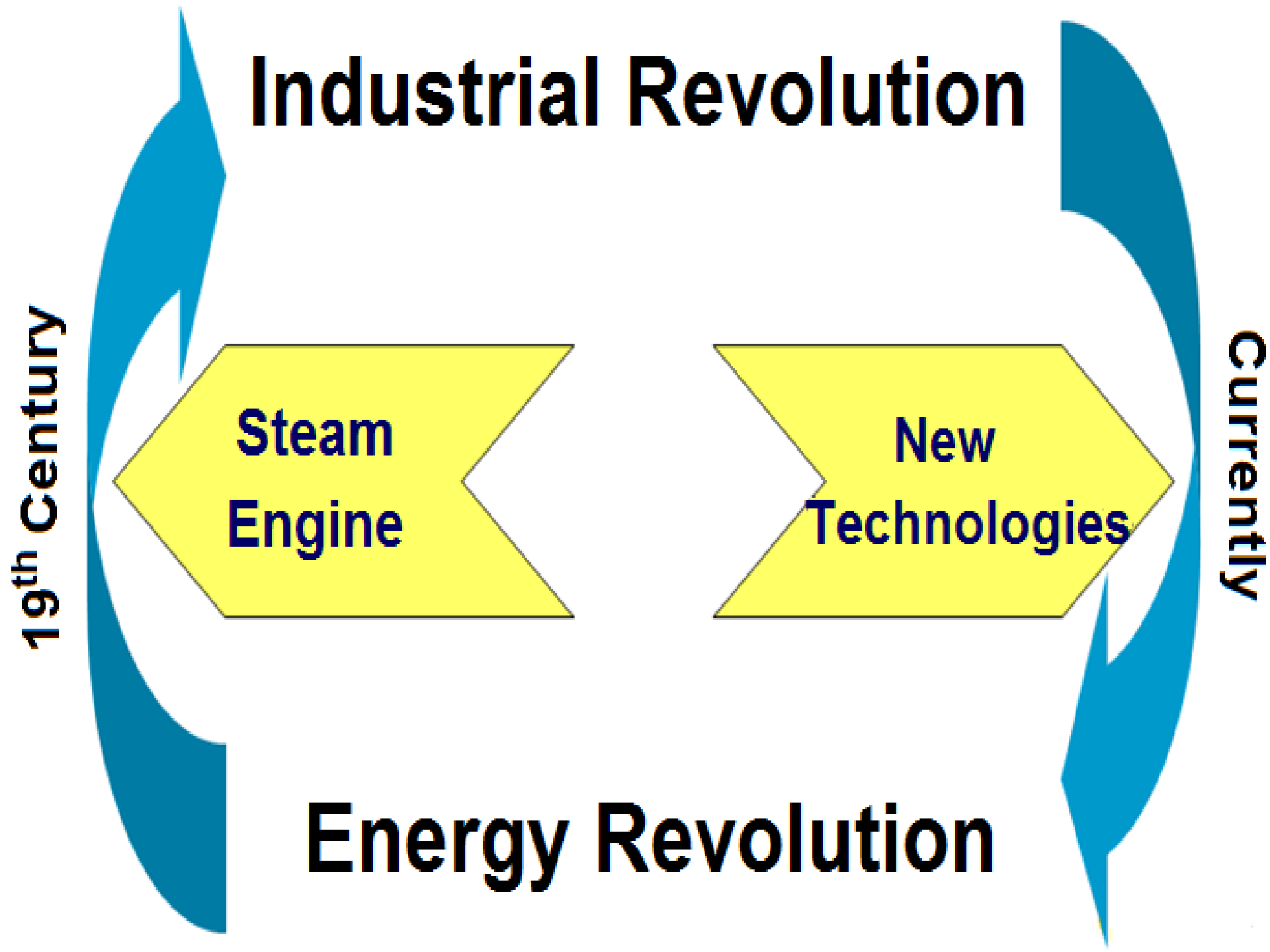
Future energy security and prosperity of Mankind

Which alternative for the current energy system?

The alternative should meet two necessary and sufficient conditions :

- **The energy source should be inexhaustible**

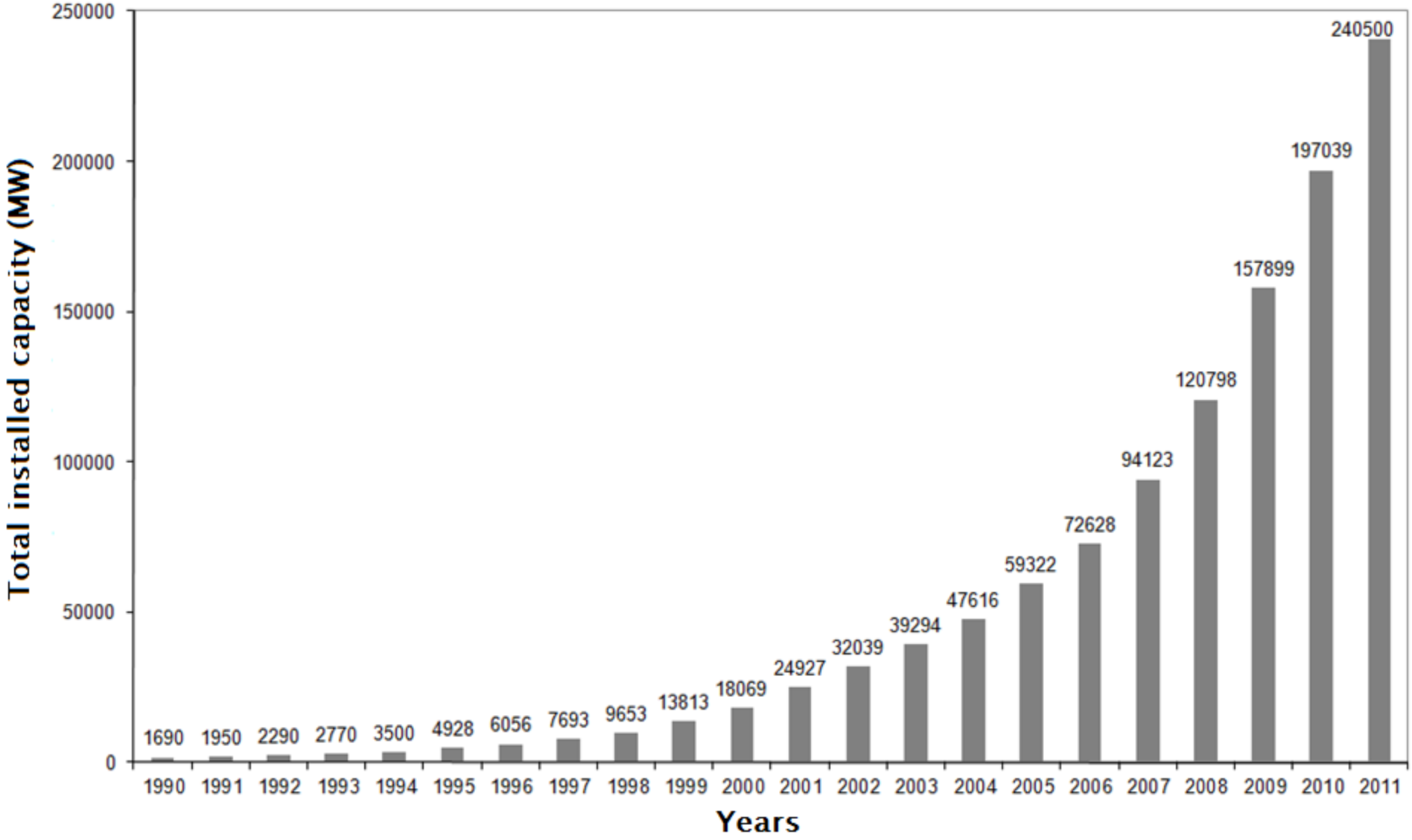
- **The energy resource should be provided without support or with a recyclable support**


Industrial Revolution
19th Century
Steam Engine
New Technologies
Currently
Energy Revolution

Investments in the field of Ren. En., 2010

(Source: REN21, 2011)

Wind Energy


Total installed capacity (MW)
250000
200000
150000
100000
50000
0
1690
1950
2290
2770
3500
4928
6056
7693
9653
13813
18069
24927
32039
39294
47616
59322
72628
94123
120798
157899
197039
240500
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Years

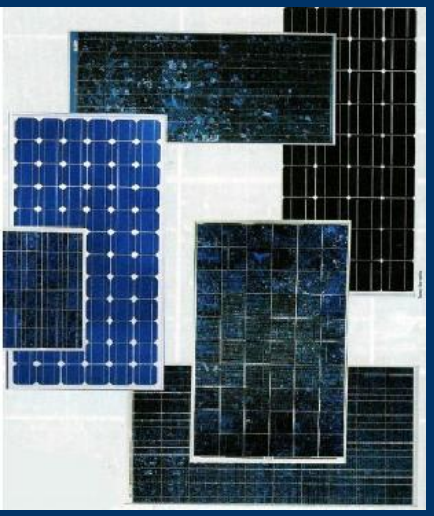
Wind Energy

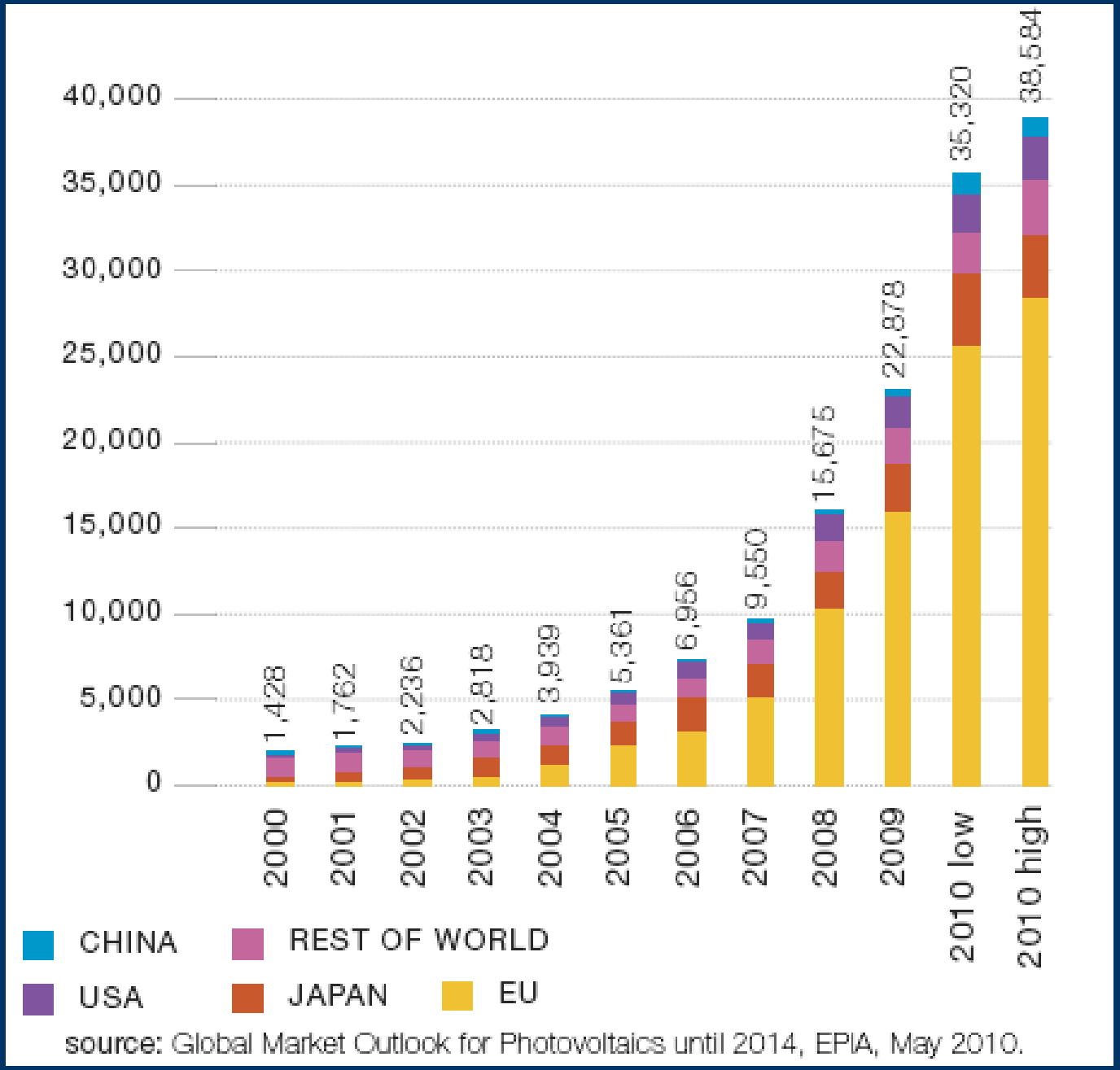
World 2010 Top Ten Manufacturers

Vestas	Sinovel	GE	Goldwind	Enercon
5842	4386	3796	3740	2846
14.8%	11.1 %	9.6 %	9.5 %	7.2 %
Suzlon	Dongfang	Gamesa	Siemens	United Power
2736	2624	2587	2325	1297
6.9 %	6.7%	6.6 %	5.9 %	3.4 %

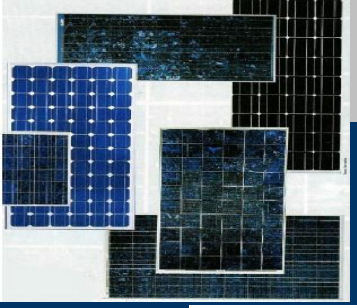
Source: BTM

Photovoltaic

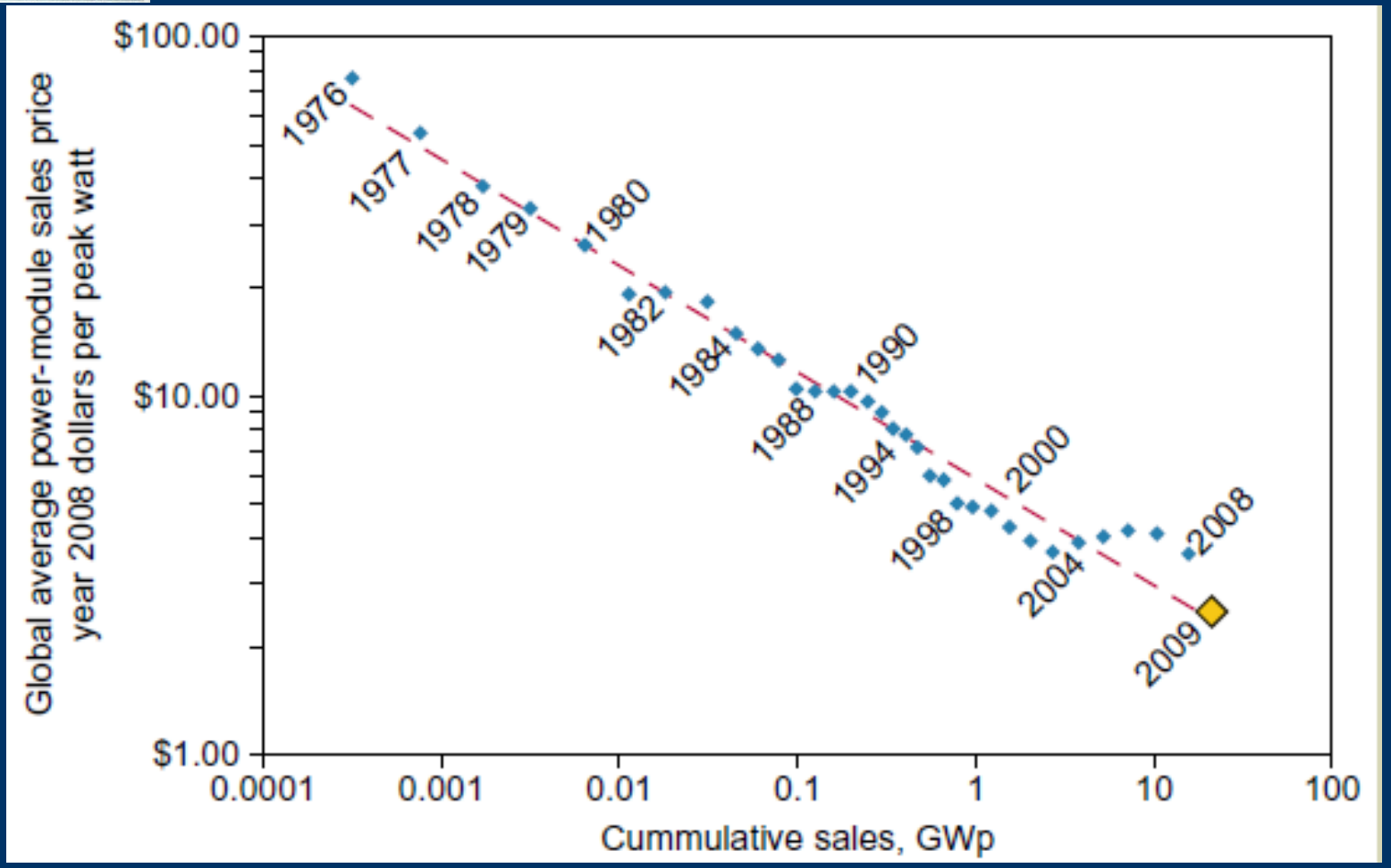




source: Global Market Outlook for Photovoltaics until 2014, EPIA, May 2010.

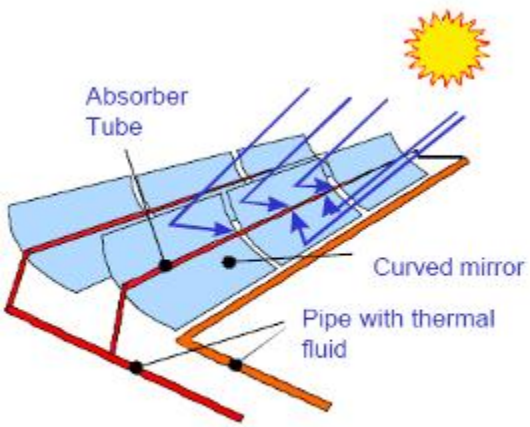


Photovoltaic

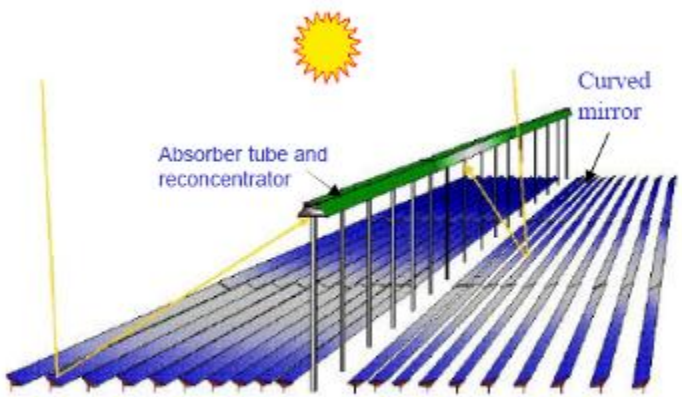


(G. Hauser and al. 2011)

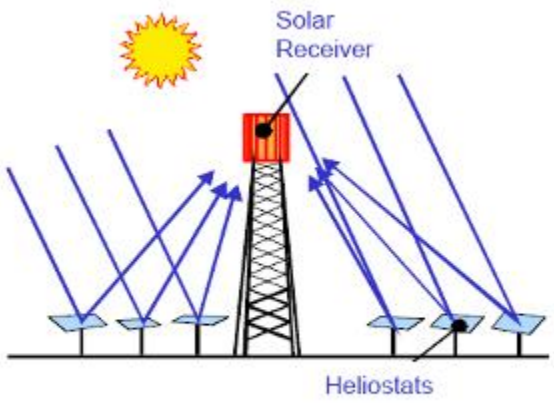
Concentrating Solar Power



Parabolic troughs



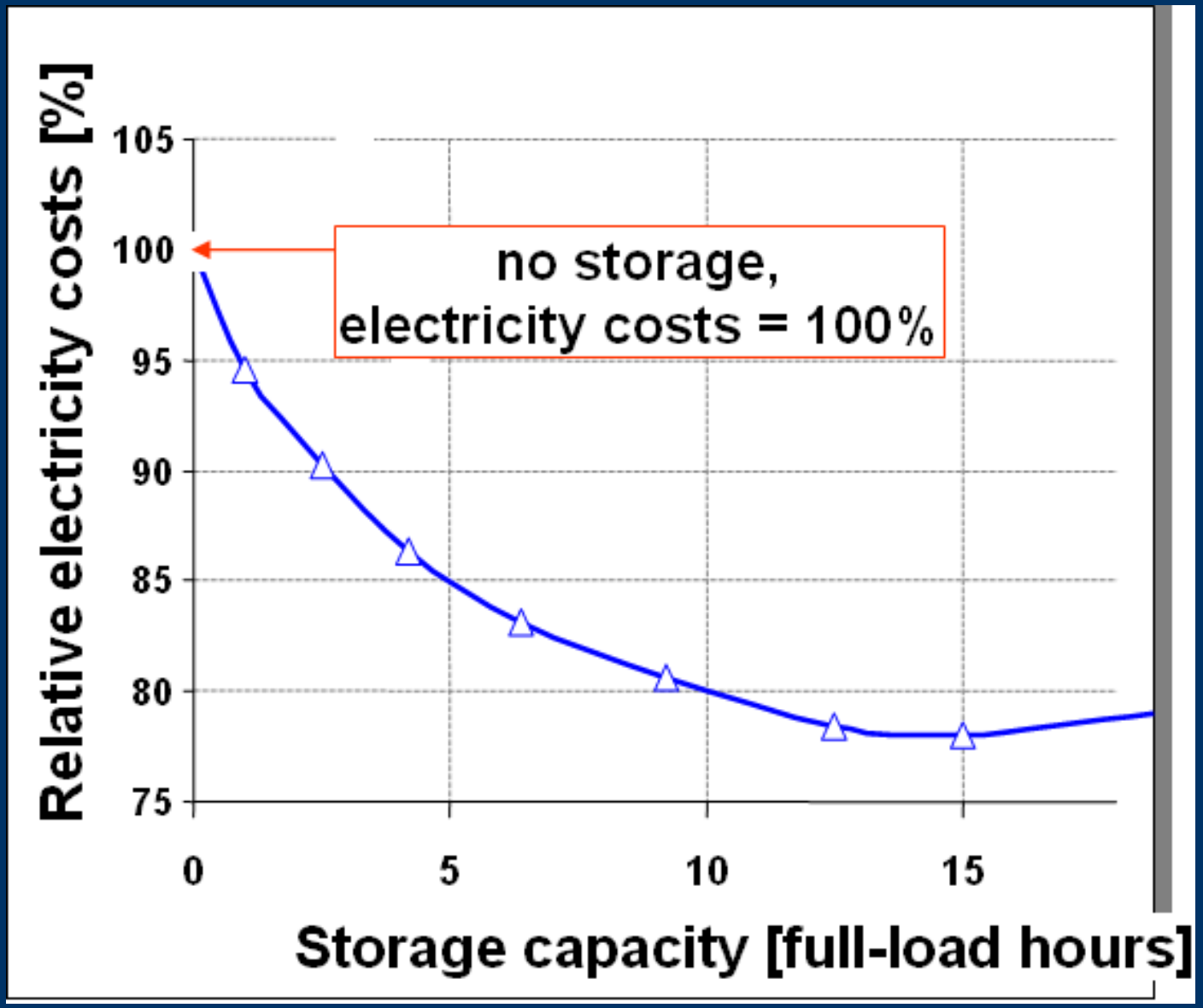
Linear Fresnel reflector



Central Receiver

- **1095 MW are installed around the world.**
- **The United States of America and Spain dominate the market with respectively 47% and 52% of the market.**
- **The capacity in construction in the world: 1934 MW.**
- **The announced capacity: 13.9 GW**

Concentrating Solar Power



(Source: Robert Pitz-Paal, 2004)

Parabolic Trough Technology

Parabolic Trough Technology

Strengths

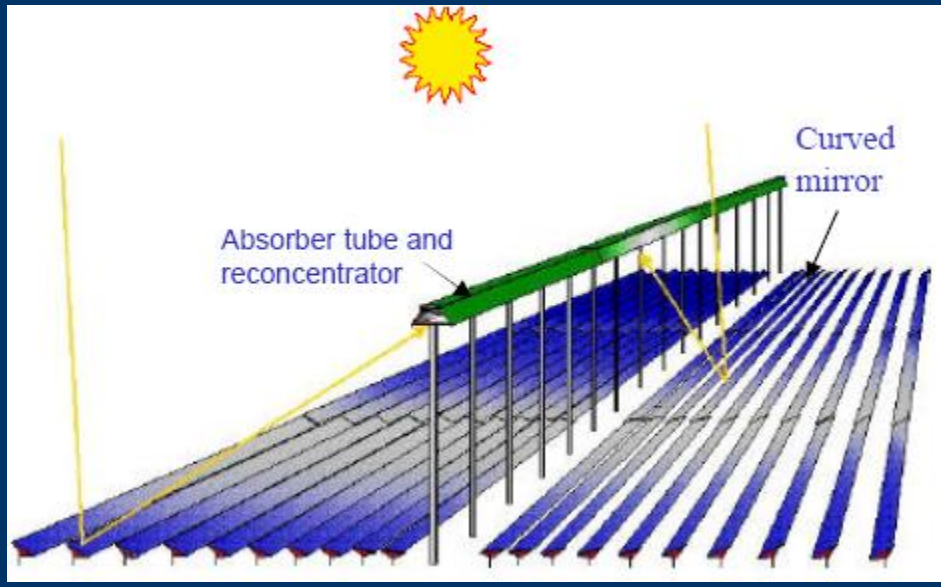
Mature technology

- Commercial evidence, more than 800 MW installed
- Long-term experiment, 9 units (SEGS) over 20 years of operation

Weaknesses

- Few manufacturers for key components (absorber tubes, mirrors), limited skills
- Limited maximum temperature, limited efficiency
- Expensive heat transfer fluids with pollution risks

Linear Fresnel Technology



Linear Fresnel Technology

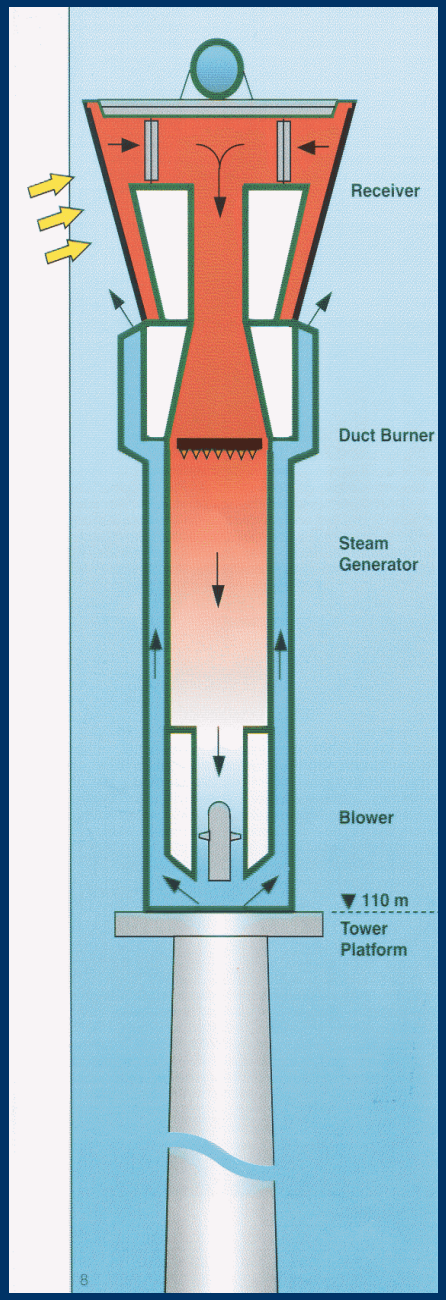
Strengths

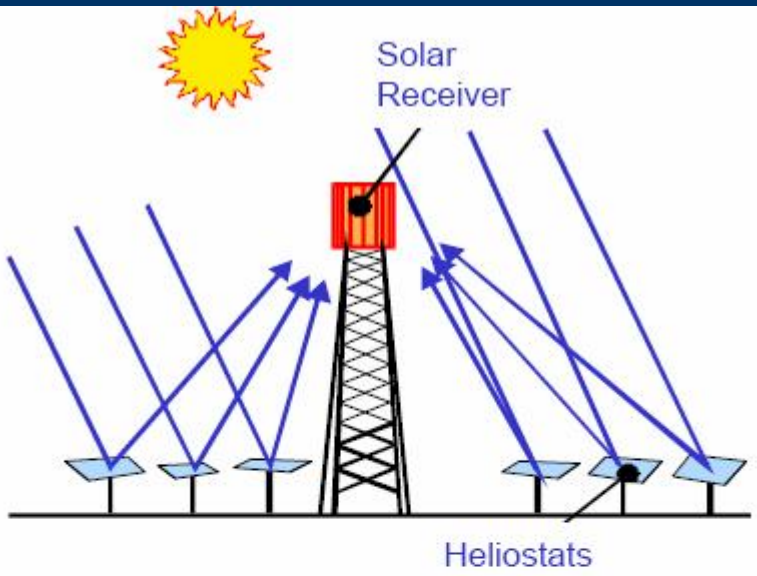
- Fixed receiver
- Predisposition to the direct steam generation
- Possibility of having long receivers, hence reducing losses due to bends
- Capital and operating costs lower than those of the parabolic trough technology

Weaknesses

- Lower efficiency

Solar Tower Technology





Central Receiver

Solar Tower Technology

PS10 et PS20 (Espagne)

Solar Tower Technology

Strengths

- High temperatures resulting in better mechanical efficiency
- Great potential of cost reduction and performance improvement

Weaknesses

- Complexity
- Limited commercial experiences

The New Energy Strategy in Morocco

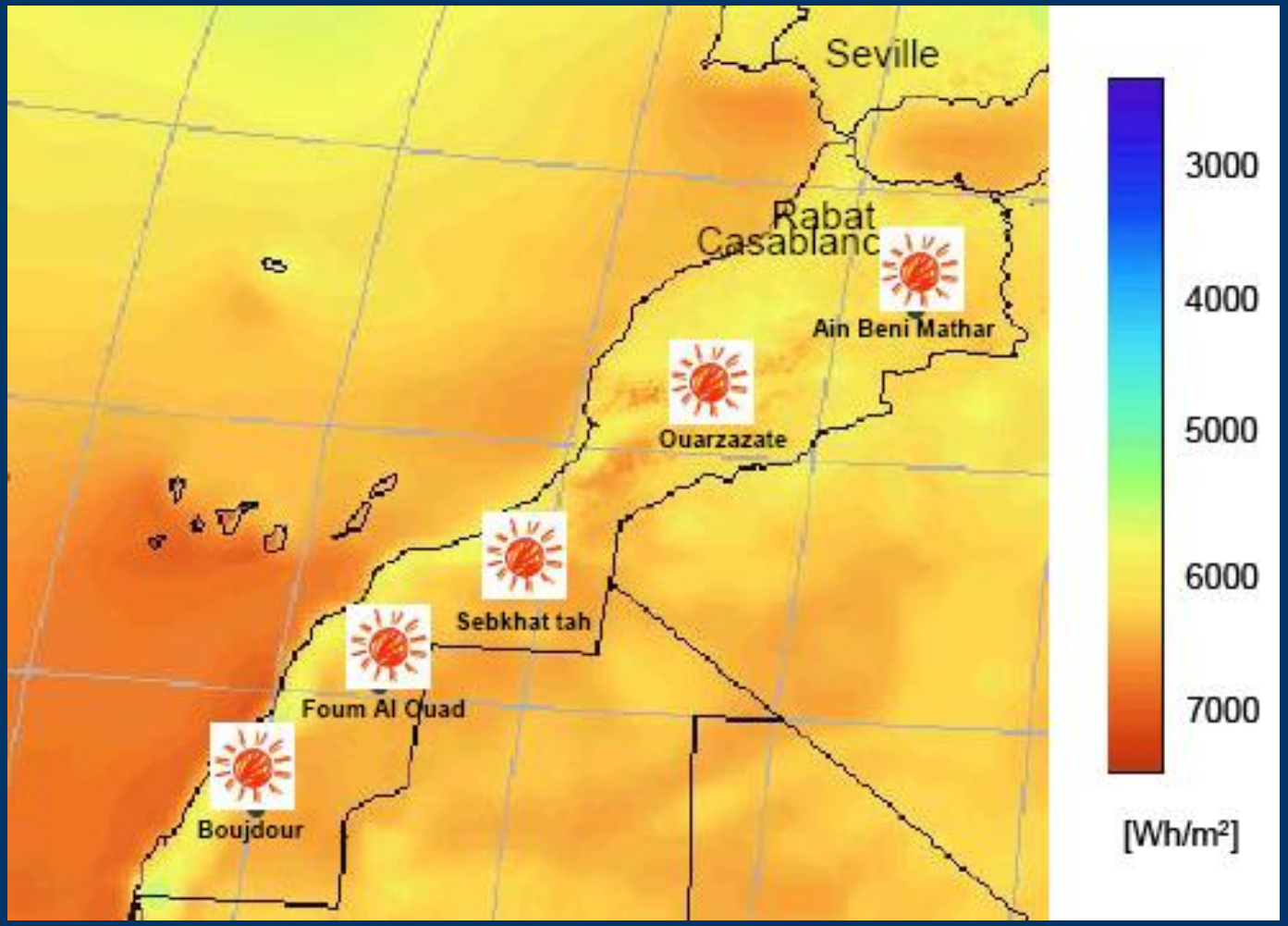
Morocco is placing the bar higher

W

The Moroccan Solar Plan

MW

Moroccan Solar Plan

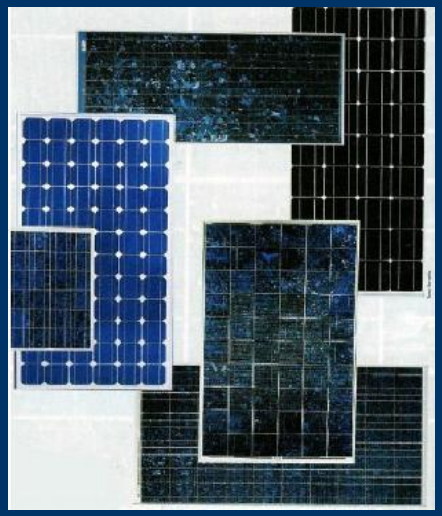


(Source: MASEN)

Moroccan Solar Plan

An investment of 9 billion USD

- Installed Capacity : 2000 MW
- 4500 GWh per year
- 10 000 hectares dedicated
- First plant : Ouarzazate - 2015



The Moroccan Integrated Wind Project

An investment of 3.5 billion USD

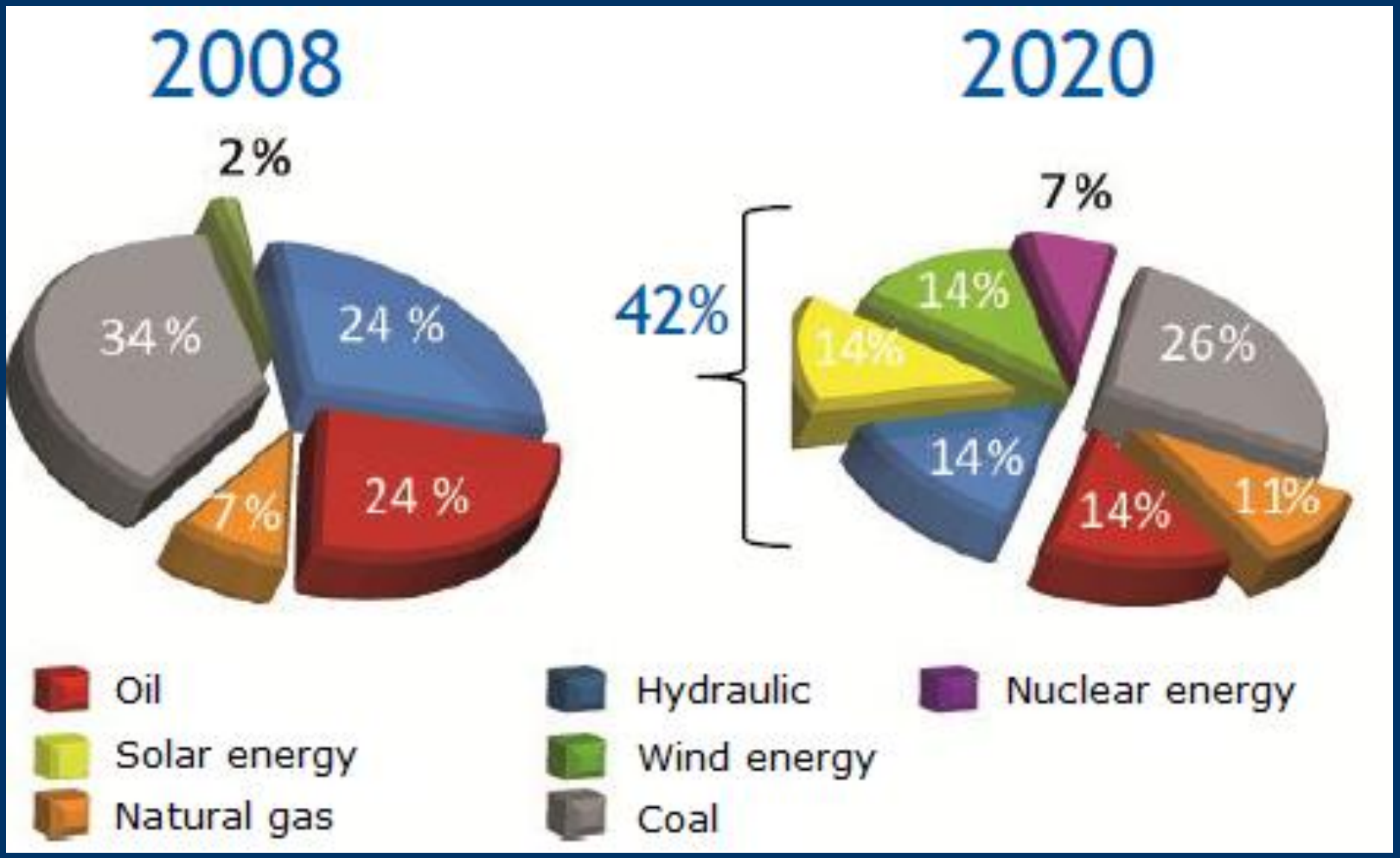
- Installed Capacity : 2000 MW
- 6600 GWh per year
- Investment: 3.5 Billion USD

Development of Renewable energies in Morocco

Towns	Installed capacity (MW)
Tétouan	54 32
Tanger	75 65
Essaouira	60

(Total : 286 MW)

(Source : www.compagnieduvent.com)



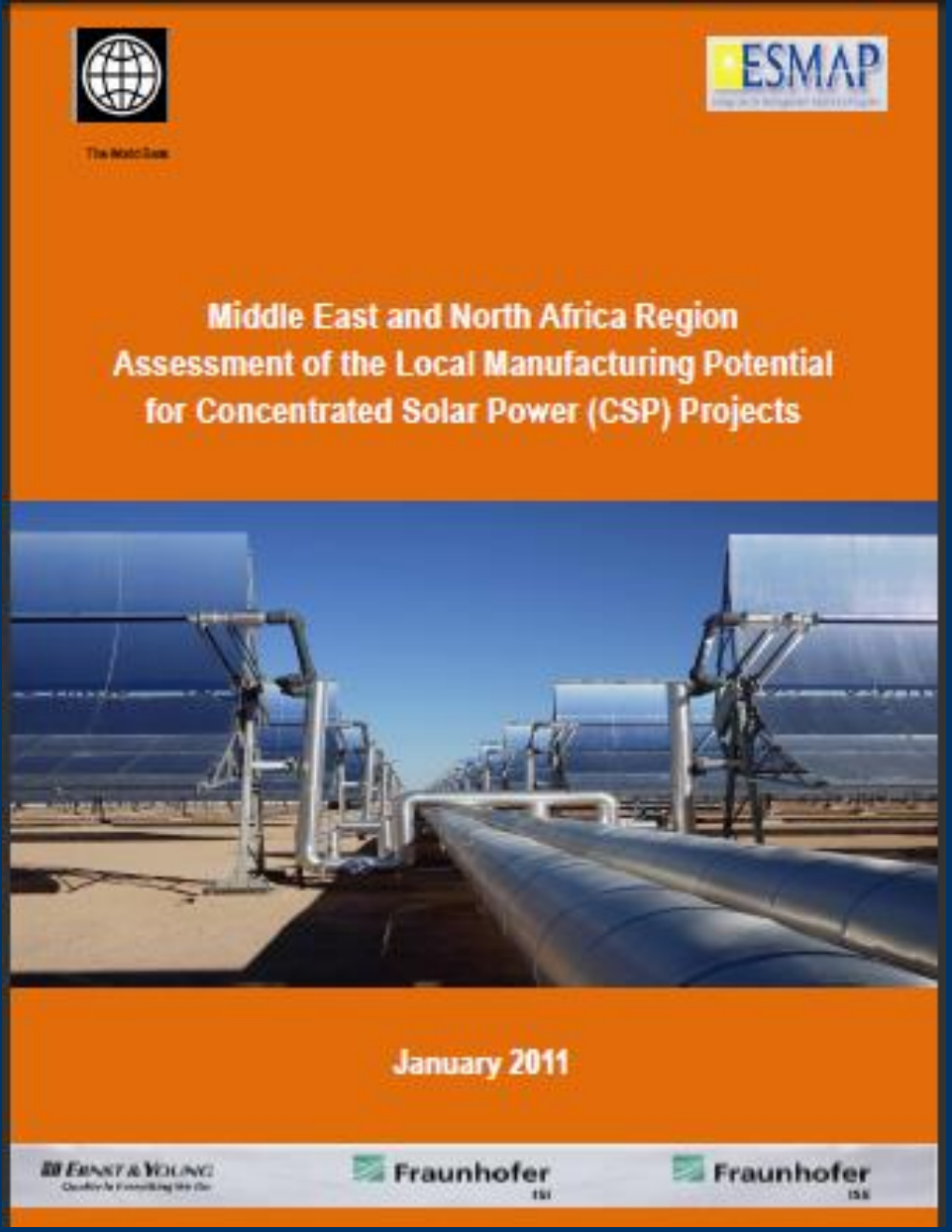
(Source: Ministère de l'Energie, des Mines, de l'Eau et de l'Environnement)

Which technology would be chosen?

Making the Right Choice by Asking the Right Questions

- Which parts of the value chain of CSP and PV technologies are suitable for local manufacturing?

- Which parts of those could compete with the ones produced in other Countries?



http://arabworld.worldbank.org/content/dam/awi/pdf/CSP_MENA__report_17_Jan2011.pdf

How to bridge

the financing

gap

How to bridge the financing gap without using Feed-in-Tarif Policy?

- Choosing a financing package for each project
- The international development finance institutions could provide opportunities for initial steps and reference projects.
- Exporting renewable electricity to European Union based on Article 9 of the EU Renewable Energy Directive. However, the transmission of this article into national regulation is still lacking.

To achieve the export of electricity to Europe, continuous efforts of negotiation and lobbying for some years are needed

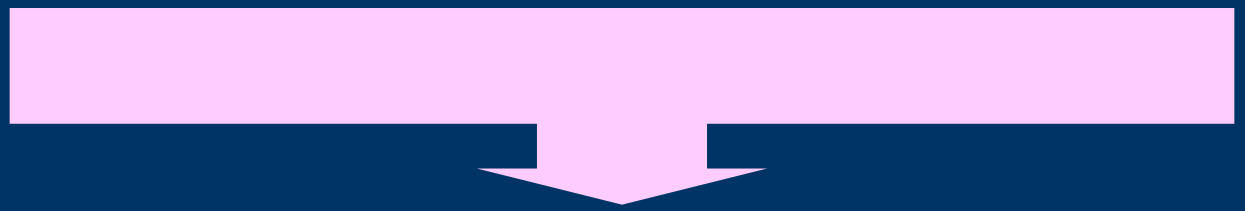
How to bridge the financing gap without using Feed-in-Tarif Policy?

It should be noted that the implementation of the Moroccan Solar Plan was not just a question of electricity production, but a strategic choice for Morocco's development

Some problems with high penetration of renewable energies in the network

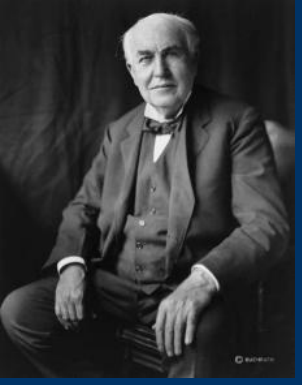
Intermittency

Limited predictability



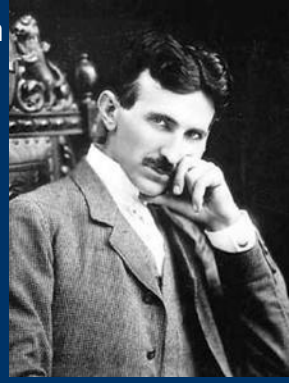
- **Grid congestions: Need for new grid infrastructure**
- **Necessity of reserve capacity**
- **Frequent of connections and disconnections**
- **Reliability issues: high penetration of RE-DG into a power network can result in risk of making the entire network less reliable**
- **Power quality issues, measured by level of voltage variations**

The Electric Grid
From Dumb to Smart Grid
Towards an evolutionary System of Systems

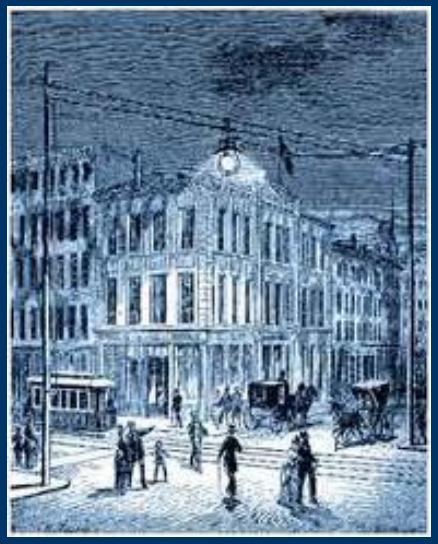


Thomas Edison

Nikola Tesla



If Thomas Edison and Nikola Tesla could see the current electricity grids, they would consider themselves still living in the 19th century

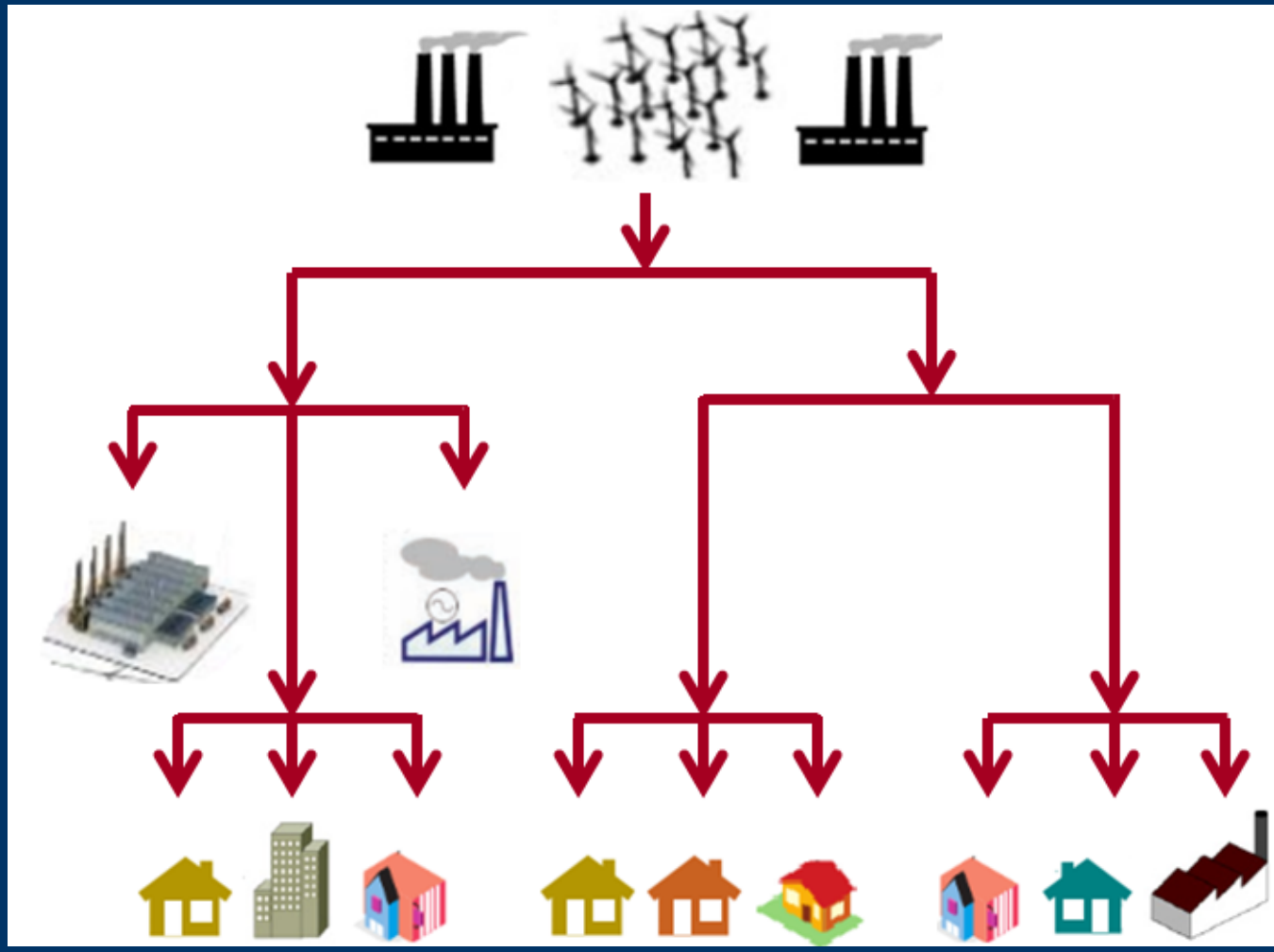


The current Grid

Production

Transmission

Distribution



The Network is being operated with fewer resources

Main drawbacks of the centralized generation

Main drawbacks

- Transmission and distribution costs: transmission and distribution costs amount for up to 30% of the cost of delivered electricity on average.
- Security and reliability :
  -Less fossil diversity
  - The bigger the power stations, the greater the threat of a chain reaction as one station fails
- Environmental Impact: heavy reliance on fuel, coal and natural gas

Orientation

Distributed generation is a promising concept that is considered as an alternative solution for addressing technical, economical and environmental issues of conventional power systems

Distributed Generation

In a Distributed generation (DG) all the generating technologies available in a given centralized or decentralized region are integrated in the power supply system according to the availability of their respective resources.

Distributed Generation

DG is often described as "integrated" and "decentralized" to distinguish it from traditional centralized systems

Distributed Generation system and the consumer are close together; so little energy is lost in transmission and in distribution lines

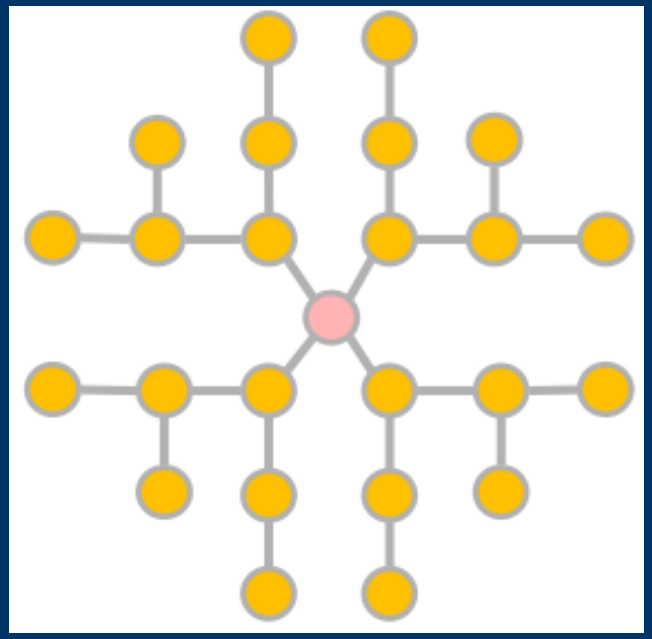
Distributed Generation

Different ratings of Distributed Generation

- **Micro Distributed generation: 1 W - 5 kW**
- **Small Distributed generation: 5 kW - 5 MW**
- **Medium Distributed generation: 5 MW - 50 MW**
- **Large Distributed generation: 50 MW - 300 MW**

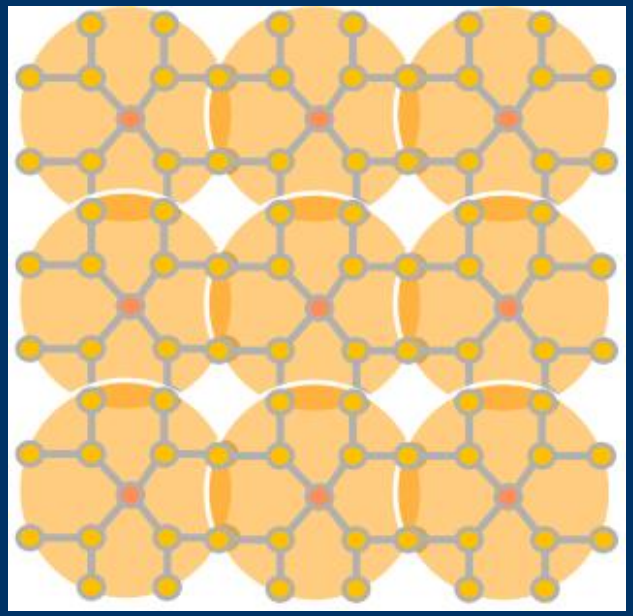
The trend of the electric power system configuration's evolution

Centralized generation

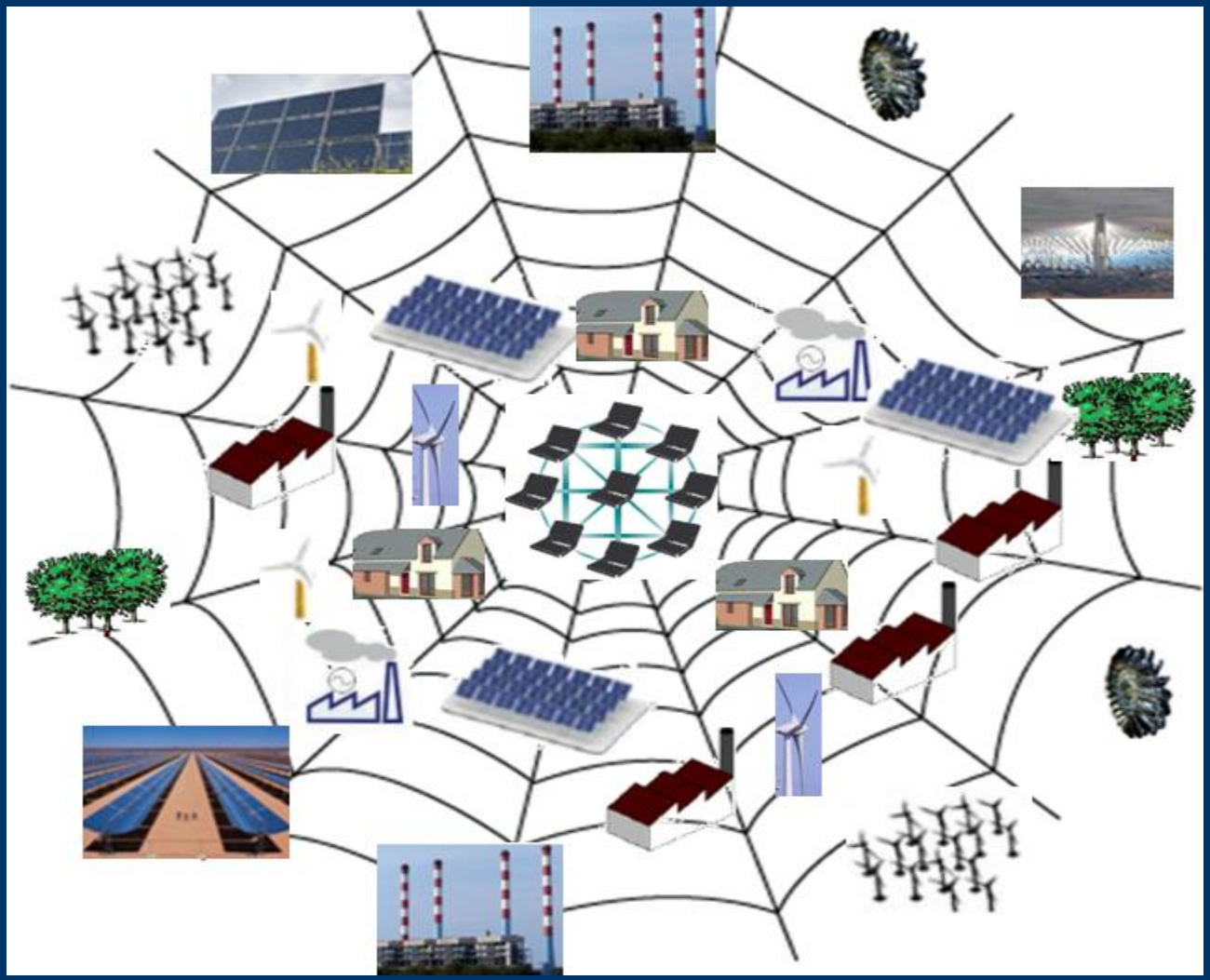


The Network is being operated with fewer resources

Distributed generation



The future generation mix is changing



Smart Grid → System of Systems

The Smart Grid as an evolving networked System of systems

A system of systems as one in which its components

- **Fulfill valid purposes in their own right, and continue to operate to fulfill those purposes if disassembled from the overall system**

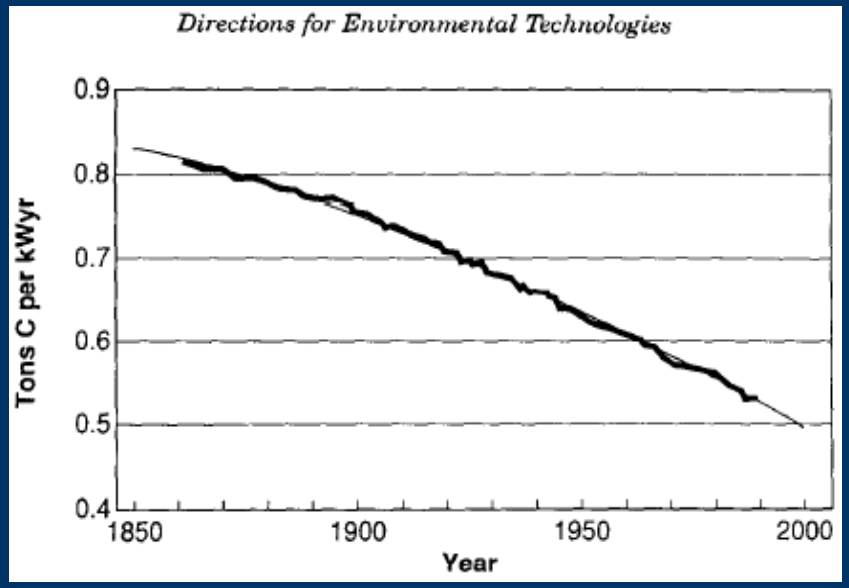
- **Are managed (at least in part) for their own purposes rather than the purposes of the whole; the components systems are separately acquired and integrated but maintain a continuing operational existence independent of the collaborative system**

The Smart Grid as a System of Systems

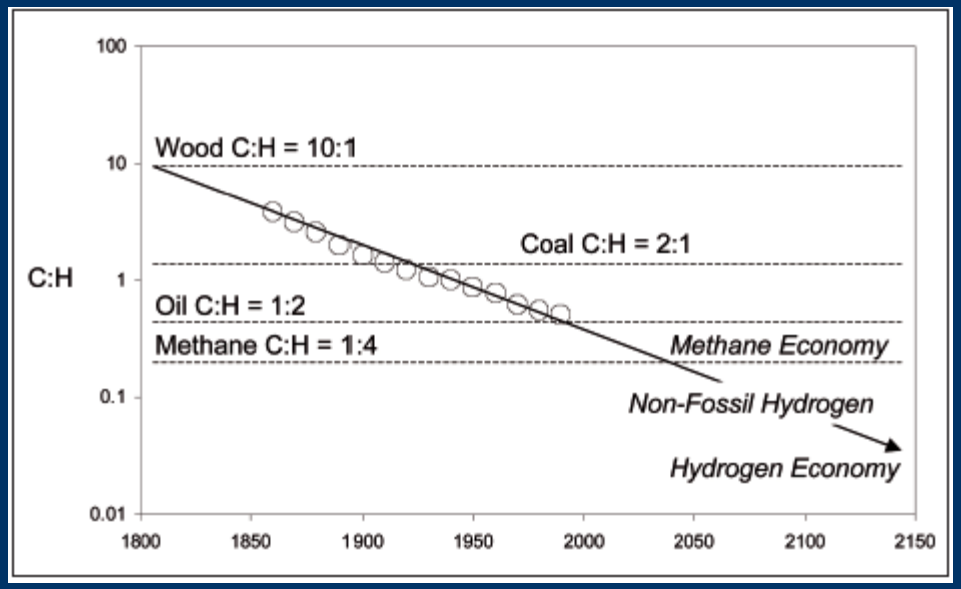
Towards the Electricity Economy?

A Mirage or a Reality?

Decarbonisation of global primary energy



Decarbonisation or the Changing Carbon Intensity of the Primary Energy for the World



Evolution of the Ratio of Carbon (H) to Hydrogen (C)

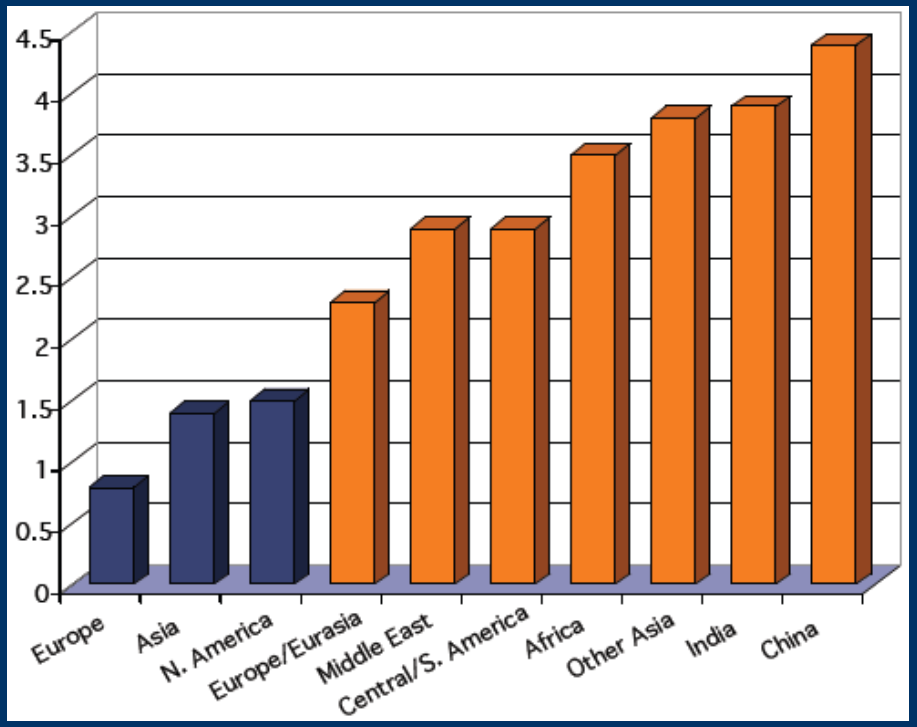
[Source: J. H. Ausubel, 2007]

Revolution by Evolution of the Electric Power Infrastructure

Category	1950	2000	2050 (est.)
World Population	2.56B	6.22B	8.29B
Electricity usage	2.06 TW	3.80 TW	6.99 TW
Electricity as % of total energy	10.4%	25.3%	33.7%

Electricity Growth Trends

[Source: Global Environment Fund,2008]



Annual Percentage Growth in Electricity Generation by Region, 2004-2030. System for the Analysis of Global Energy Markets, EIA, 2007

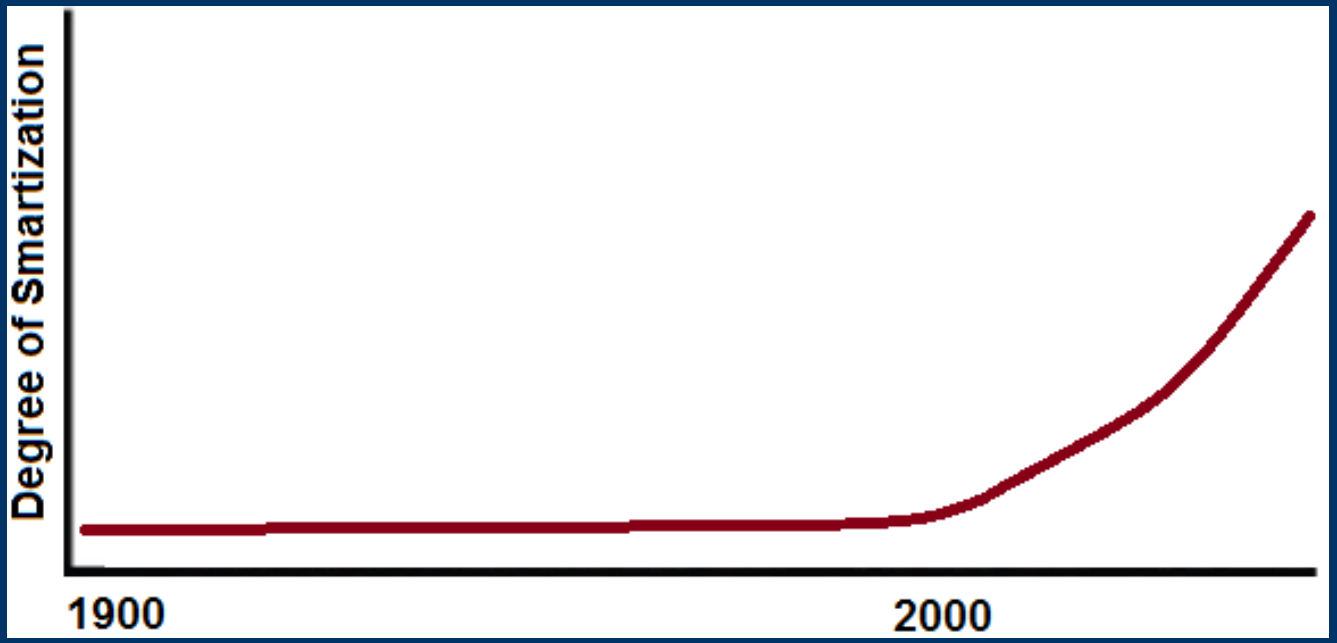
Revolution by Evolution of the Electric Power Infrastructure

"Micropower" plants produced one sixth of the world's total electricity and one third of the new electricity added in 2005. For the first time, micropower plants produced more electricity worldwide than nuclear power.

[Source: Global Environment Fund,2008]

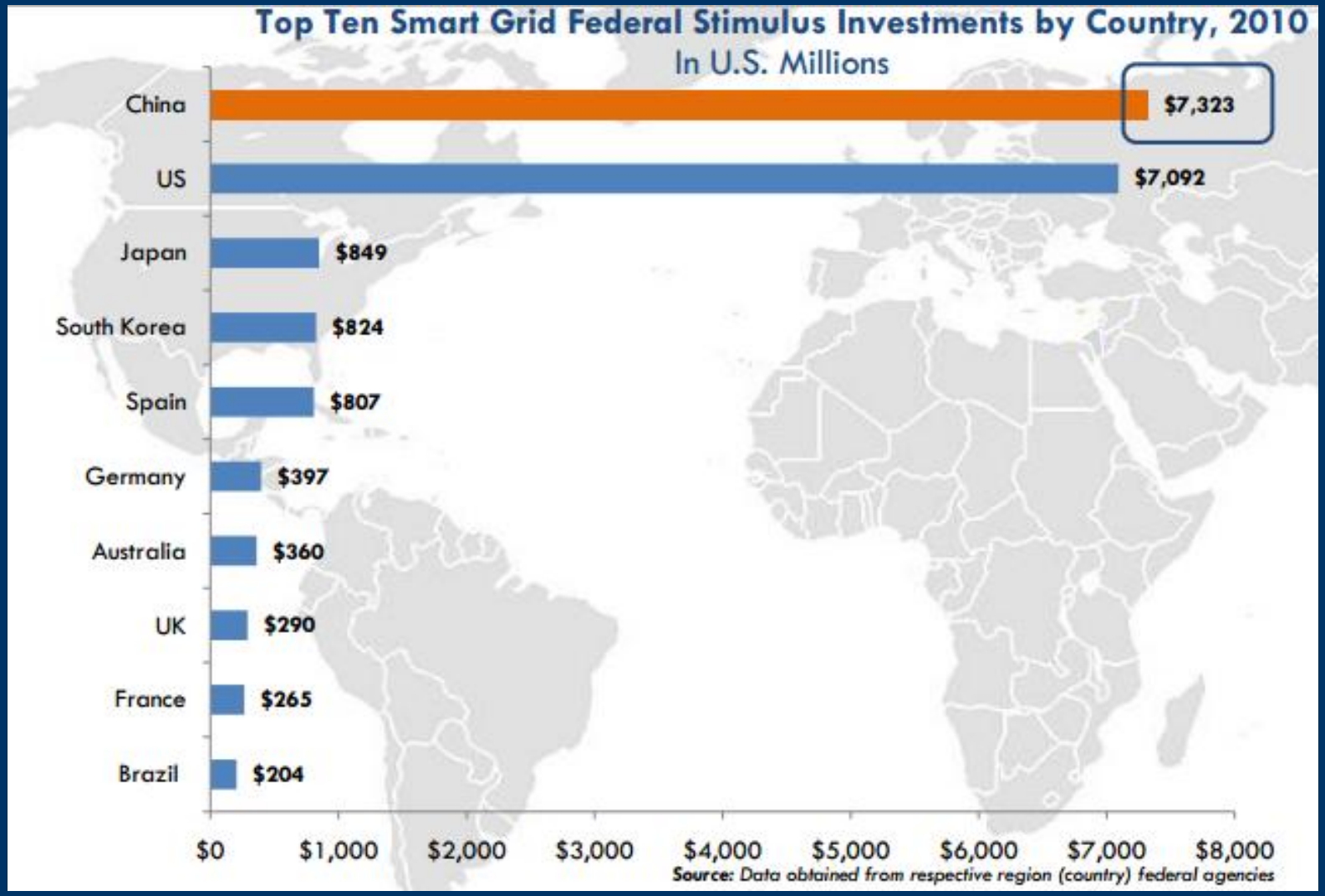
Revolution by Evolution of the Electric Power Infrastructure

Smartization of the Electric Grid



- Intelligent devices
- Two-way communications
- Advanced control systems

Revolution by Evolution of the Electric Power Infrastructure



CONCLUSION

Decarbonization of global primary energy

Evolution of the electric power infrastructure

The coming Electric Economy through a Smart Grid as a System of Systems

Thank you for your attention