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# *Experience from Europe*
## *ESI challenges and identification of pertinent research issues*

William D'haeseleer
KU Leuven Energy Institute / EnergyVille

# Setting the Stage / Context

- Energy Strategy Drivers – **Sustainable Energy Provision**
  - Security of Supply

Europe, 1 January 2006 & 2009

USA, August 14 2003



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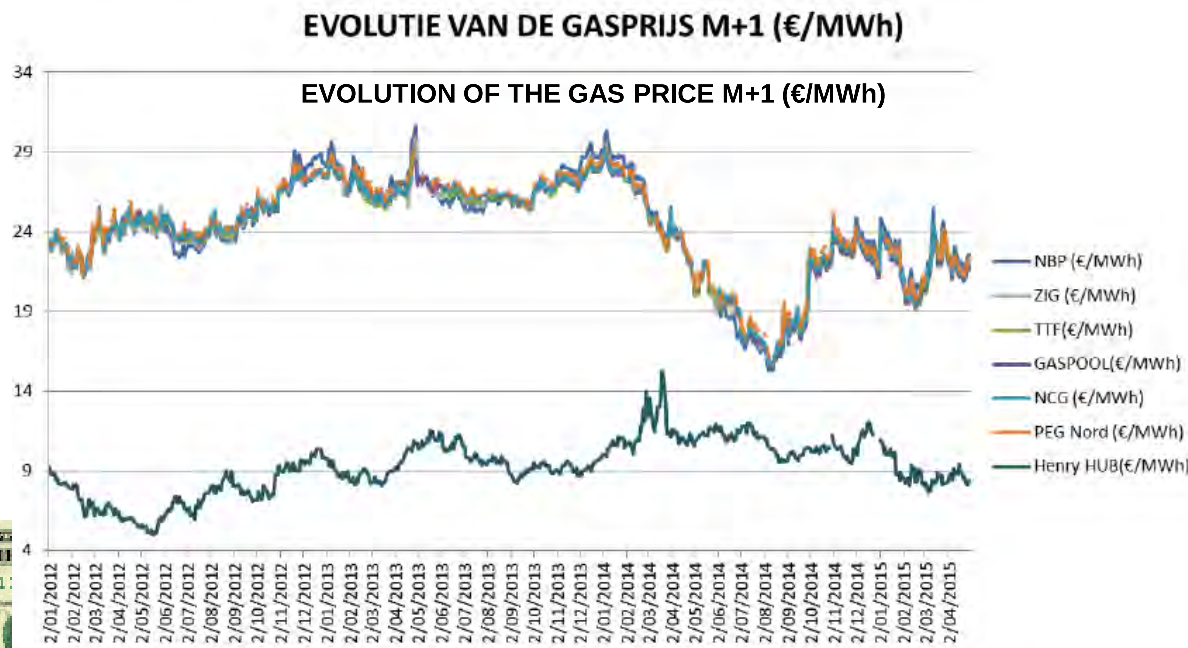
# Setting the Stage / Context



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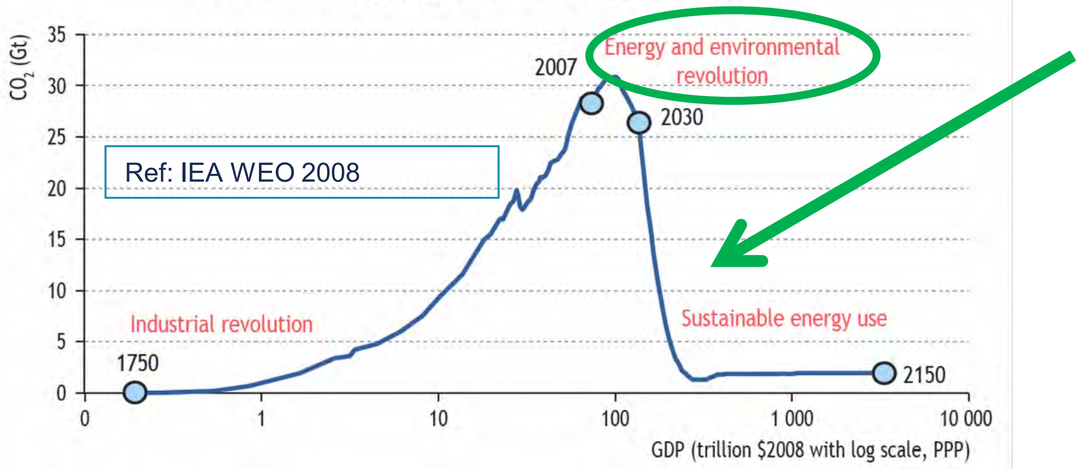
# Setting the Stage / Context

- Energy Strategy Drivers – **Sustainable Energy Provision**
  - Security of Supply
  - Affordability & Competitiveness
  - Clean Energy Conversion (Climate Change)

**Figure 4.3** • Historical link between energy-related $CO_2$ emissions and economic output, and the pathway to achieving a 450 Scenario







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# But …Uncertainties

## Often “ignored” … ☹

- Economic & financial crisis ($ - €) → investments?
- Uprisings in MENA?… Geopolitics Iran, Ukraine, Turkey, Venezuela,…?
- Future energy prices (oil, gas)? High or low?
- Shale gas? Will the US export NG? Shale gas in Europe or China?
- Biofuels?
- Carbon Capture & Storage (CCS)? …
- Role of nuclear power?
- *Rate* of penetration intermittent renewables?
- Possible game changers / disruptive technologies – electricity storage (batteries, renewable methane, hydrogen)?
- Unstable regulatory & policy framework (“regulatory uncertainty”)

# A Priori Observations

- World primary energy mix *is*,
  and is "*expected*" *to remain* ...for quite some time,
  **fossil** based...

- 2010 ... ~ 80% primary energy is fossil
  2050 ... ~ 60% to 75% fossil (depending on scenarios)

- Three major end-use sectors:
  - Electricity
  - Heat (buildings & industry)
  - Transportation

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# Security of Supply

- Energy supply interuptions do happen!

- Structured delineation of SoS

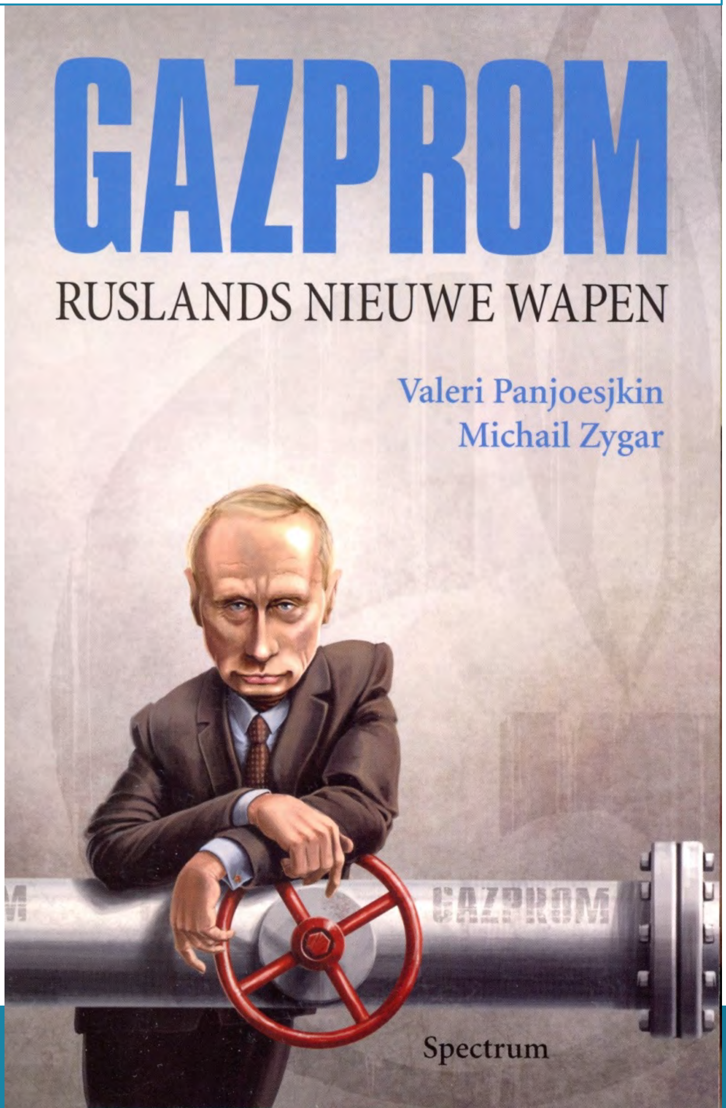
# Security of Supply

- Energy supply interuptions do happen!

- Structured delineation of SoS

# SoS – Natural Gas

**Russia's new weapon**




**Book published in 2008 …**

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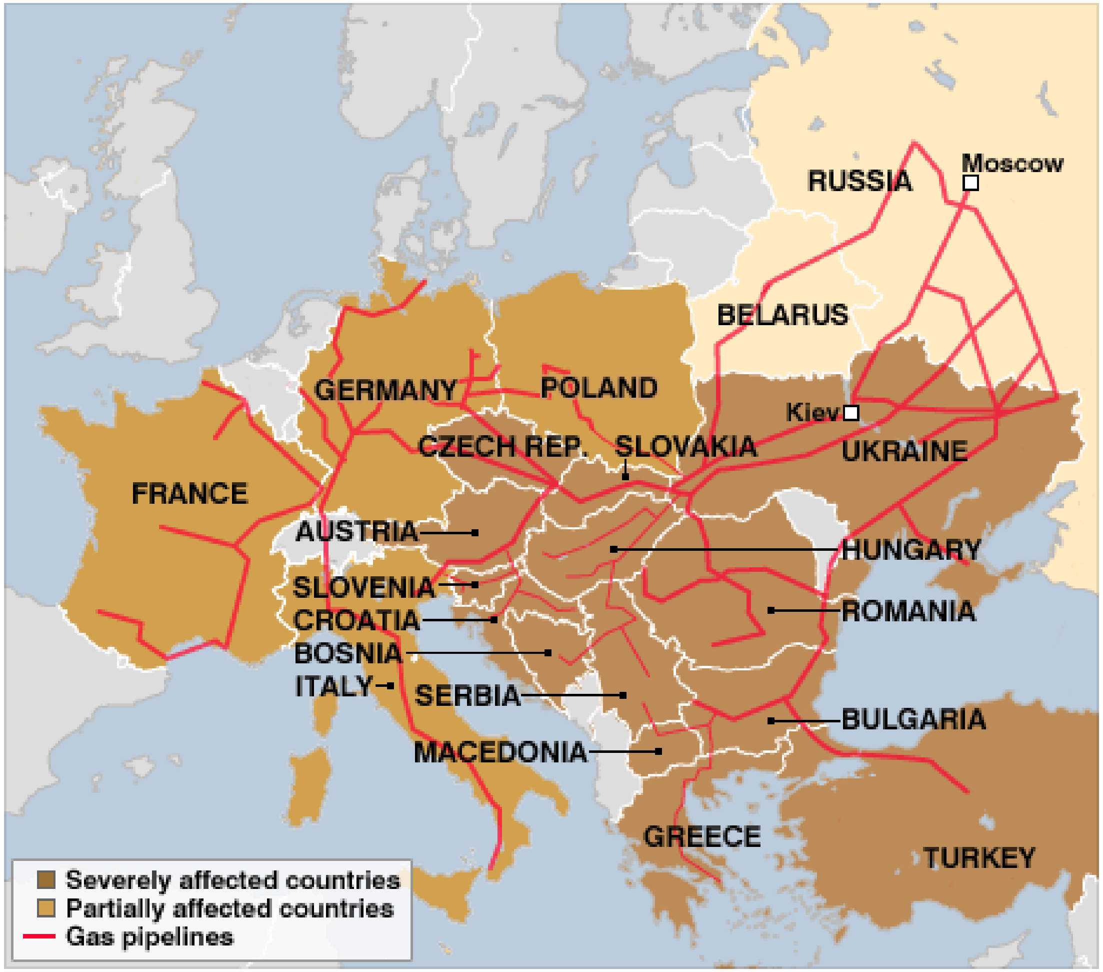
# January 01 2009

# Russia – Ukraine conflict Jan 2009

COUNTRIES AFFECTED BY CRISIS

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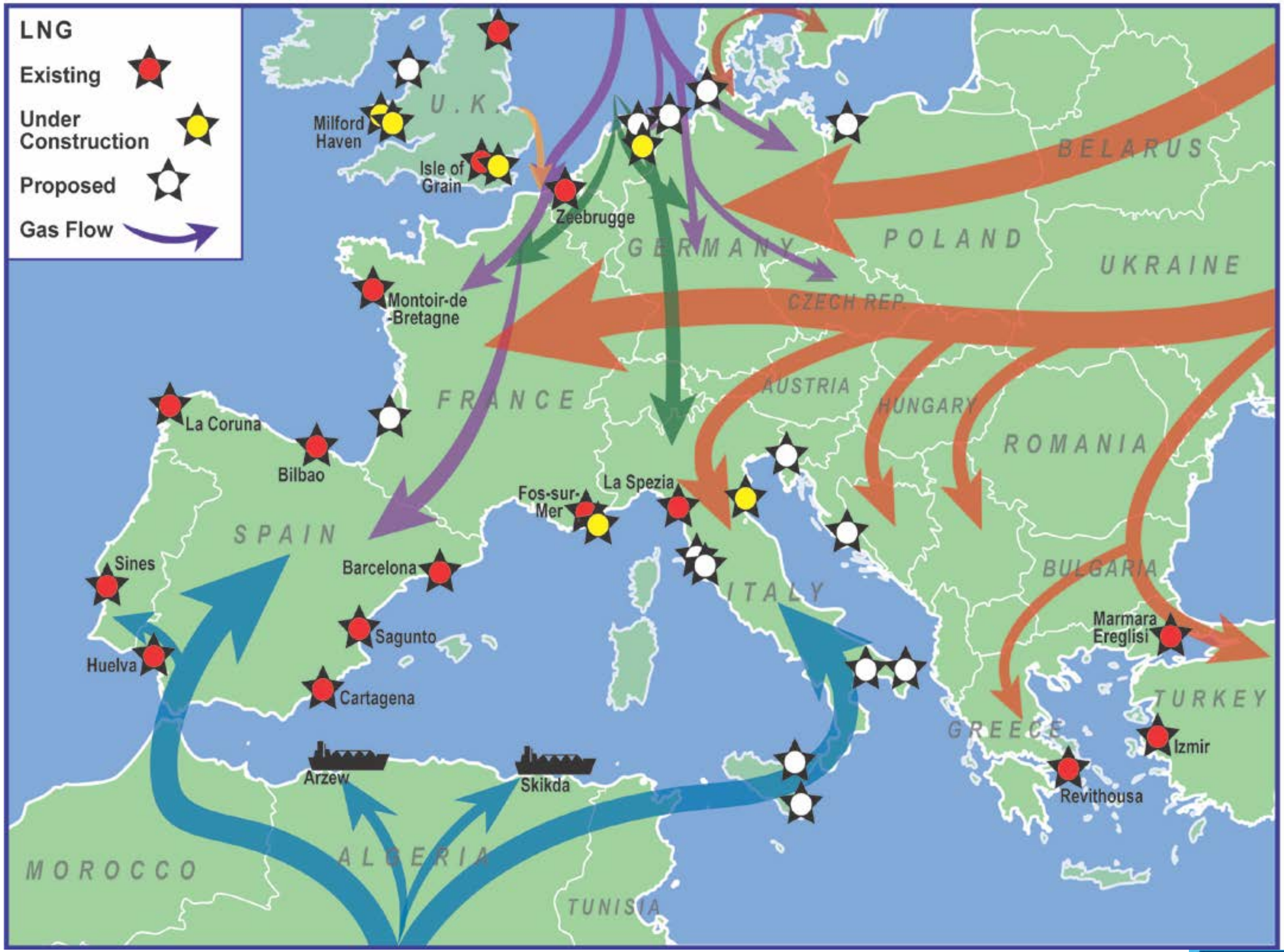
# Gas flows in Europe




OK

# To be avoided !

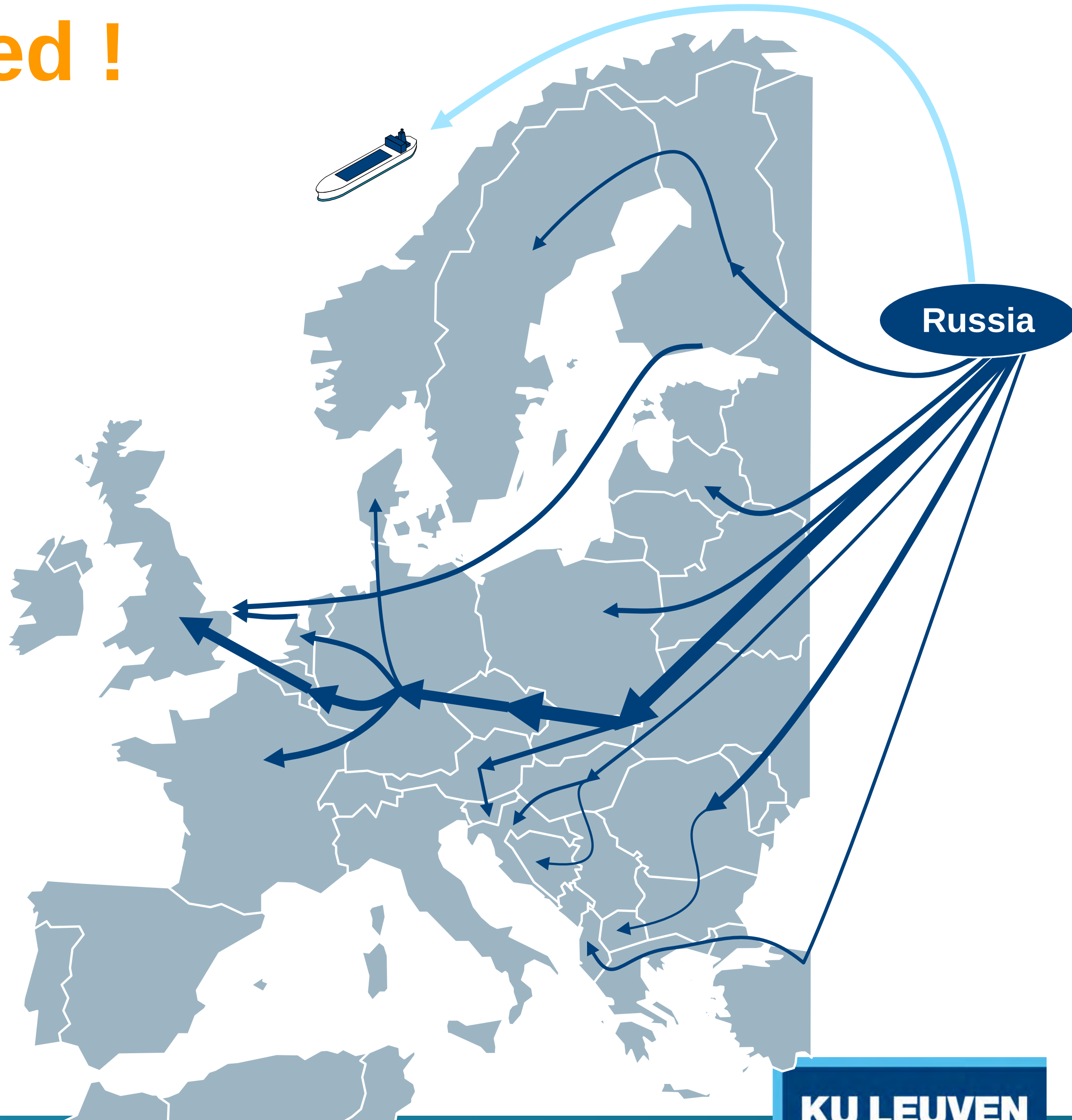
**Avoid**

**unidirectional**

**or**

**unilateral**

**dependence !**

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*Source: Wood Mackenzie / Fluxys*

# SoS - Electricity

# SoS - Electricity

**New York by night …. on August 14 2003 ...**

# Security of Supply

- Energy supply interuptions do happen!

- Structured delineation of SoS

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# Preliminary Reflections

- SoS ≠ Import Independence
  - E.g., *Belgium, Japan,…*
- What is the meaning of national borders?
  - E.g., *USA / Canada* or *EU*
- But need for liquid well-functioning markets & stable geo-political situation

→ Dangerous if only *one* energy form and from *one* supplier

→ Possible abuse (self-centered actions) by countries or big companies ??

→ Geopolitical unstable situations…(Middle East, Russia, China…) ??

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# Preliminary Reflections

- Need to properly distinguish between
  - **Energy** (as time integral of power) $E = \int_0^T P(t)\,dt$
  - **Power** (as derivative of energy) $P(t) = {dE}/{dt}$
    - Power is a flow, a flux,
    - Instantaneous power ↔ installed power or "capacity"

**Note:**

The word "power" is *not* really a synonym of *electrical* power

I.e.: electrical power, thermal power, electrical energy, thermal energy

E.g., filling up your gasoline tank is a chemical power flux; the content of your gasoline tank is chemical energy

*Funny mistakes these days… "The amount of power you can store in a battery."*

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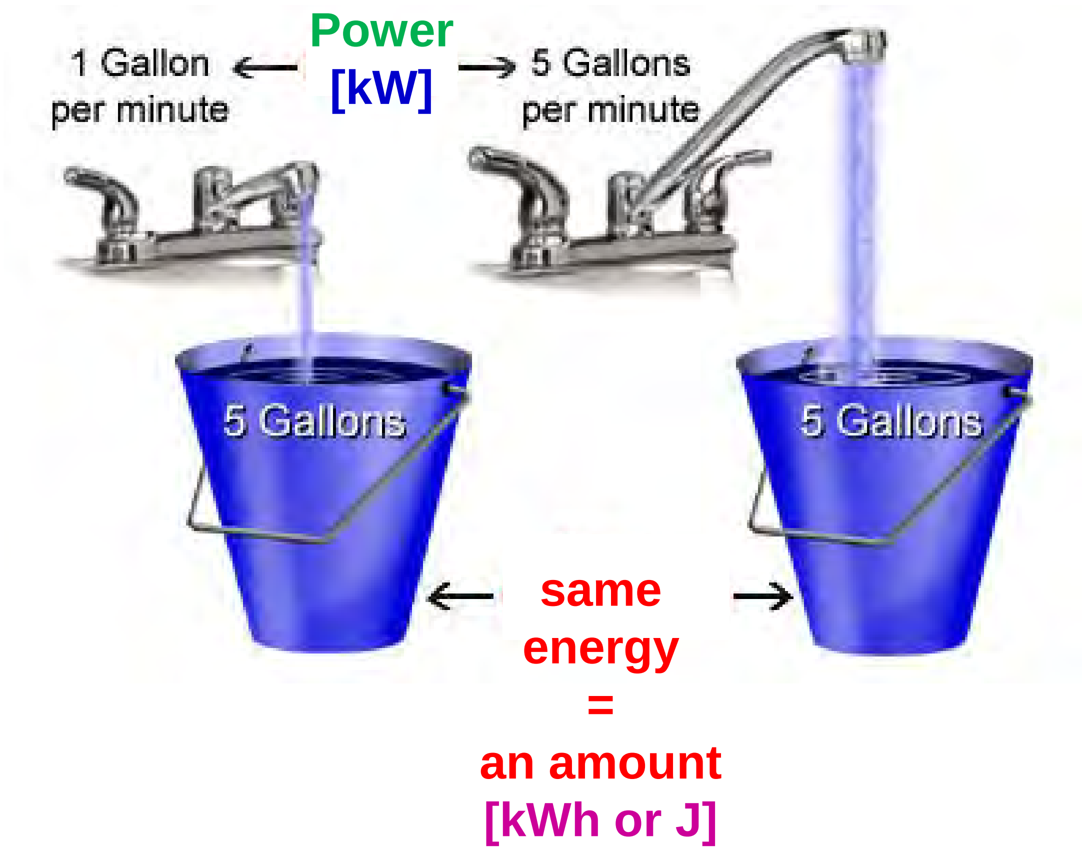
# Energy versus Power



# SoS – Structured definition

1. **Strategic Security of Supply**

2. **Adequacy**

3. **Avoiding Black outs or Sudden Cuts**

# SoS – Structured definition

1. **Strategic Security of Supply**
2. **Adequacy**
3. **Avoiding Black outs or Sudden Cuts**

# SoS – Structured definition

## (1) Strategic Security of Supply

= Continued provision of *primary* fuels/sources *to satisfy the request of the end consumer, given that all means exist to get the energy flux from producer to consumer*

This level concentrates on the

**producer countries**

# SoS – Structured definition

## (1) Strategic Security of Supply

### 1. Physical availability of primary energy sources

enough non-empty wells (reserves), coal mines, uranium mines, good meteorological conditions, biomass, geothermal conditions

*For oil, partly the issue of "peak oil"*

# SoS – Structured definition

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1. **Physical availability of primary energy sources**

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   e.g., investments in oil & gas production – also peak oil

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2. **Sufficient investments in production capacity in producer countries**

   e.g., investments in oil & gas production – also peak oil

3. **Geopolitics**

   unpredictable…

   … (Iran… Ukraine/RF… Middle East…)

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# Geopolitics
# USA & World


## Iran nuclear: Ayatollah Khamenei chastises 'arrogant' US

18 July 2015 | Middle East

The supreme leader (centre) told supporters that US policies in the Middle East are diametrically opposed to Iran's policies

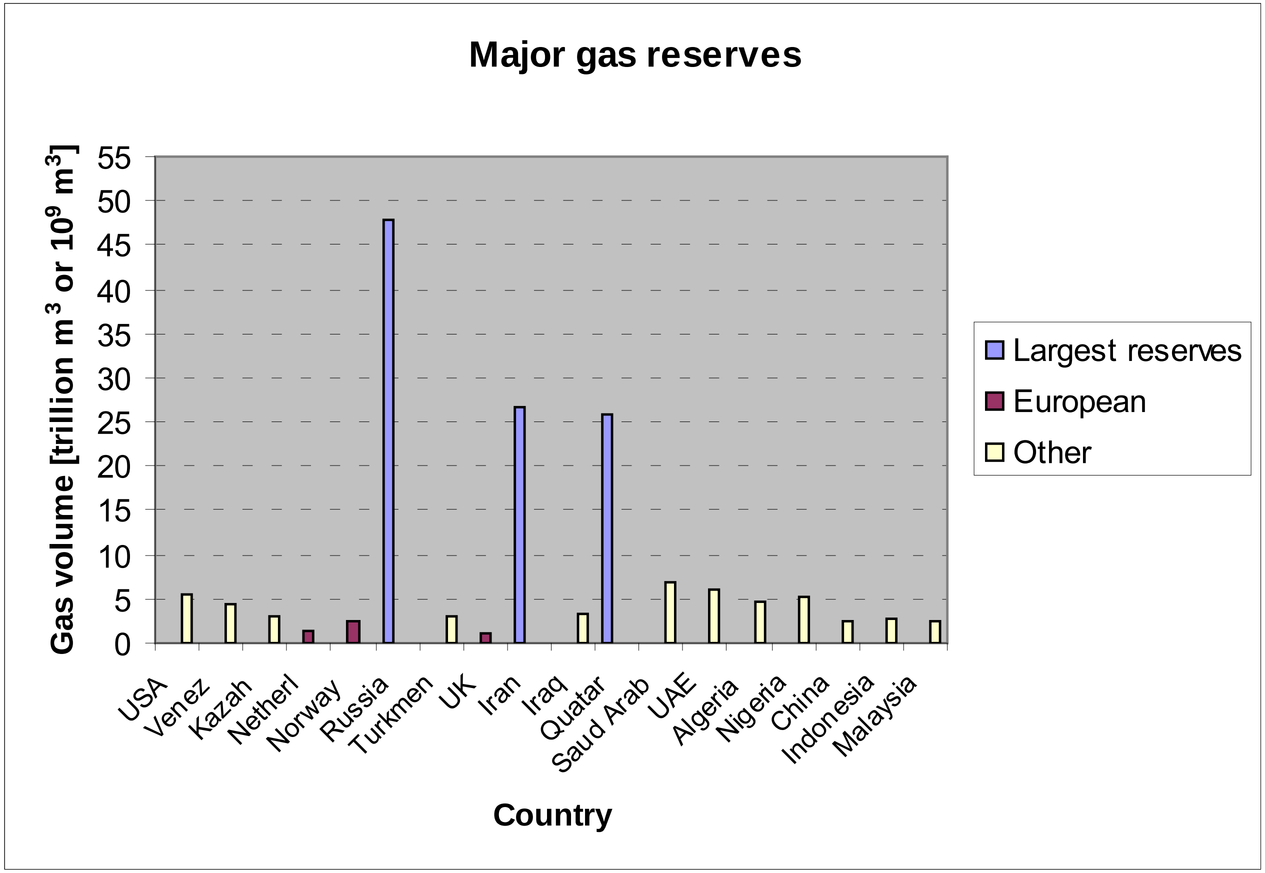
**Iran's stance towards the "arrogant" US will not change despite the nuclear deal reached earlier this week, supreme leader Ayatollah Ali Khamenei has said.**

'Death to America' and 'Death to Israel' slogans were chanted during Friday prayers at the Tehran University campus in spite of the nuclear deal agreed earlier this week

# Geopolitics
# Europe


## Geopolitics

### Conventional gas reserves ... Important for Europe...



# SoS – Structured definition

1. Strategic Security of Supply
2. Adequacy
3. Avoiding Black outs or Sudden Cuts

# SoS – Structured definition

## (2) Adequacy

= **Sufficient *investments* in consumer and or transit countries**

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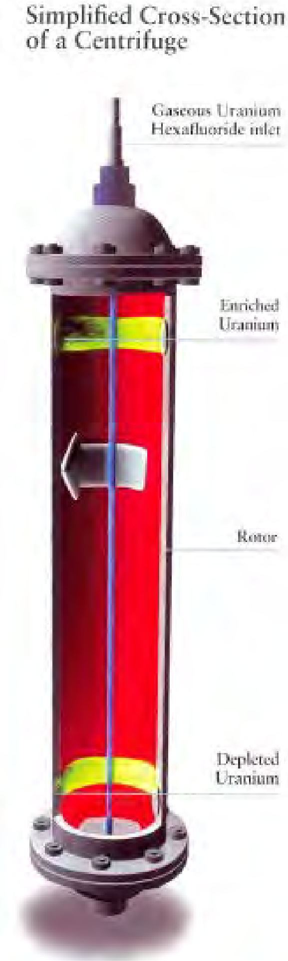
# SoS – Structured definition

## (2) Adequacy

A – Electric power plants, HV grid, high-p NG pipelines, LV and low-p distribution grid, oil refineries, U-enrichment plants

installations need to be able to cope with baseload, peak load & variable load (transient flexibility, variability, unpredictability)

## Adequacy




*Cascades of Centrifuges. URENCO Company.*

## Adequacy

# SoS – Structured definition

## (2) Adequacy

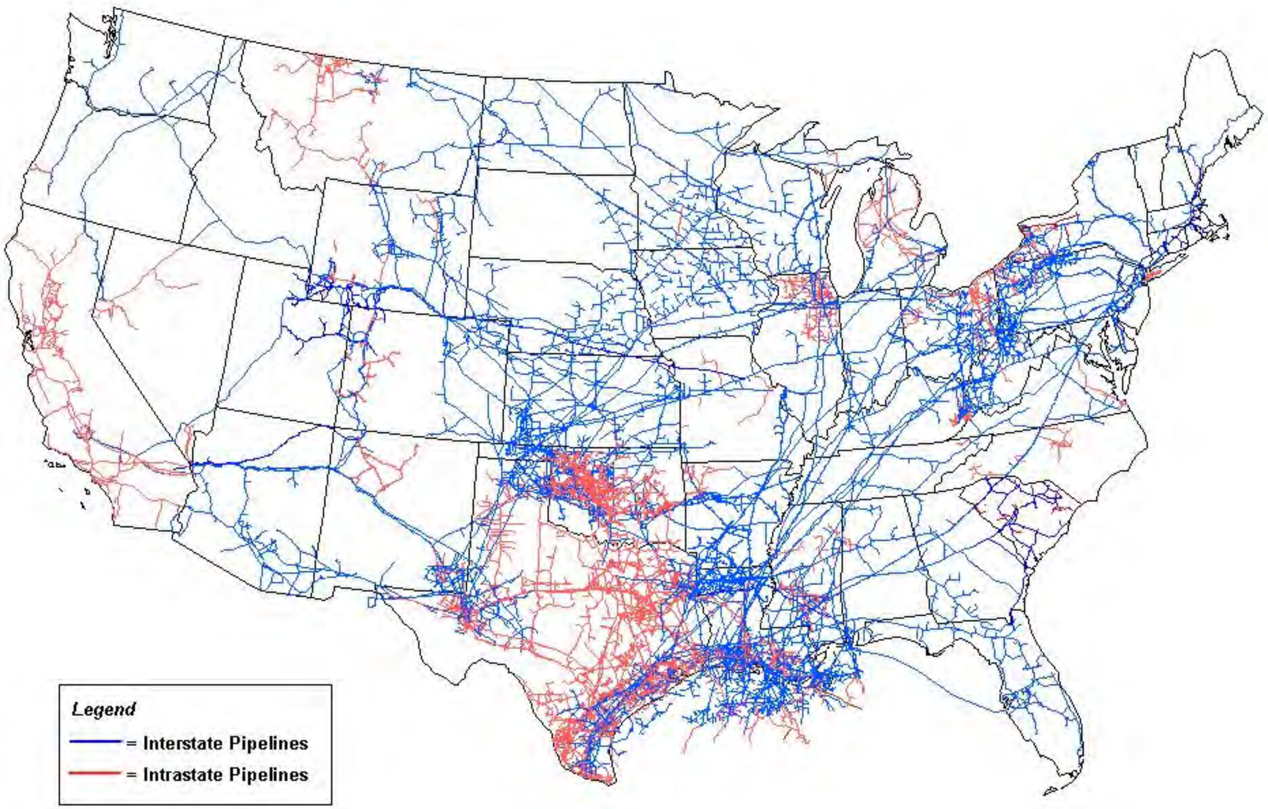
A – Electric power plants, HV grid, high-p NG pipelines, LV and low-p distribution grid, oil refineries, U-enrichment plants

installations need to be able to cope with baseload, peak load & variable load (transient flexibility, variability, unpredictability)

B – Transit pipelines (NG), LNG ships, cross-border HV lines, oil-tanker fleet,…

assure more than one single route/means

# Adequacy

## Adequacy


**Transit Russian gas through the Ukraine**

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# Adequacy



## Nord Stream

# SoS – Structured definition

## (2) Adequacy

Issues that may hamper "adequacy":

→ Nature of ***deregulated/liberalized*** *markets* (economic risk) -- investors demand a higher IRR

→ Unstable ***regulatory*** situation

- → Conflict with environmental policy
- → Uncertain regulatory character; often price caps

→ Complex permitting/licensing processes

# SoS – Structured definition

## (2) Adequacy

Issues that may hamper “adequacy”:

→ ***Circumstantial*** influencing elements

- → Financial market expectations/tendencies
- → Energy policy expectations (policy papers, intentions)
- → Political uncertainties (ideological tensions btwn executive and legislature, upcoming elections,…)
- → Too low electricity prices (driven by RES); small load factors for thermal plants

# SoS – Structured definition

1. **Strategic Security of Supply**
2. **Adequacy**
3. **Avoiding Black outs or Sudden Cuts**

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# SoS – Structured definition

## (3) Avoiding sudden cuts (black outs)

= make sure that the overall system performs as “expected” (for end customer) even in case of <u>unexpected</u> events

i.e., capacity to absorb transients, dynamics, mishaps

= issue of **reliability/security**

→ **redundancy** (e.g., N-1 rule)

→ related to **maintenance**, **control strategies**,…

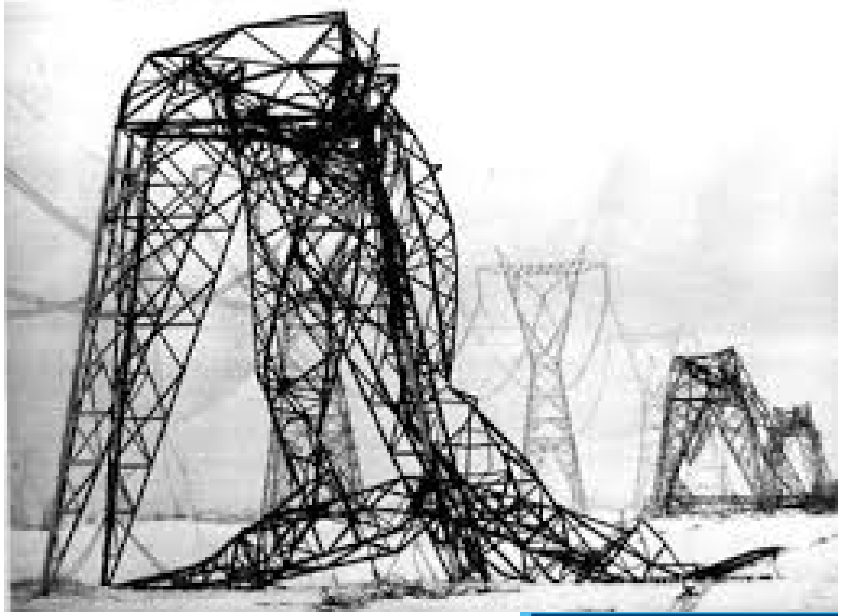
# SoS – Structured definition

## (3) Avoiding sudden cuts (black outs)

**Cope with storms,…**

**Need redundancy**

**N-1**



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# SoS – Structured definition

## (3) Avoiding sudden cuts (black outs)

**Good maintenance**

# SoS – Structured definition

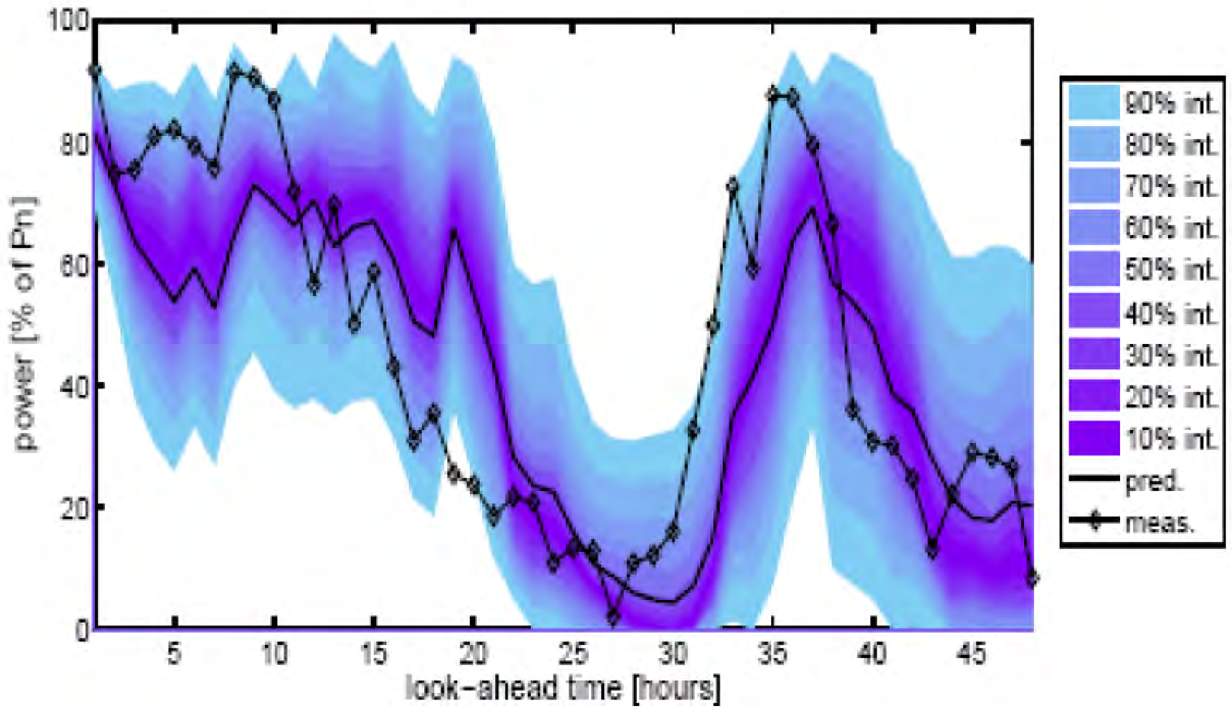
## (3) Avoiding sudden cuts (black outs)

**Good dispatch & control strategies**

# SoS – Structured definition

## (3) Avoiding sudden cuts (black outs)

- Reserves to be committed to deal with RES uncertainty

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# Solutions for SoS – General Principles

- Well functioning markets
- Diversity; spread the risks
  - Types of fuels / renewable energy sources (RES)
  - Origin of fuels / meteorological conditions for RES
  - Delivery routes for fuels / Robust grid for gas & elec
  - Types of technologies / Standardization vs diversity / Dispatchability
- Storability
  - Primary fuels (oil, natural gas, coal, uranium, biomass)
  - Secondary carriers
    - Gasoline / diesel stocks
    - Electricity: hydro-pump stations, batteries (plug-in hybrids,…)
    - Gas (on way to consumer): linepack
    - Heat buffers

# Solutions… for SoS

**Strategic security**

- International agreements
  - Bilateral/multilateral
- Frame cooperation in organizations
  - IEA, IAEA, WTO, …
- Solidarity within regions/alliances
  - EU, North America, OECD…
- Guarantee security of demand
  - E.g., long term gas contracts

# Solutions… for SoS

## Adequacy

- Allow/Stimulate sufficient investments
  - EU:
    - stable regulatory framework (otherwise no new plants!)
    - allow pass on regulated costs via tariffs (otherwise no smart grid!)
  - Provide adequate licensing/permitting framework
  - Capacity Mechanisms (?) …

# Solutions… for SoS

**Operational reliability**

- Load/supply predictability & response
- Careful planning, maintenance strategies
- Redundancy, optimized system operation
- Market design
    - Prevent abuse of dominant players, unbundling,…
- Market instruments
    - Interruptible contracts

# Conclusions on SoS

**SoS - most important elements:**

→ **Temporal and spatial dimension**

→ **Diversity of supply & technologies**

→ **Sufficient investments**

→ **Flexibility, redundancy, control, storability**

→ **Stable regulatory framework / solidarity**

→ **Functioning markets**

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# EU’s Energy Policy — implementation

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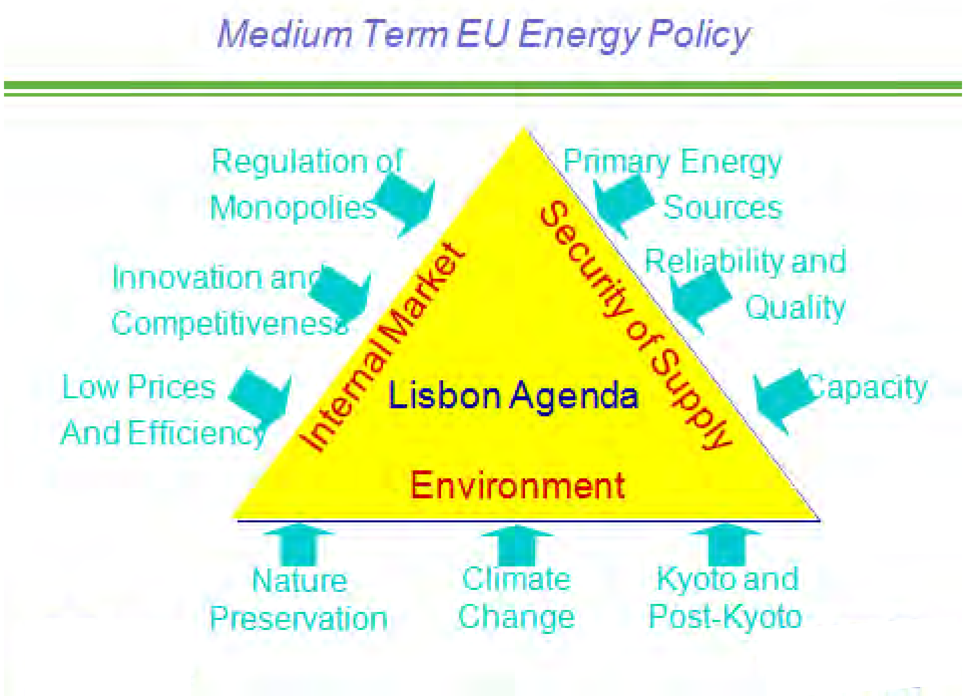
Major challenge to satisfy all three simultaneously

EU’s **trilemma** !



# EU's Energy Policy — implementation

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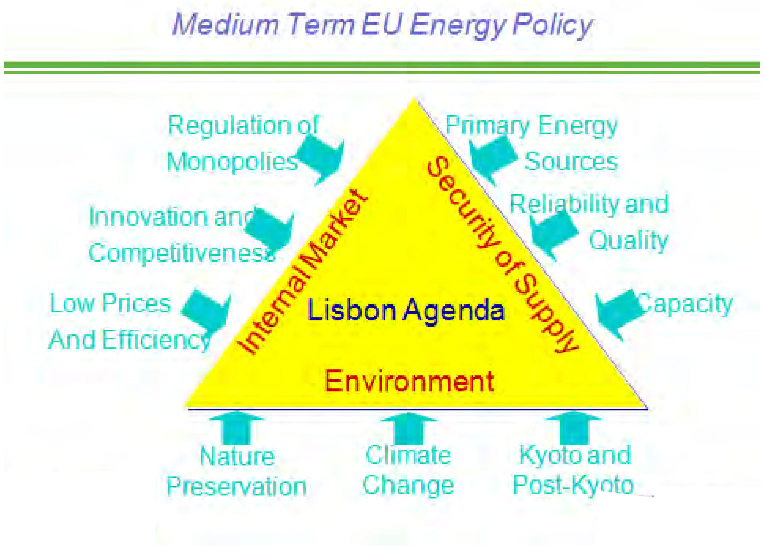
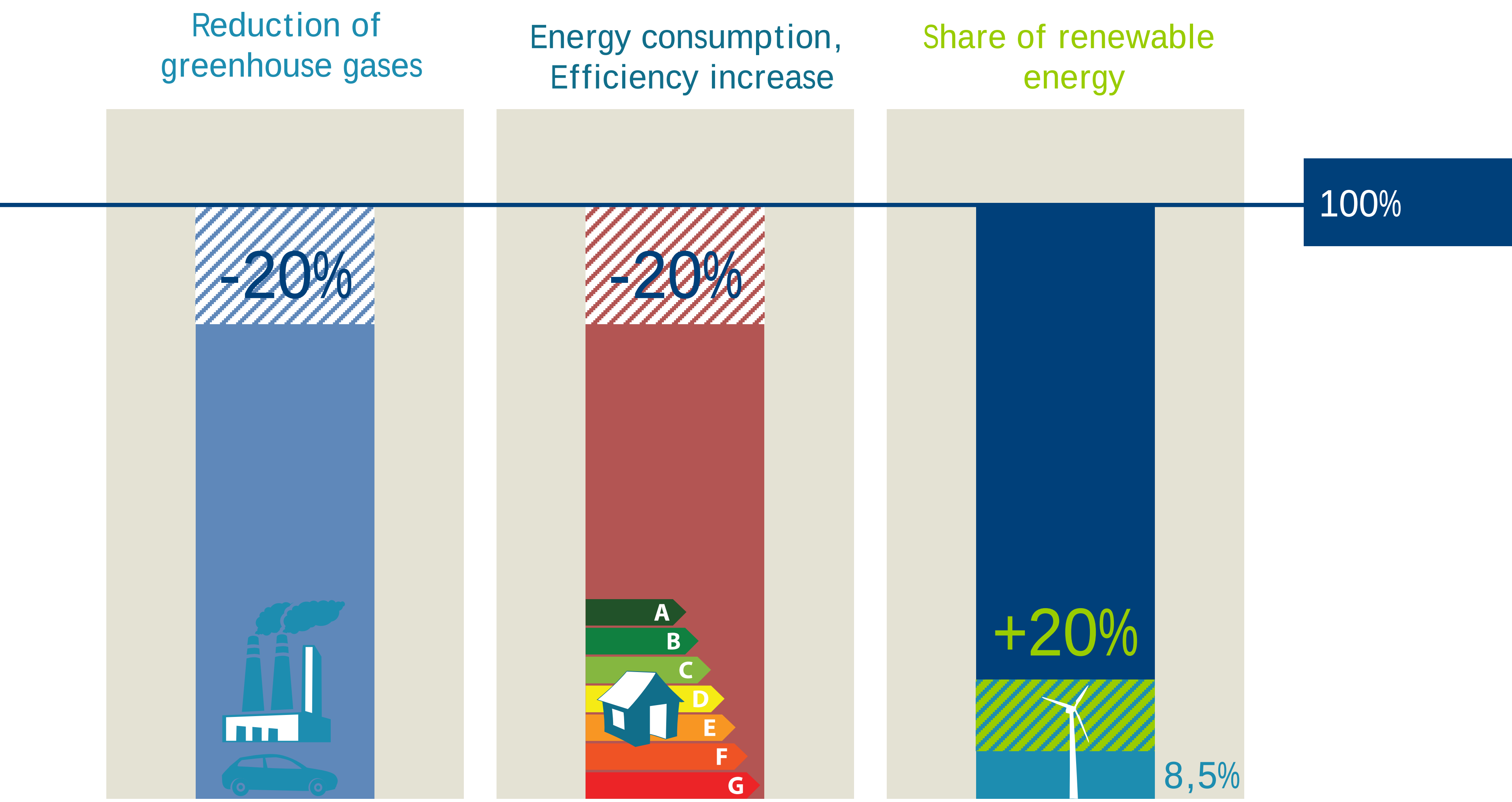



- Objectives
  - o 2020 targets (20-20-20)
    - By EU considered as "given" /
  - o 2030 as intermediate step
    - Long enough to do something; close enough to say meaningful things
  - o 2050 vision (reduction $CO_2$ by > 85%)
    - Need **energy revolution / paradigm shift**

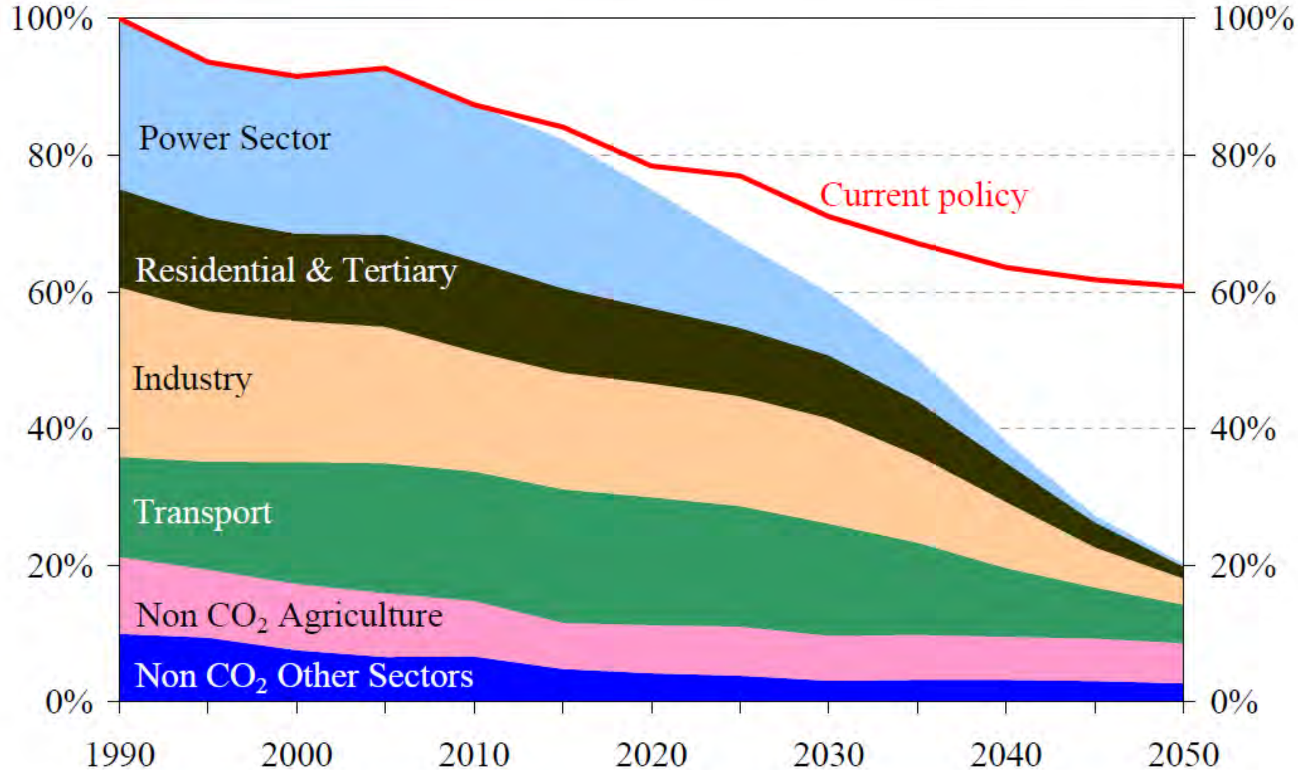
# EU 20-20-20 targets by 2020



## EU's long-term $CO_2$ reduction targets

## Climate Change Roadmap - 2050

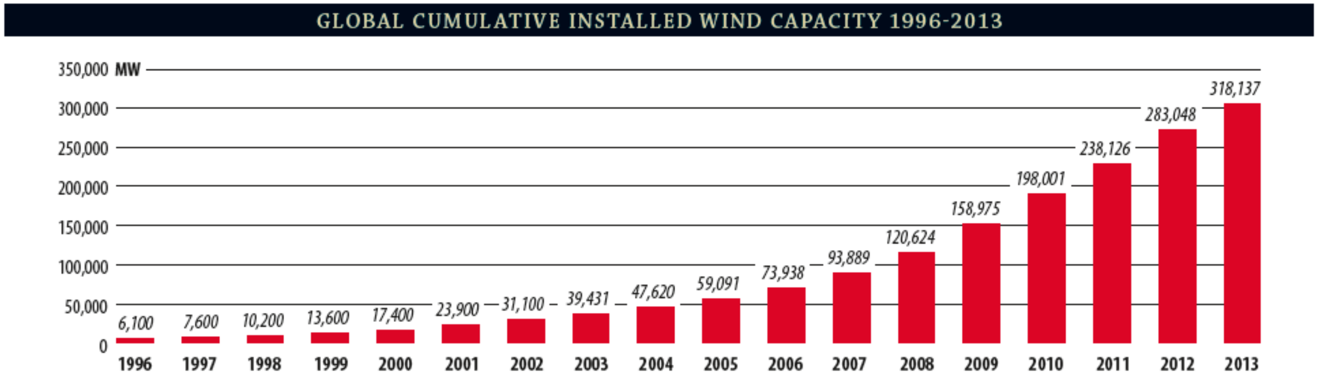
**Figure 1: EU GHG emissions towards an 80% domestic reduction (100% =1990)**

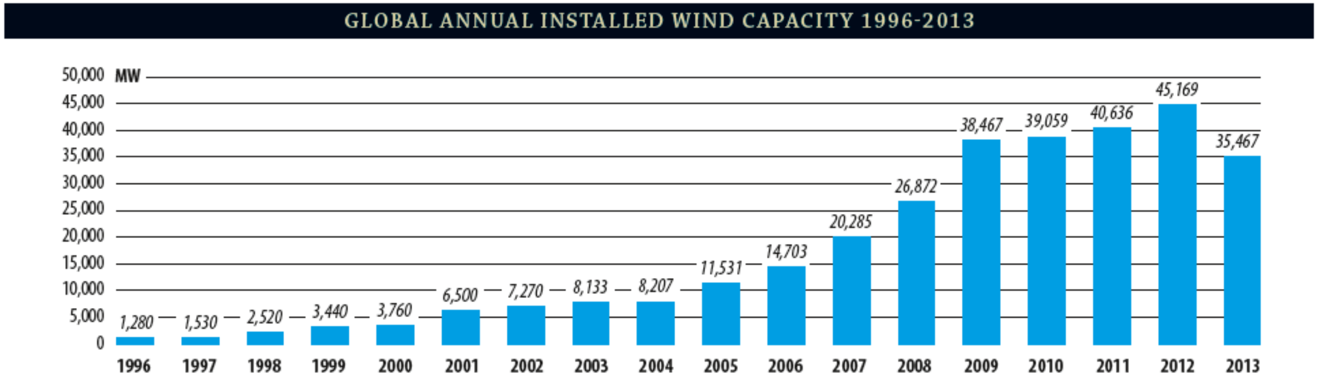



Reference: European Commission COM(2011) 112/4

# EU's implementation - currently

## Wind evolution worldwide




Ref: GWEC 2014

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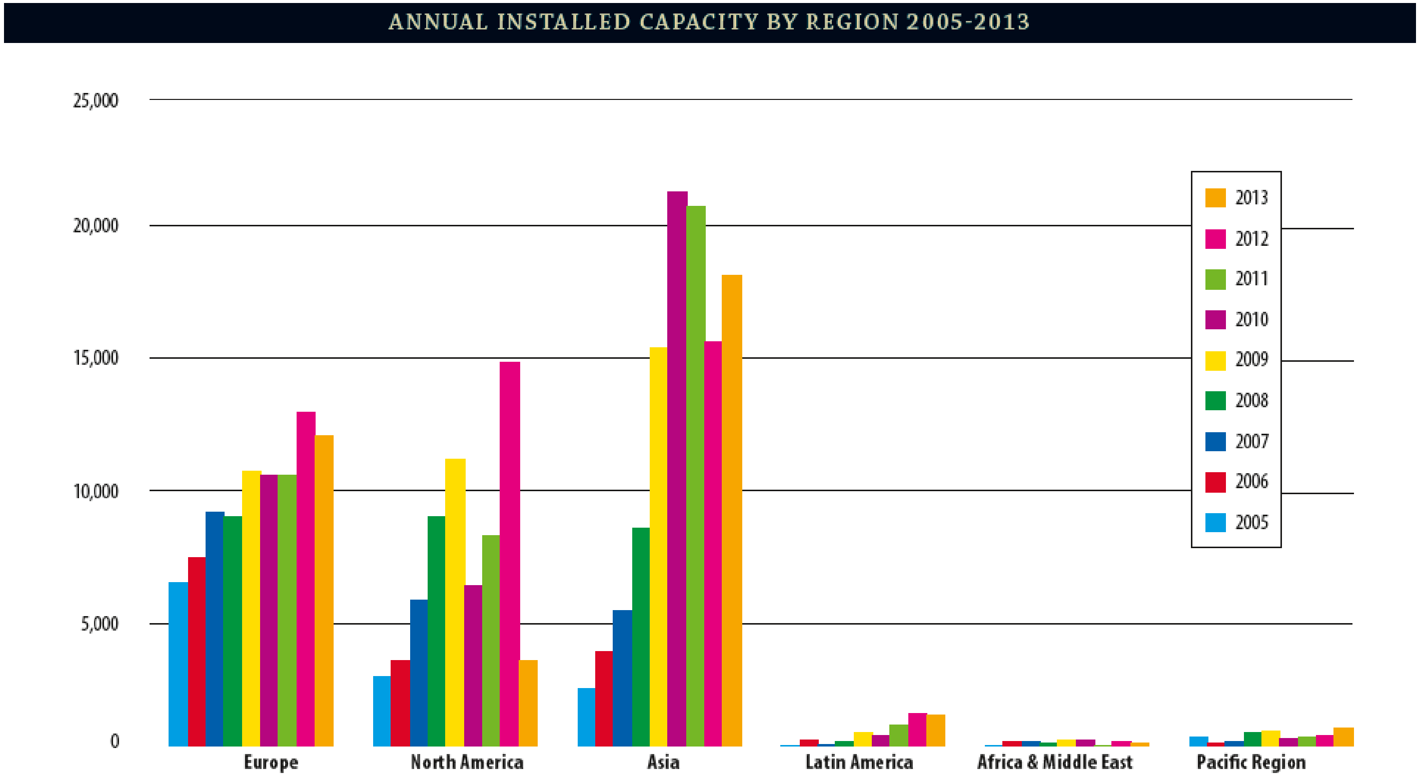
# EU's implementation - currently

## Wind annual installed capacity worldwide per region

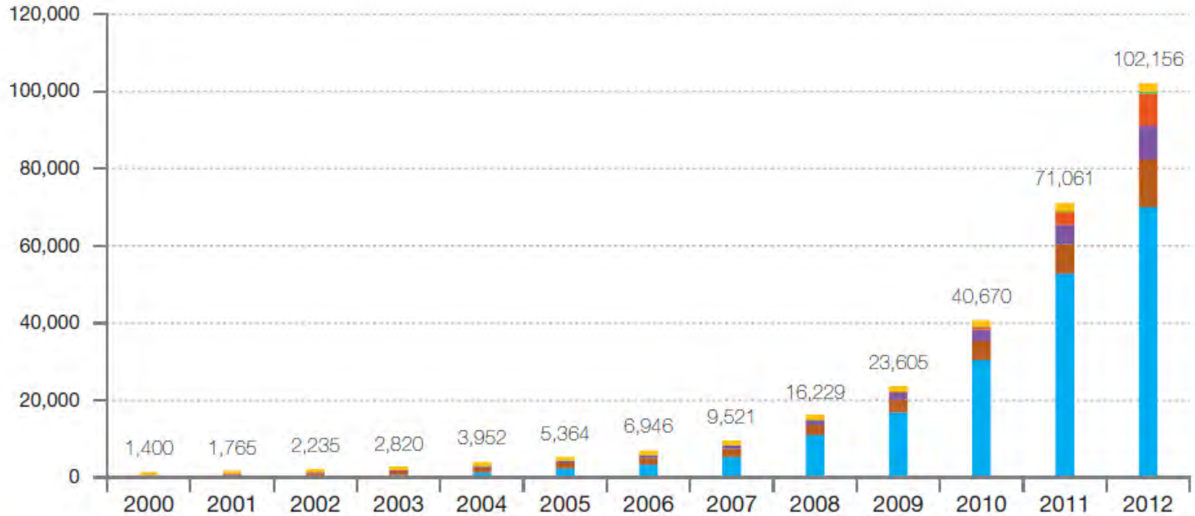



Ref: GWEC 2014

# EU’s implementation - currently

## PV evolution worldwide

Figure 1 - Evolution of global PV cumulative installed capacity 2000-2012 (MW)




| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ROW | 751 | 807 | 887 | 964 | 993 | 1,003 | 1,108 | 1,150 | 1,226 | 1,306 | 1,590 | 2,098 | 2,098 |
| MEA | n/a | n/a | n/a | n/a | 1 | 1 | 1 | 2 | 3 | 25 | 71 | 192 | 601 |
| China | 19 | 24 | 42 | 52 | 62 | 70 | 80 | 100 | 140 | 300 | 800 | 3,300 | 8,300 |
| Americas | 146 | 178 | 225 | 290 | 394 | 501 | 650 | 863 | 1,209 | 1,752 | 2,780 | 4,959 | 8,717 |
| APAC | 355 | 495 | 686 | 916 | 1,198 | 1,500 | 1,825 | 2,096 | 2,631 | 3,373 | 4,956 | 7,628 | 12,397 |
| Europe | 129 | 262 | 396 | 598 | 1,305 | 2,289 | 3,281 | 5,310 | 11,020 | 16,850 | 30,472 | 52,884 | 70,043 |
| **Total** | **1,400** | **1,765** | **2,235** | **2,820** | **3,952** | **5,364** | **6,946** | **9,521** | **16,229** | **23,605** | **40,670** | **71,061** | **102,156** |

Ref: EPIA 2012

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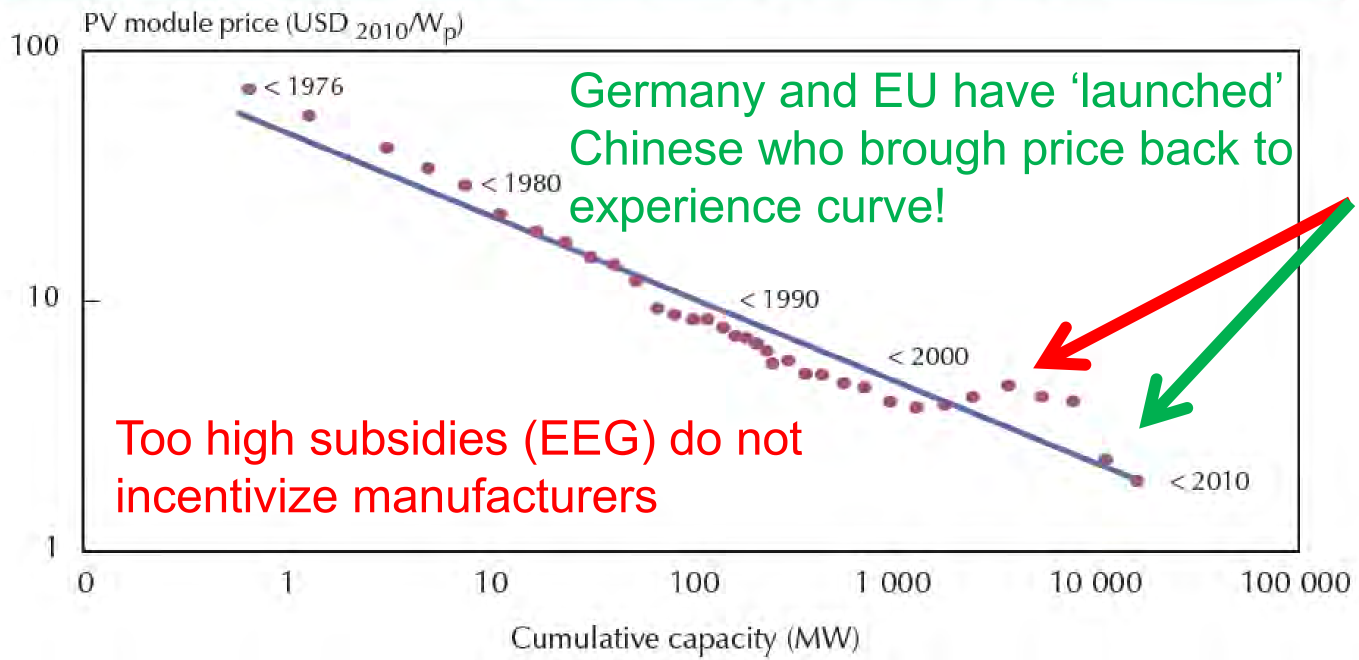
# Cost aspects RES

Ref: IEA Deploying Renewables

Figure 2.13 **Cost degression of solar PV modules, 1976-2010**



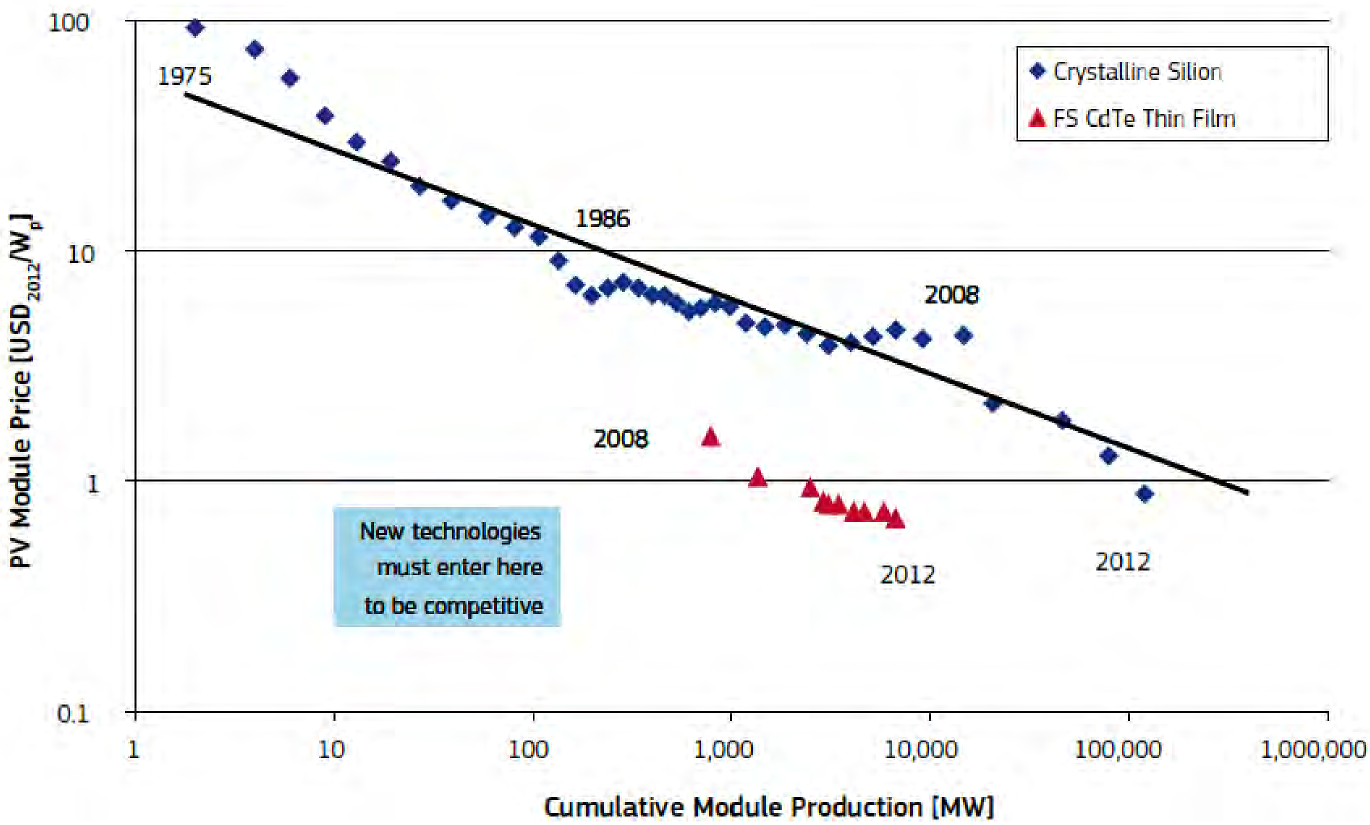

*Source: Breyer and Gerlach (2010).*

**→Good for worldwide price PV**
**→Bad for EU & US PV industry**

Key point

*Historically, every doubling of installed capacity coincided with a 19.3% reduction of PV module prices.*

# Cost aspects RES




Ref: JRC 2013

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# EU’s implementation - currently

- All this progress seems to be too nice to be true...
  And it is...

- There are major *system effects* that have been neglected and that may jeopardize further success of RES deployment!

- One has gone too rapidly recently, with *danger of losing support of population!*

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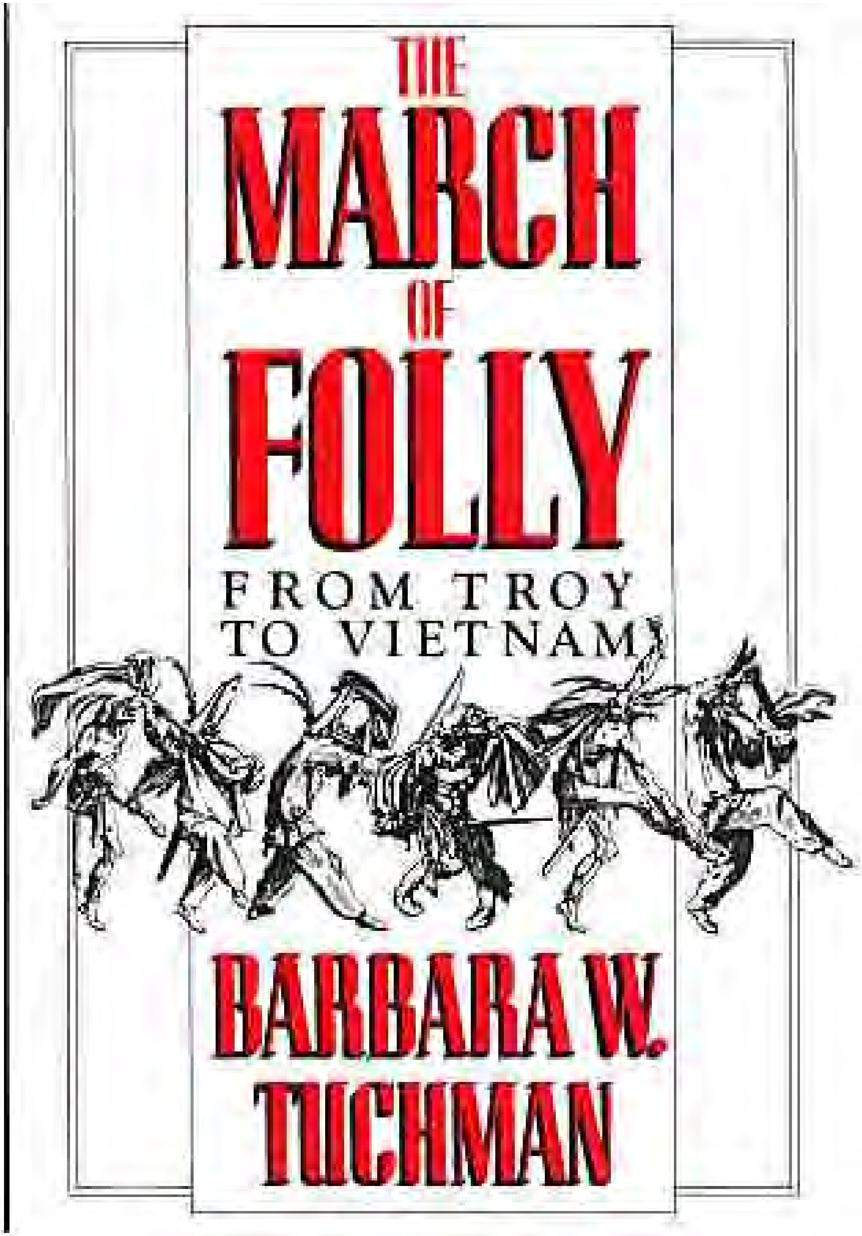


THE MARCH
OF FOLLY

***Pursuit of policy***

***contrary to self-interest***

# Cost aspects RES – system costs

UKERC

2006

**The Costs and Impacts of Intermittency:**

An assessment of the evidence on the costs
intermittent generation on the British elec

NREL National Renewable Energy Laborator
*Innovation for Our Energy Future*

**Calculating Wind Integration Costs: Separating Wind Energy Value from Integration Cost Impacts**

Michael Milligan and Brendan Kirby

***Technical Report***
**NREL/TP-550-46275**
**July 2009**

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

**Cost-Causation and Integration Cost Analysis for Variable Generation**

Michael Milligan, Erik Ela, Bri-Mathias Hodge, Brendan Kirby (Consultant), and Debra Lew
*National Renewable Energy Laboratory*

Charlton Clark, Jennifer DeCesaro, and Kevin Lynn
*U.S. Department of Energy*

2011

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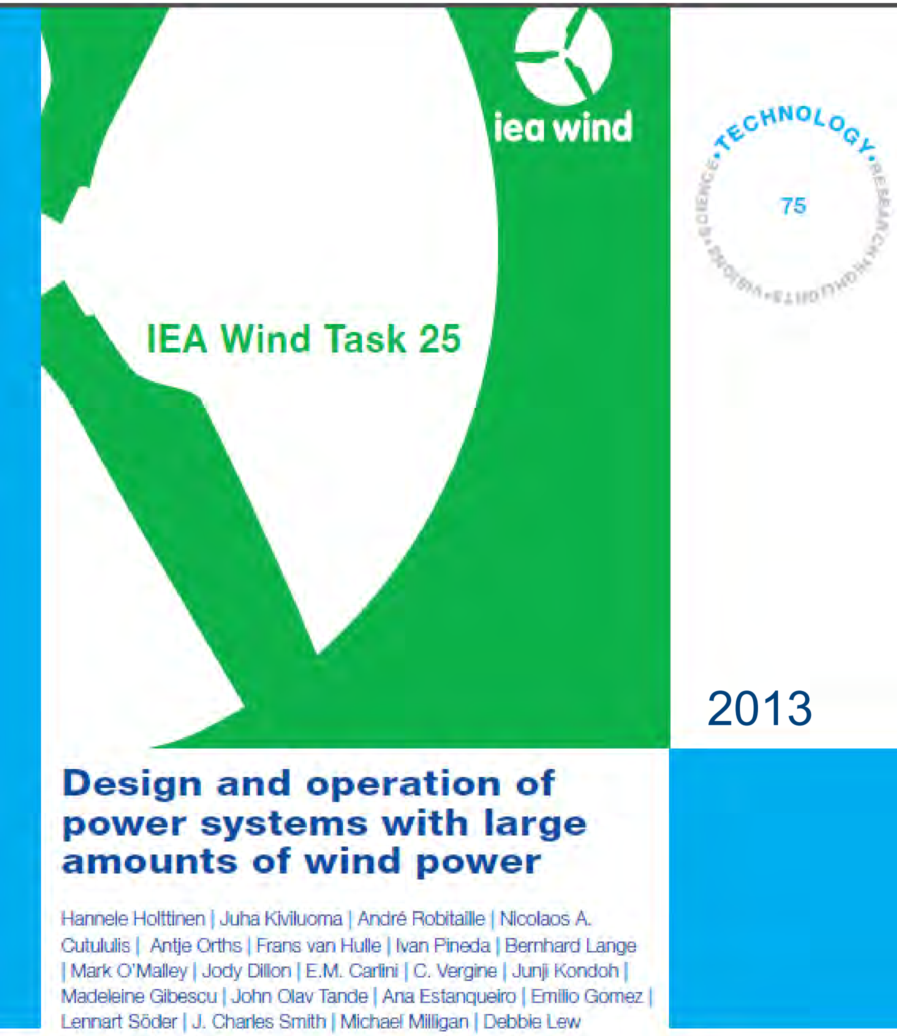
# Cost aspects RES – system costs


iea wind

TECHNOLOGY · RESEARCH HIGHLIGHTS · VISIONS · SCIENCE · 75

IEA Wind Task 25

**Design and operation of power systems with large amounts of wind power**

Hannele Holttinen | Juha Kiviluoma | André Robitaille | Nicolaos A. Cutululis | Antje Orths | Frans van Hulle | Ivan Pineda | Bernhard Lange | Mark O'Malley | Jody Dillon | E.M. Carlini | C. Vergine | Junji Kondoh | Madeleine Gibescu | John Olav Tande | Ana Estanqueiro | Emilio Gomez | Lennart Söder | J. Charles Smith | Michael Milligan | Debbie Lew

2013


NREL
NATIONAL RENEWABLE ENERGY LABORATORY

**The Western Wind and Solar Integration Study Phase 2**

D. Lew, G. Brinkman, E. Ibanez, A. Florita, M. Heaney, B.-M. Hodge, M. Hummon, and G. Stark
*NREL*

J. King
*RePPAE*

S.A. Lefton, N. Kumar, and D. Agan
*Intertek-APTECH*

G. Jordan and S. Venkataraman
*GE Energy*

**2013**

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# Cost aspects RES – system costs

THE ECONOMICS OF RENEWABLE ELECTRICITY MARKET INTEGRATION

AN EMPIRICAL AND MODEL-BASED ANALYSIS OF REGULATORY FRAMEWORKS AND THEIR IMPACTS ON THE POWER MARKET

Inauguraldissertation
zur Erlangung des Doktorgrades
der Wirtschafts- und Sozialwissenschaftlichen Fakultät
der Universität zu Köln
2011

vorgelegt von
Dipl.-Kfm. Marco Nicolosi, MBA
aus Braunschweig

TECHNISCHE UNIVERSITÄT MÜNCHEN

Lehrstuhl für Energiewirtschaft und Anwendungstechnik

Integration of Variable Renewable Energies in the European power system:
a model-based analysis of transmission grid extensions and energy sector coupling

Katrin Schaber

**2013**

# Cost aspects RES – system costs

September 27, 2010 (Revised February 9, 2011)
DISCUSSION DRAFT

**COMPARING THE COSTS OF INTERMITTENT AND DISPATCHABLE ELECTRICITY GENERATING TECHNOLOGIES**

Paul L. Joskow
Alfred P. Sloan Foundation and MIT[1]

**The Economics of Wind and Solar Variability**

How the Variability of Wind and Solar Power affects their Marginal Value, Optimal Deployment, and Integration Costs

vorgelegt von
Dipl.-Volksw. & Mag. phil.
Lion Hirth
aus München

von der Fakultät VI – Planen Bauen Umwelt
der Technischen Universität Berlin
zur Erlangung des akademischen Grades

Doktor der Wirtschaftswissenschaften
- Dr. rer. oec. -

genehmigte Dissertation

2014

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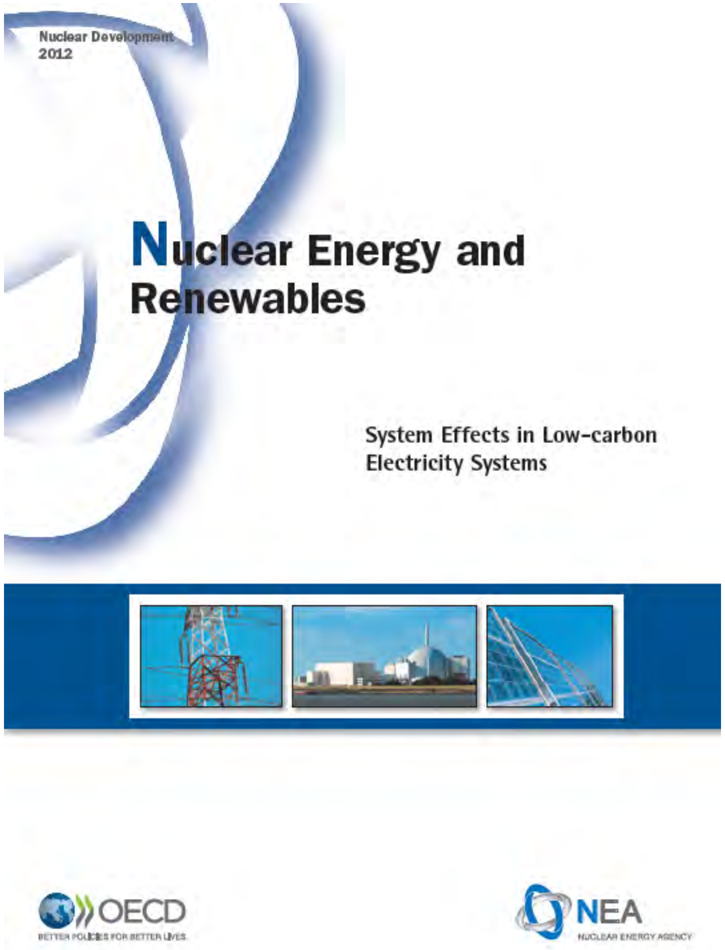
# Cost aspects RES – system costs NEA / IEA




Comprehensive document giving overall system cost figures.
End 2012.

Is currently being scrutinized – numbers to be confirmed or contested.

Available at: http://www.oecd-nea.org/ndd/pubs/2012/7056-system-effects.pdf

# Cost aspects RES – system costs NEA / IEA

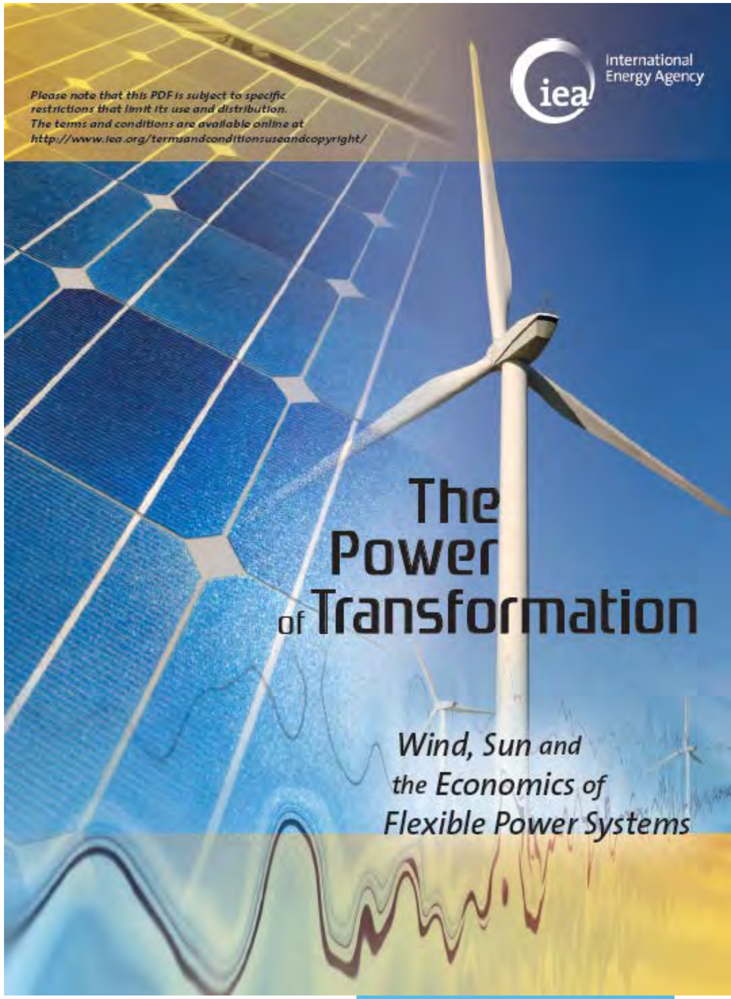
Released on February 26, 2014
System-cost report by IEA

States in Executive Summary (ES):

*«… a major finding of this publication is that large shares of VRE (up to 45% in annual generation) can be integrated <u>without significantly increasing power costs</u> in the long run. However, cost-effective integration calls for a system-wide transformation.»*

?? IEA/OECD in contrast with NEA/OECD ??

Not quite… ES is not in line with main report!

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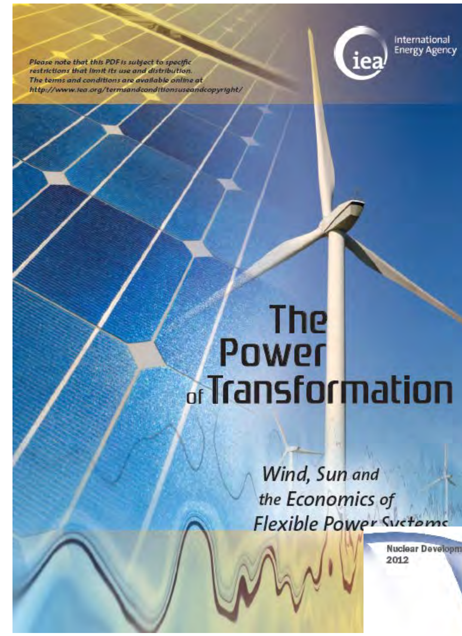
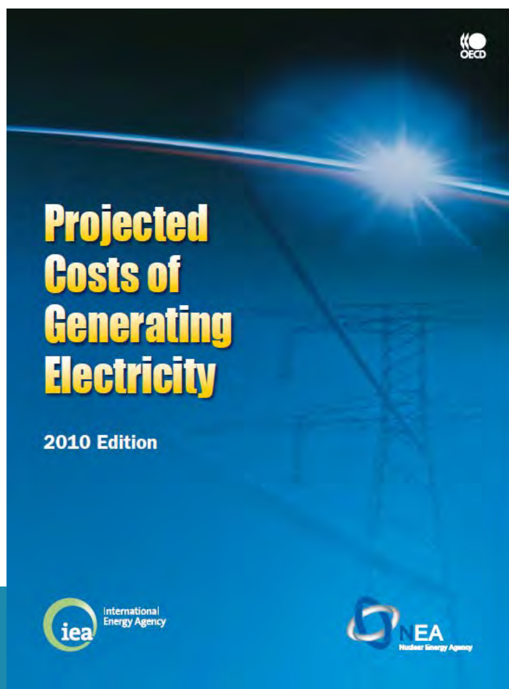
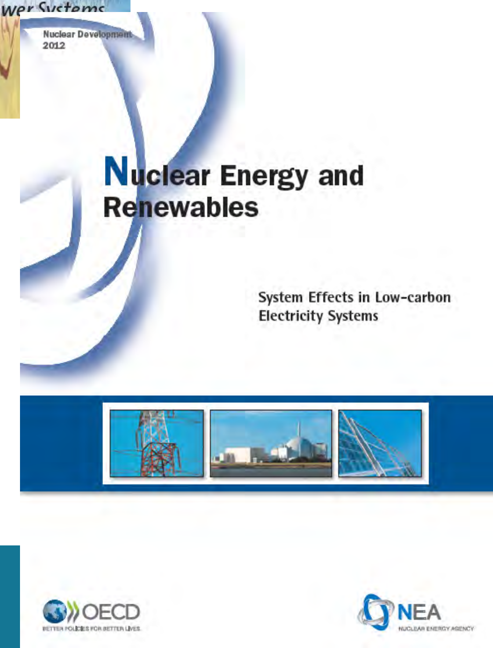
# Cost aspects RES – system costs NEA / IEA

- Currently exercise to “reconcile” both studies in the 2015 revision of the joint IEA/NEA report : **“Projected Cost of Generating Electricity”**

  written by two authors of IEA and NEA!



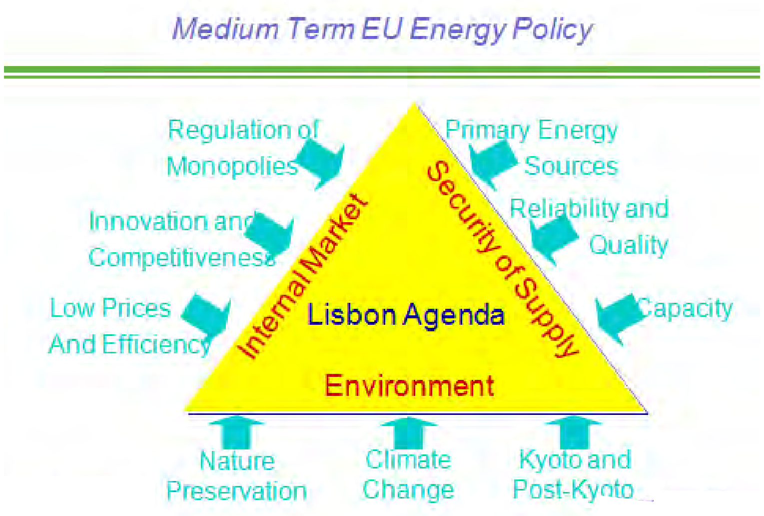



# Cost aspects RES – system costs

- Much more research needed on system-integration cost!
  - In search of an accepted methodology!
  - Boundary conditions & hypotheses crucial
  - Must distinguish between short term / long term
  - Must include aspects such as balancing, reserves, ancillary services, grid extension, adequacy, effects on existing assets...
  - How about effects of subsidies & taxes? ("transfers" but ... stranded assets)
  - Results will be very system dependent!
    - Physical system
    - Market design & Regulatory context
  - Distinguish between cost & benefits and the (market) value
  - Need interdisciplinary non-ideological research with scientific and economic arguments & counter arguments

# EU's implementation - recall




Major challenge to satisfy all three simultaneously

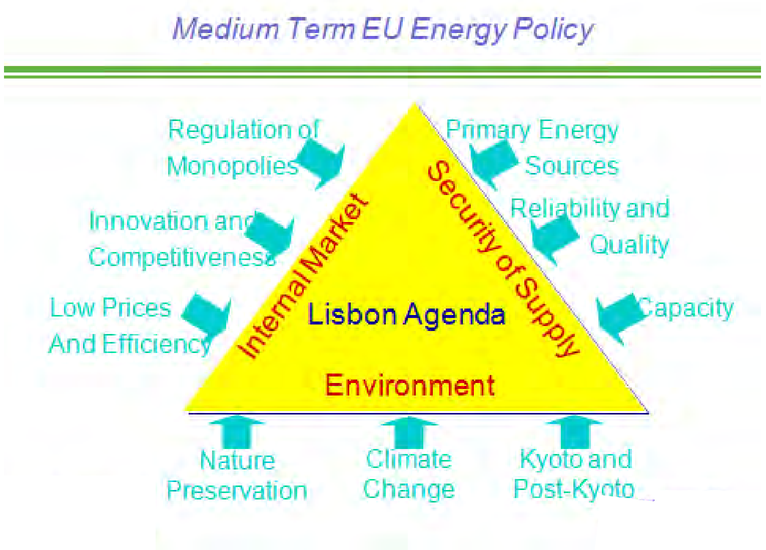
EU's **trilemma** !

- Objectives
  - 2020 targets (20-20-20)
    - By EU considered as "given" / "decided" / to be implemented
  - 2030 as intermediate step
    - Long enough to do something; close enough to say meaningful things
  - 2050 vision (reduction $CO_2$ by > 85%)
    - Need **energy revolution / paradigm shift**

# EU's implementation

Major challenge to satisfy
all three simultaneously

EU's **trilemma** !




Textbook example of
"well intended measures"
but ...

**because *lack of system thinking***
**serious issues / problems**

**→ EU electricity market in cirisis !!**



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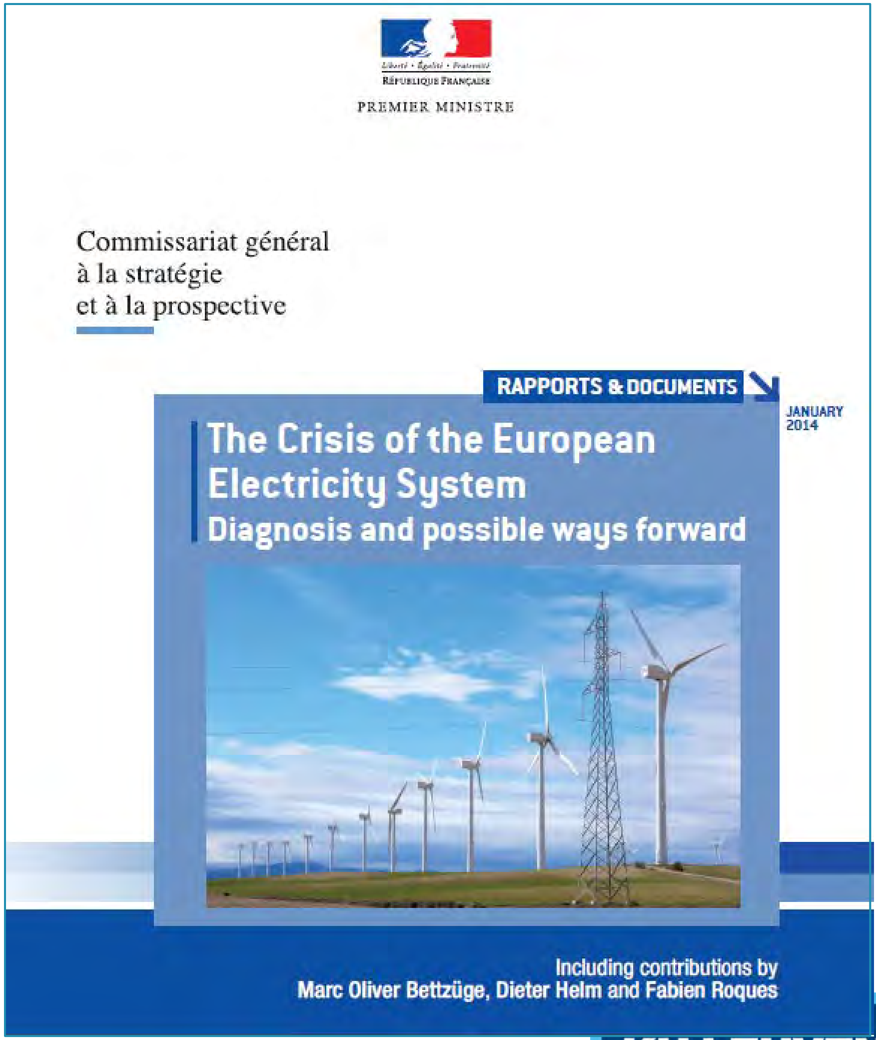
# French Report January 2014

# EU's implementation

## Issues / challenges / problems in the EU market

- Technical challenges
- Market-integration problems
- Consequences for the $CO_2$ emissions
- End-electricity prices for end consumers

# EU's implementation

## Consequences of renewables quota in end-energy terms (1)

- Total end energy = electric energy + fuel for heat + fuel for transportation
- EU requirement by 2020: 20% of end energy from RES
- For transportation only 10% ... → for electric sector ~ 34%
- Expectations / outcome ("steered" by differentiated *subsidies*):
  - Hydro ~ only small increase possible
  - Biomass ~ moderated increase (protests against co-combustion, imported biomass pellets, sustainability questions)
  - Wind onshore + offshore / ENOH onsh ~ 2200h/a offsh ~ 3500 h/a
  - Solar photovoltaics (PV) / ENOH NW Europe ~ 800-1000 h/y
- Total: 8760 h/a → low capacity factors of these intermittent sources

# EU's implementation

## Consequences of renewables quota in end-<u>energy</u> terms (2)

- Capacity factors intermittent sources (wind + PV):
  - Wind onshore + offshore / CF ~ 25% - 30%
  - Solar photovoltaics (PV) / CF ~ 10-12%
- To produce 34% electric energy with something that operates only 10-12% or 25-30% of the time, you must install a large amount of installed power ( called "capacity") → leads to massive overcapacity
- If there is a lot of wind and sun, and low demand (e.g., weekends), then <u>too much electricity produced</u>
- But sometimes in case of cold spell (cfr winter Feb 2012) – with temp inversion... little wind and 'dark' (hence no PV) at 17.00h-18.00h, when peak demand arises in NW-Europe! → <u>very little RES electricity produced</u>

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# EU's implementation

## Consequences of renewables quota in end-energy terms (3)

- *Intermittency*: defined as "variable" and "partly unpredictable"
- How deal with massive "intermittency" in electricity system?
  - Back up reserves from *flexible dispachable thermal plants* (+ & -)
  - Electrical *storage* (large scale electric storage not available)
  - Expansion of *transmission grid*
  - Encourage *active demand response* (ADR)
  - *Curtailing* of superfluous RES production / review priority access
  - Mitigate on *local level via smart grids*

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# EU's implementation

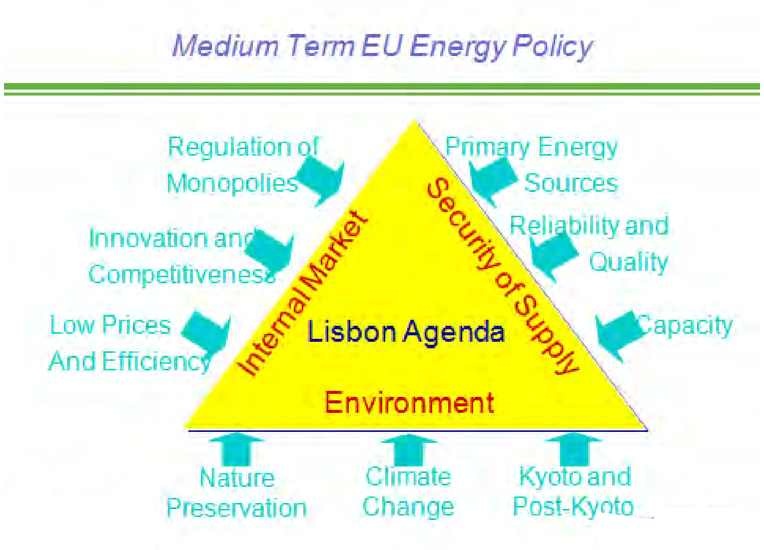
## Issues / challenges / problems in the EU market

- Technical challenges
- Market-integration problems
- Consequences for the $CO_2$ emissions
- End-electricity prices for end consumers

# EU’s implementation

Major challenge to satisfy
all three simultaneously

EU’s **trilemma** !

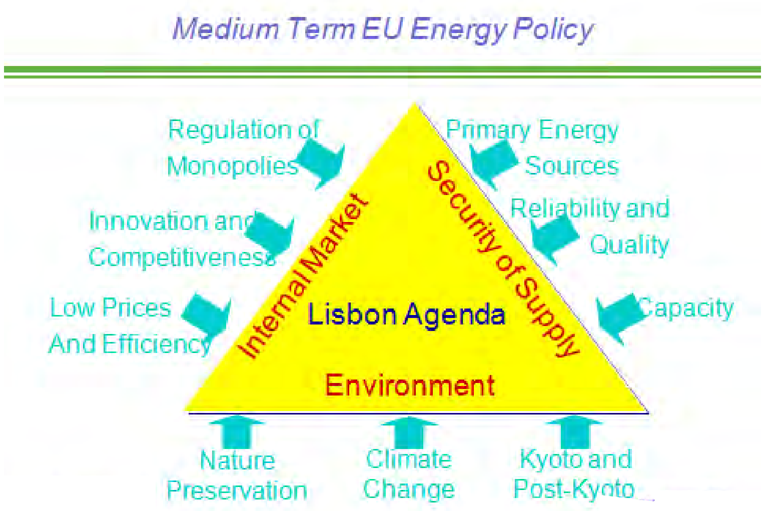



- Objectives
  - 2020 targets (20-20-20)
    - By EU considered as “given” / “decided” / to be implemented

# EU’s implementation – technical issues

Major challenge to satisfy all three simultaneously

EU’s **trilemma** !



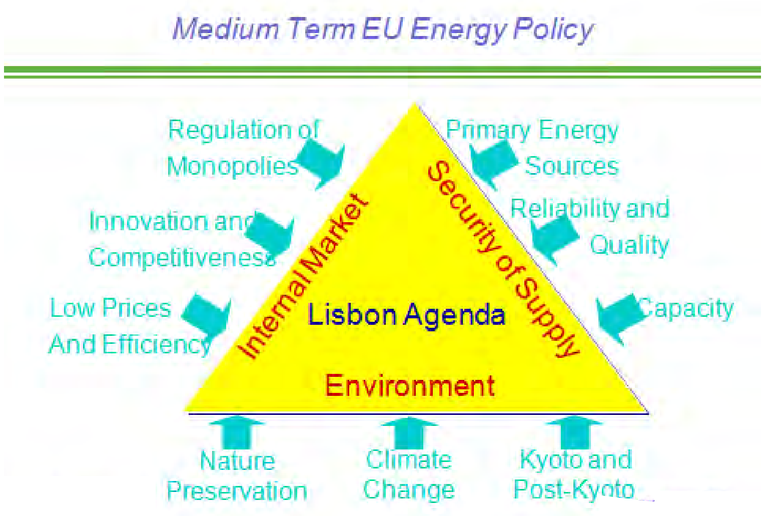

- Objectives
  - 2020 targets (20-20-20)
    - By EU considered as “given” / “decided” / to be implemented

→ 33 % renewable electric *energy*
→ installed capacity of only wind & sun ~160% of average demand level
→ highly intermittent & non-controllable / need thermal plant back up !

# EU's implementation – technical issues

Major challenge to satisfy all three simultaneously

EU's **trilemma** !




- Objectives
  - 2020 targets (20-20-20)
    - By EU considered as "given" / "decided" / to be implemented

**Technical challenge!!**

**→ often serious over production / too much electricity**
**→ thermal plants must balance very quickly**



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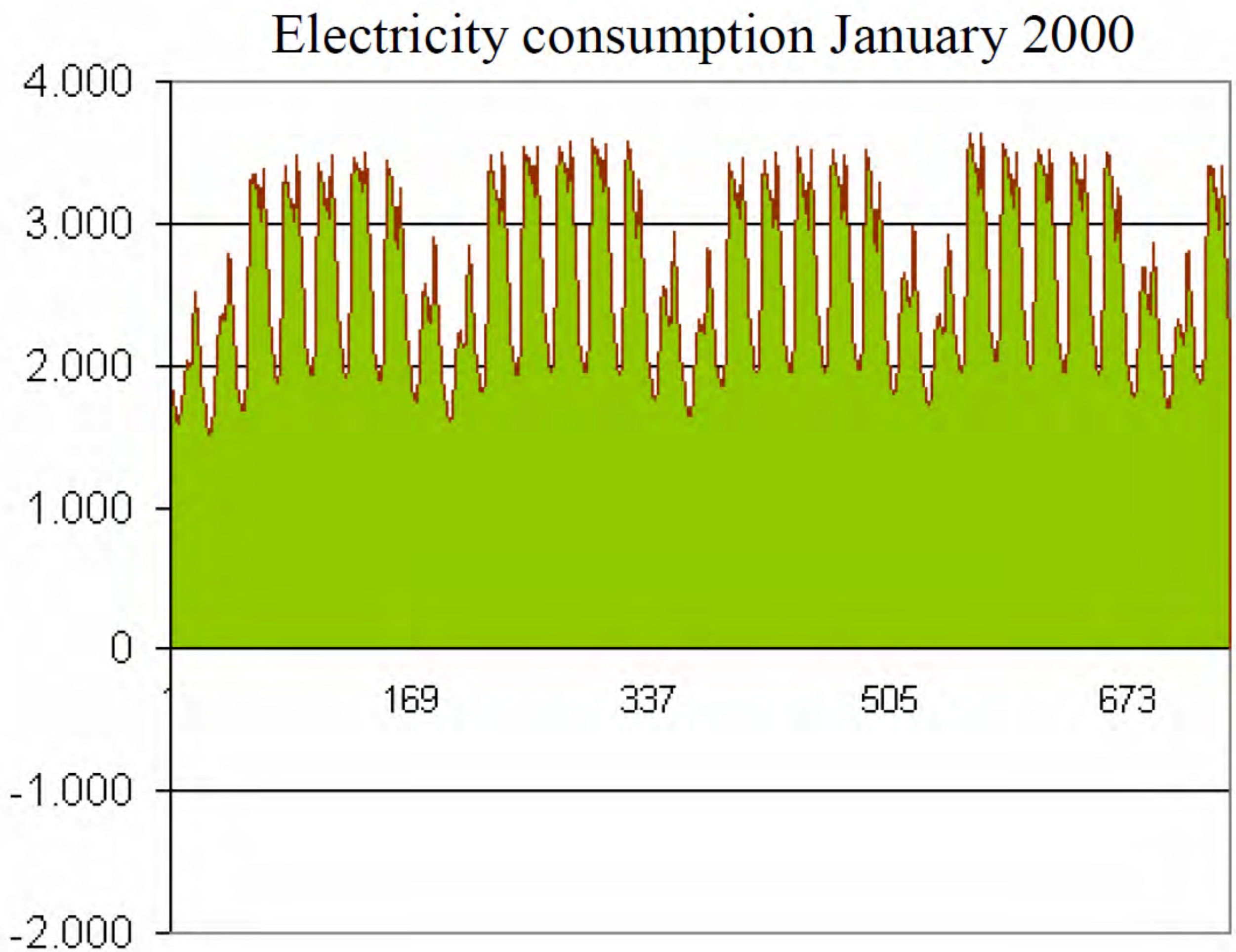
# EU's implementation – technical issues

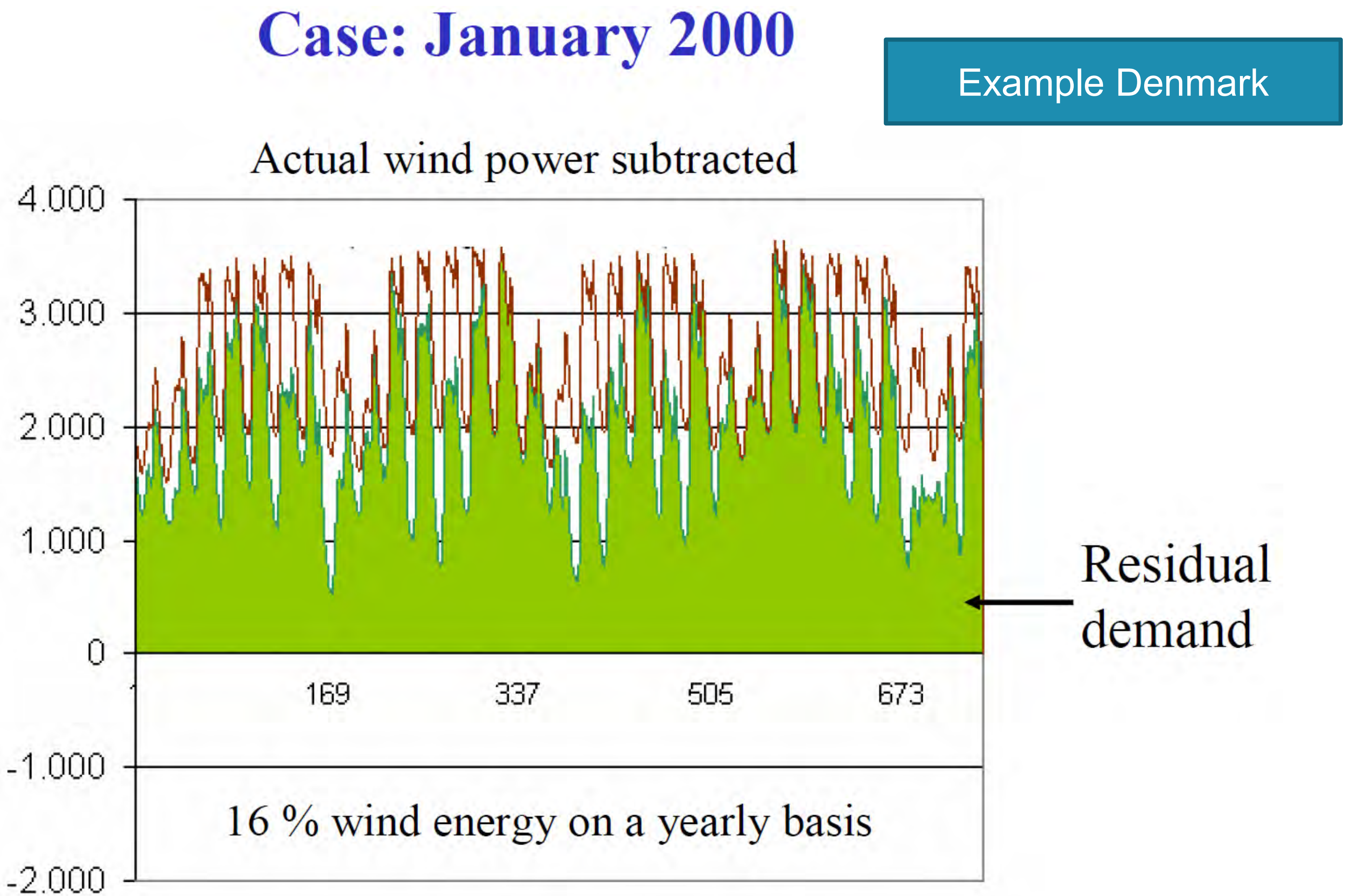
**Case: January 2000**

Example Denmark




Ref. F. Bach, ELTRA

# EU's implementation – technical issues

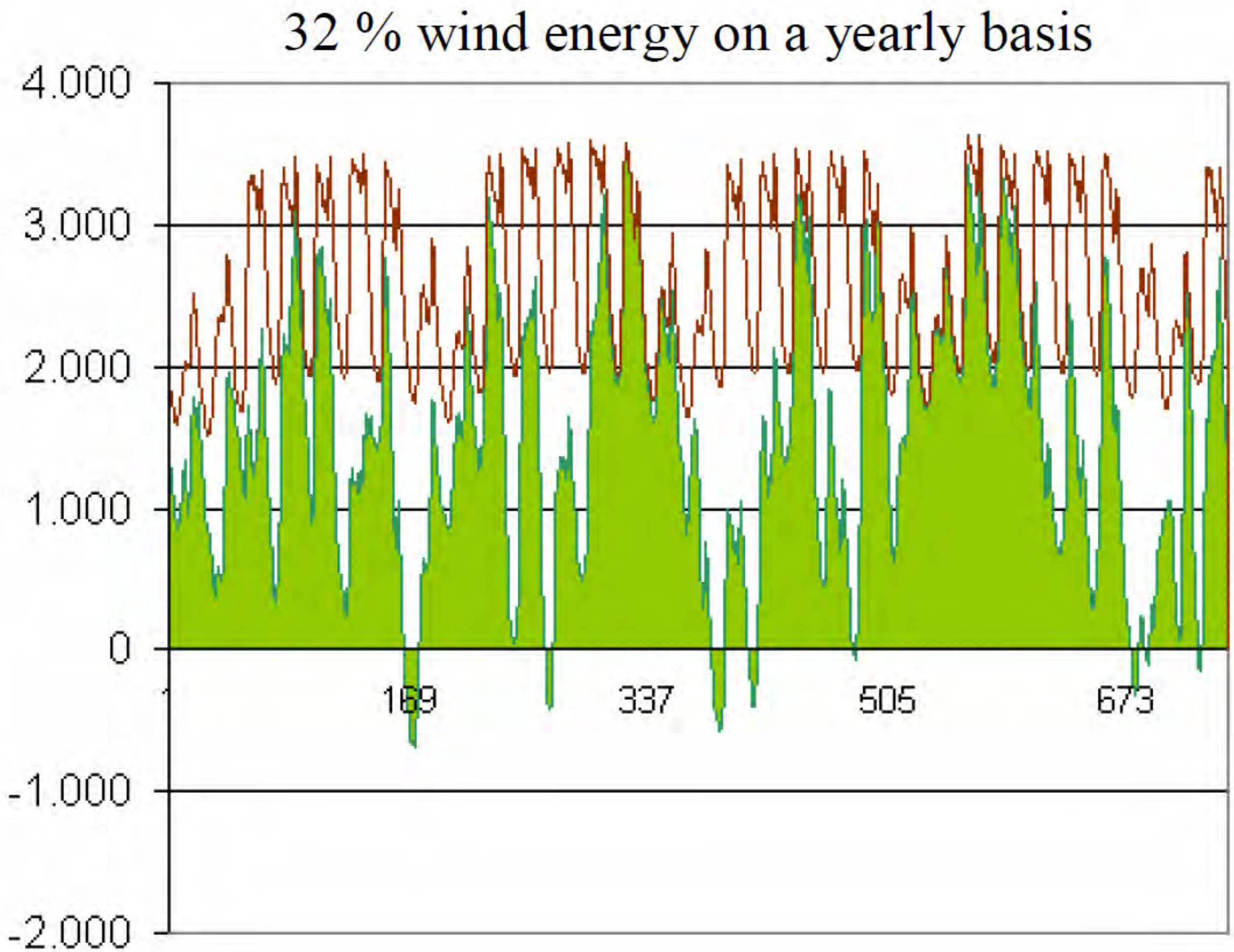



Ref. F. Bach, ELTRA

# EU's implementation – technical issues

**Case: January 2000**

Example Denmark

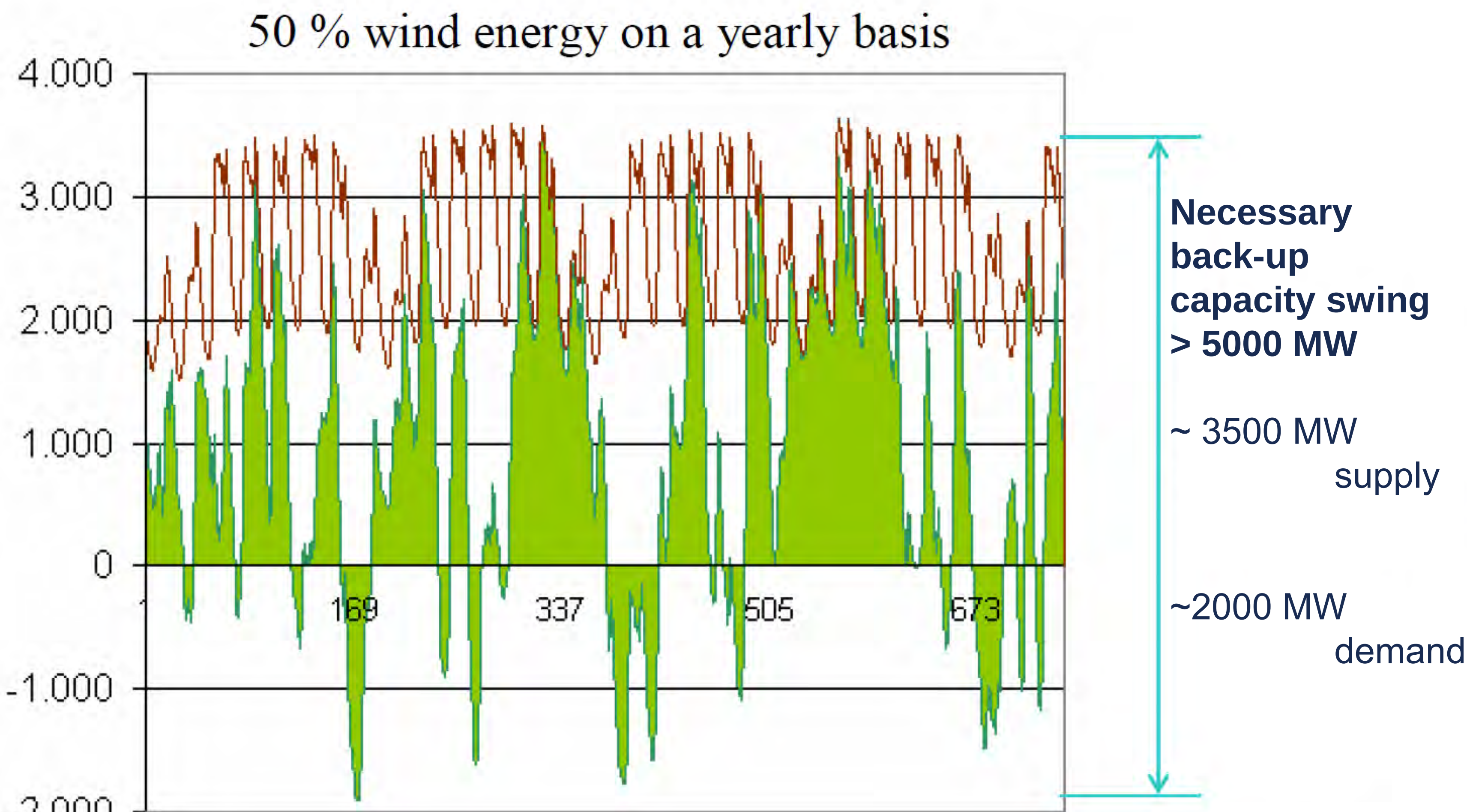



Ref. F. Bach, ELTRA

# EU's implementation – technical issues

## Case: January 2000

Example Denmark




Ref. F. Bach, ELTRA

# EU's implementation – technical issues

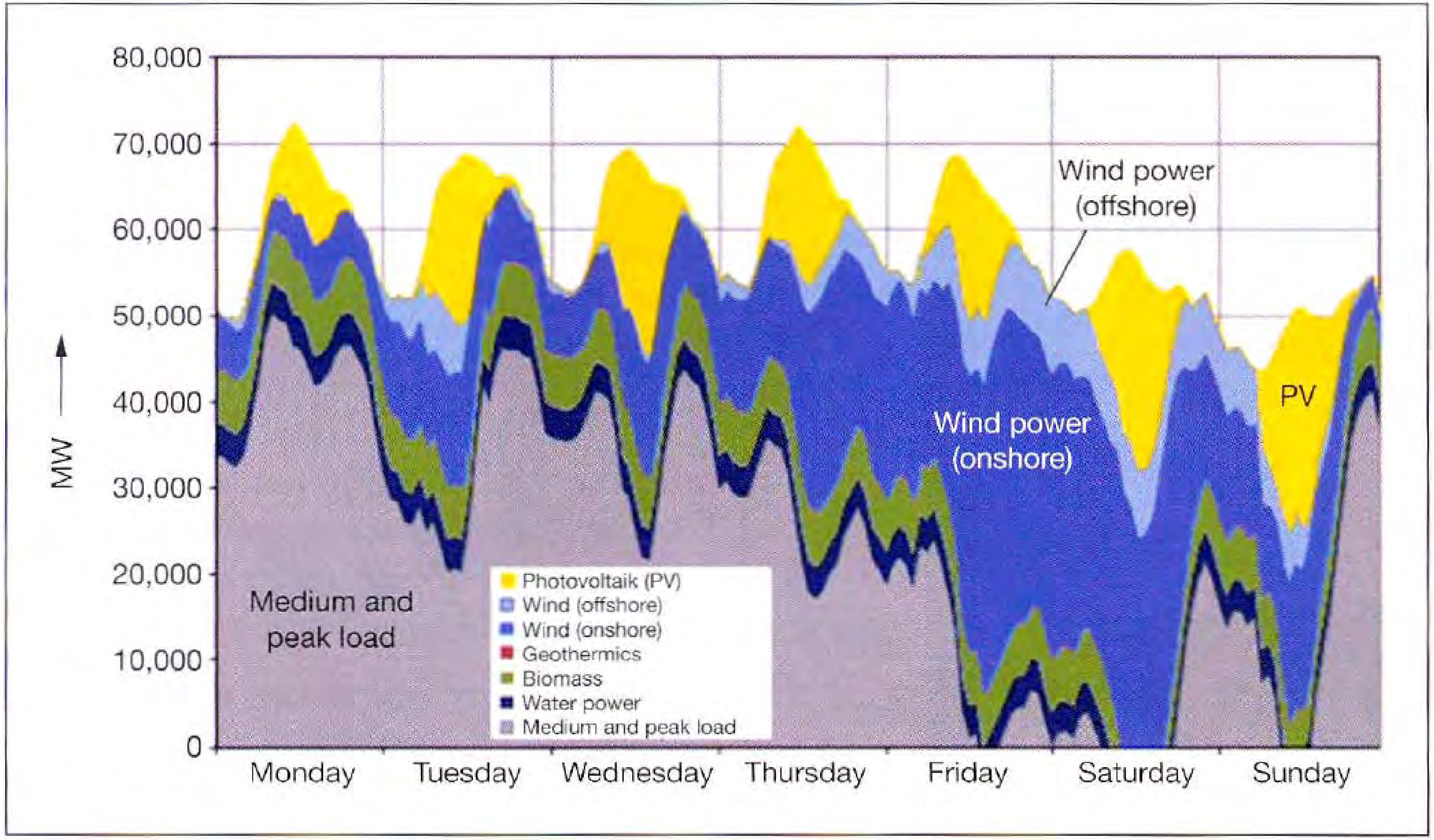
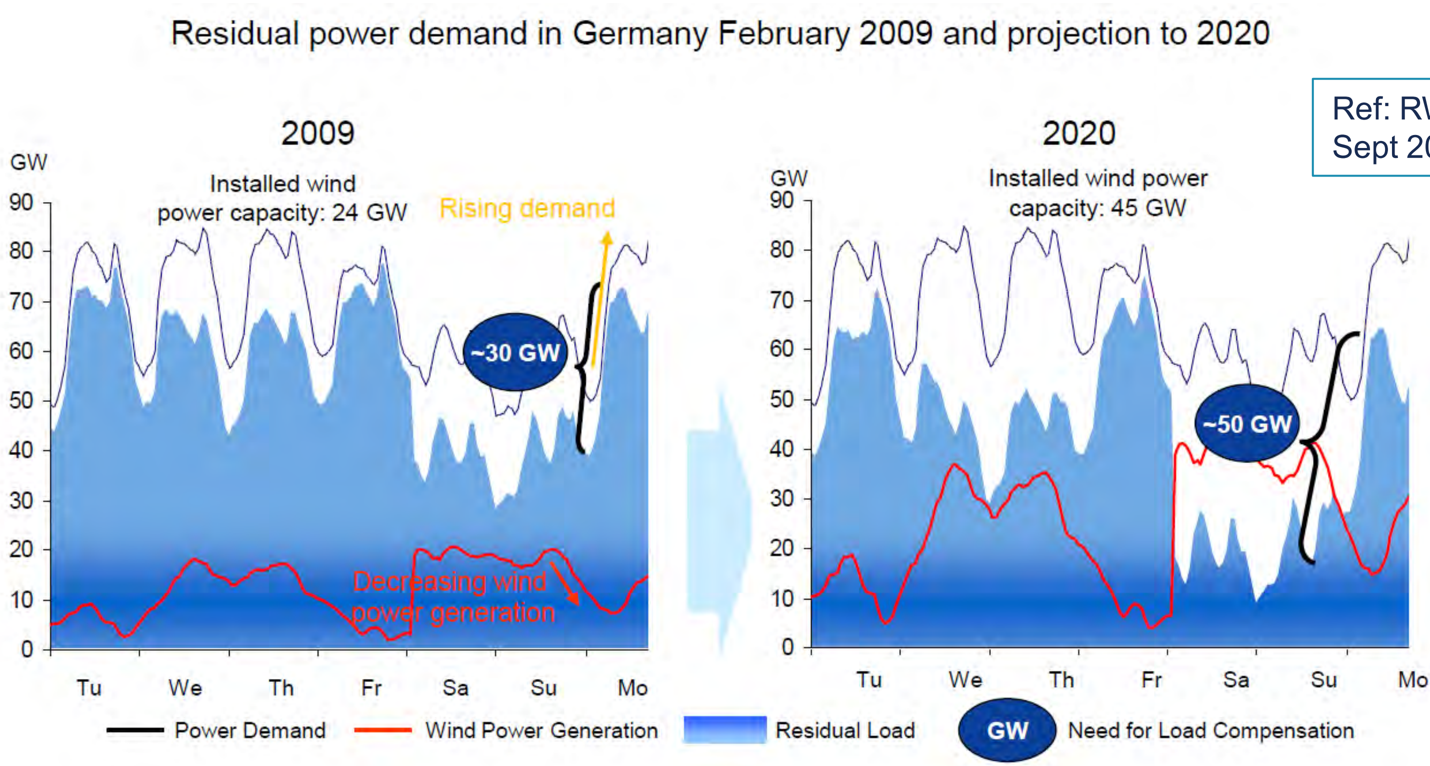



*Figure 1. Power generation across one week in July 2020, BEE scenario [6].*



Ref: Lehner & Schlipf, VGB Powertech, 8/2011

# EU's implementation – technical issues

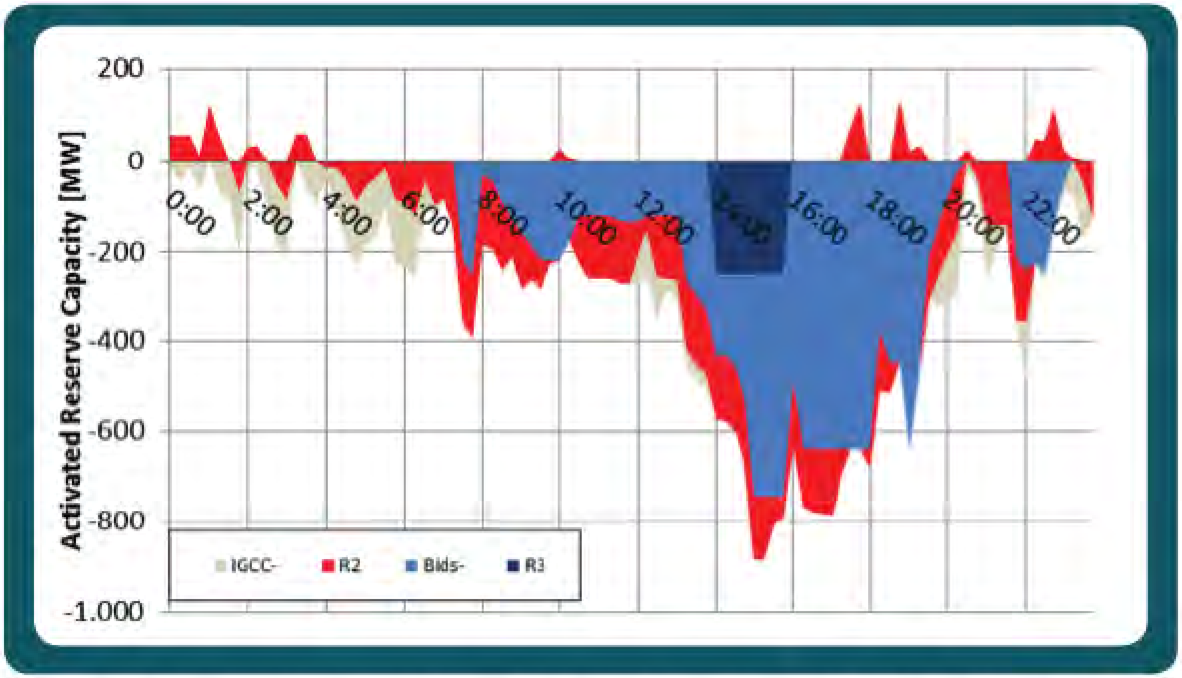



Ref: RWE – ALSTOM
Sept 2011

→ thermal plants must balance very quickly

→ **challenging requirements for thermal power plants!**

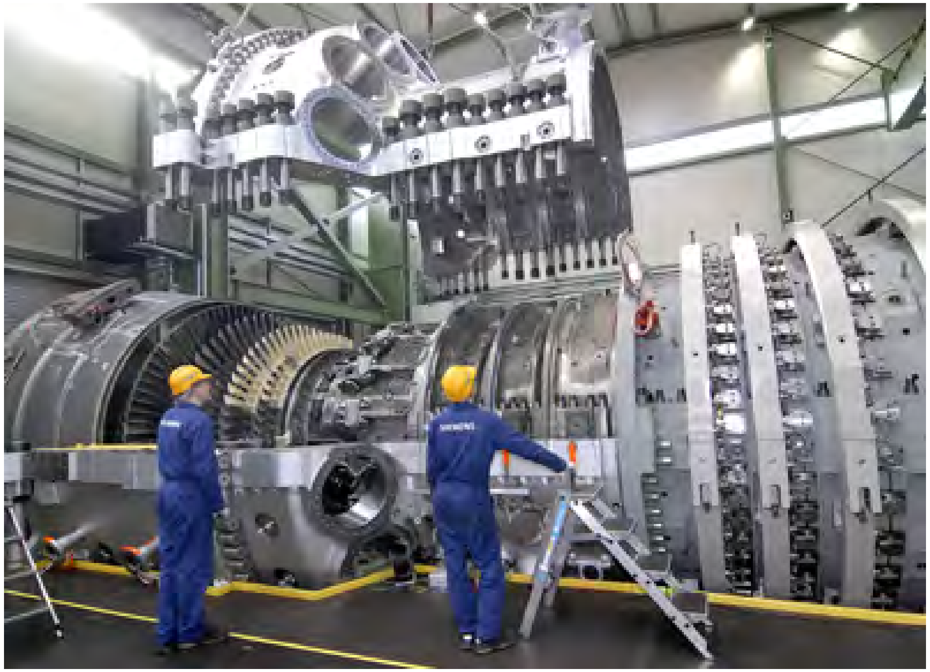
# EU's implementation – technical issues

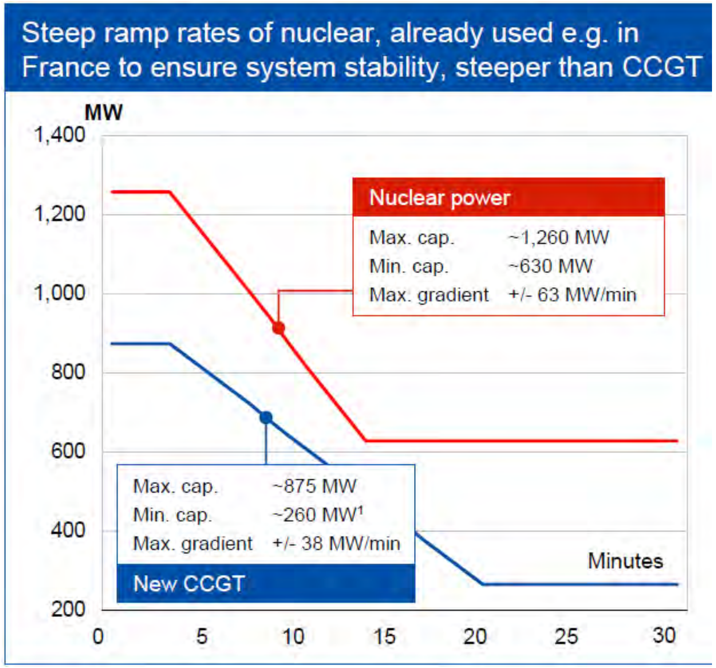



*Upward (positive) and downward (negative) regulation volume on April 1, 2013*

# EU’s implementation – technical issues

- What are critical generation-technology parameters?
  - Ramp rates compatible with technology
  - Overall dynamic behavior





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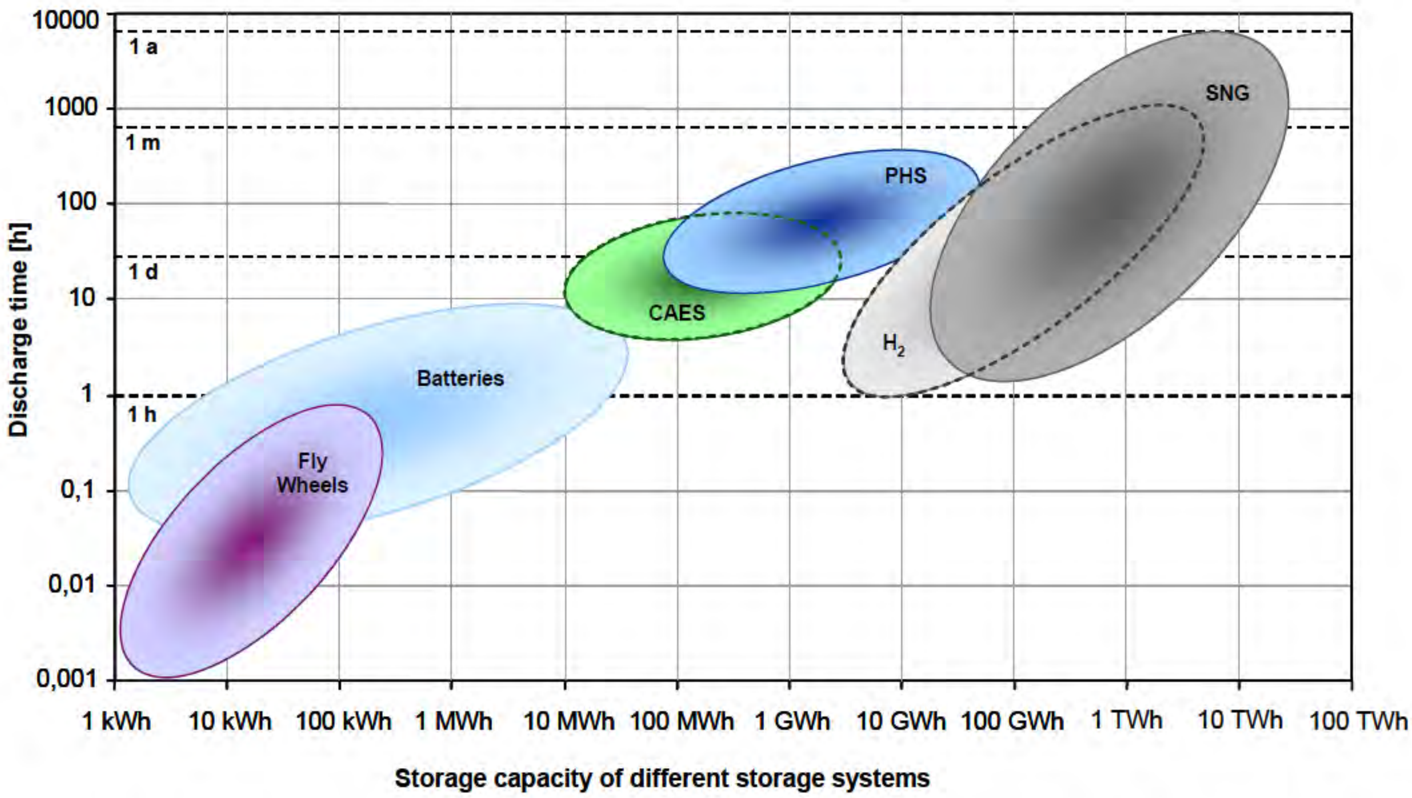
# EU's implementation – technical issues

Comparision of storage capacity and discharge time of RE-SNG




Different solutions for different tasks: ancillary vs. arbitrage

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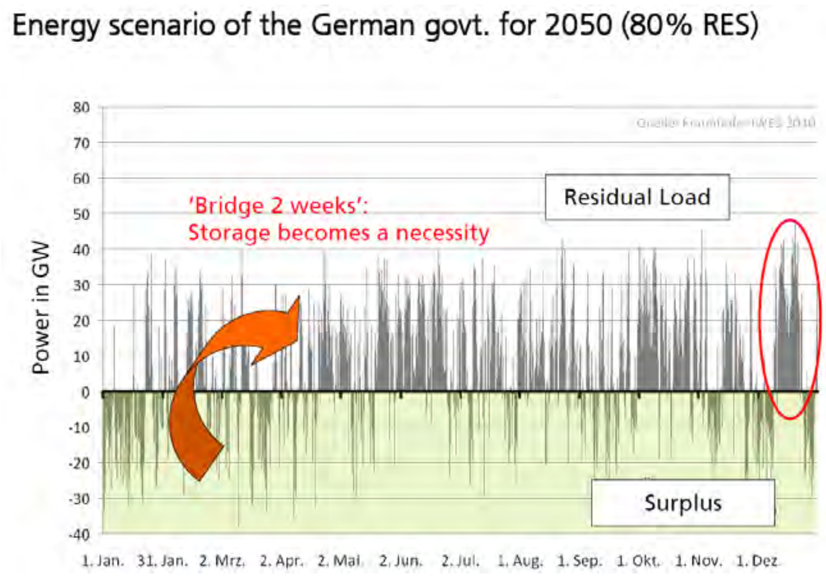
# EU's implementation – technical issues

- To what extent will there be a shift of imbalance/fluctuations to other carriers/networks?
  - Shift to synfuel storage?







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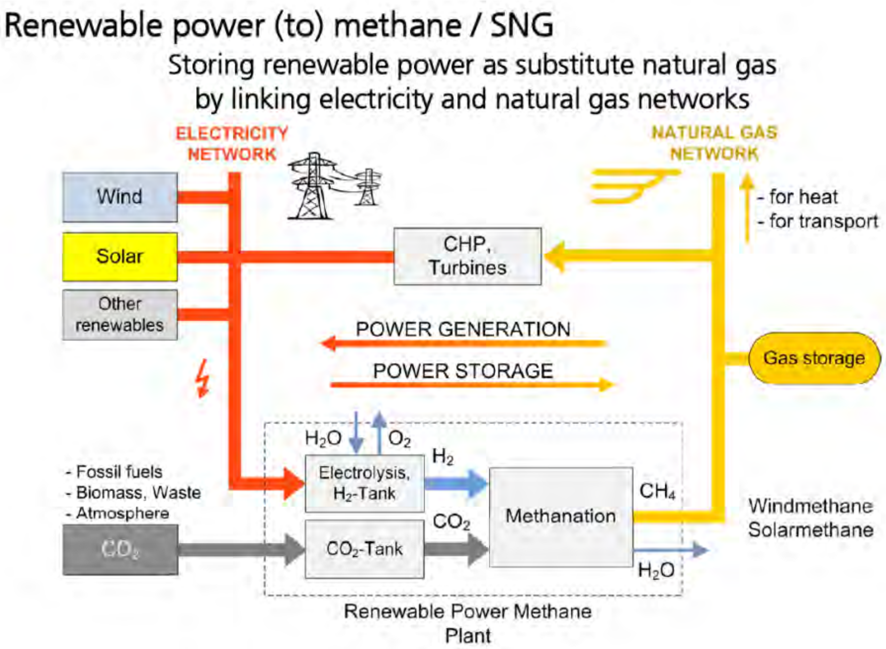
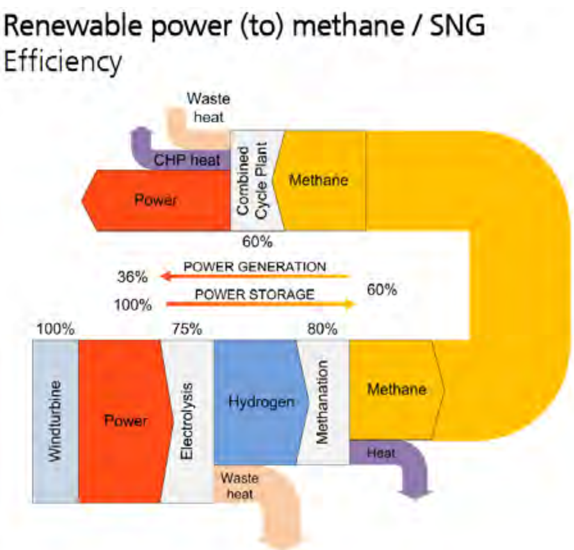
# EU's implementation – technical issues

- To what extent will there be a shift of imbalance/fluctuations to other carriers/networks?
  - Shift to synfuel storage?




60-65% SNG

35-40% Power

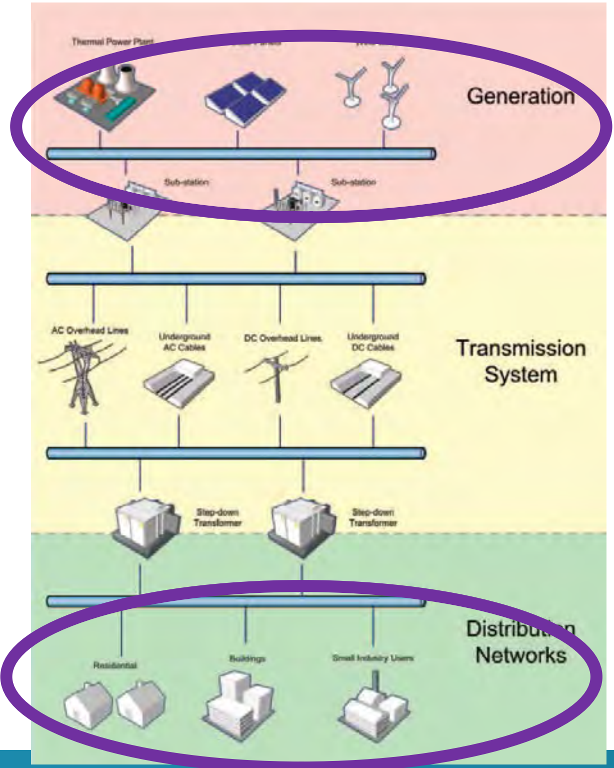
50-60% CHP

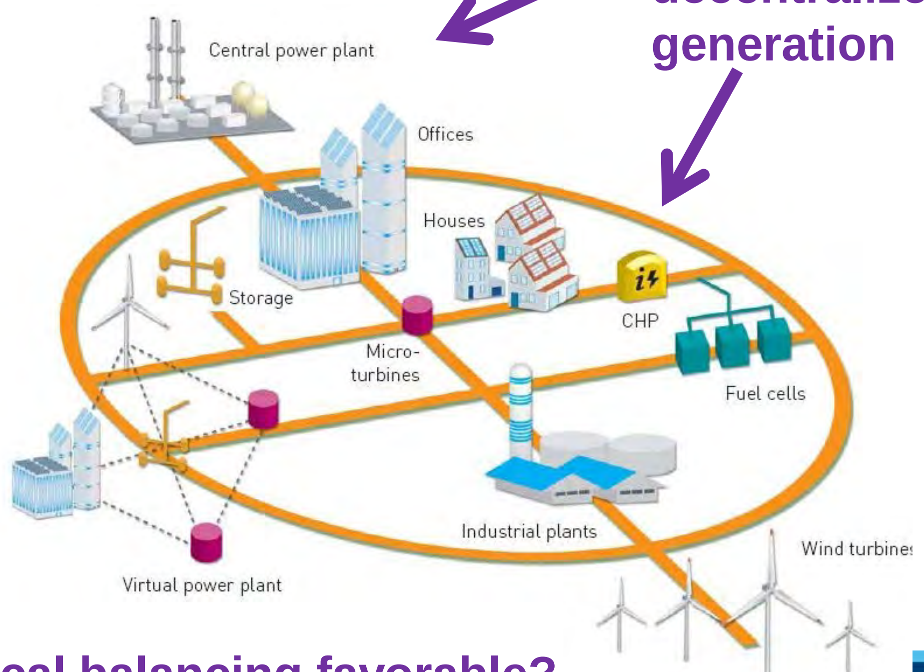
Vs. 0% due to power cut off / power curtailment

# EU's implementation – technical issues

- Where to perform the balancing (at which level)?
  - Should houses/neighborhoods/cities aim for a net load profile as flat as possible?
  - What are the proper objective functions?

**Centralized & decentralized generation**




**Local balancing favorable?**

# EU's implementation – technical issues

## Unplanned flows (loop flows / transit flows)

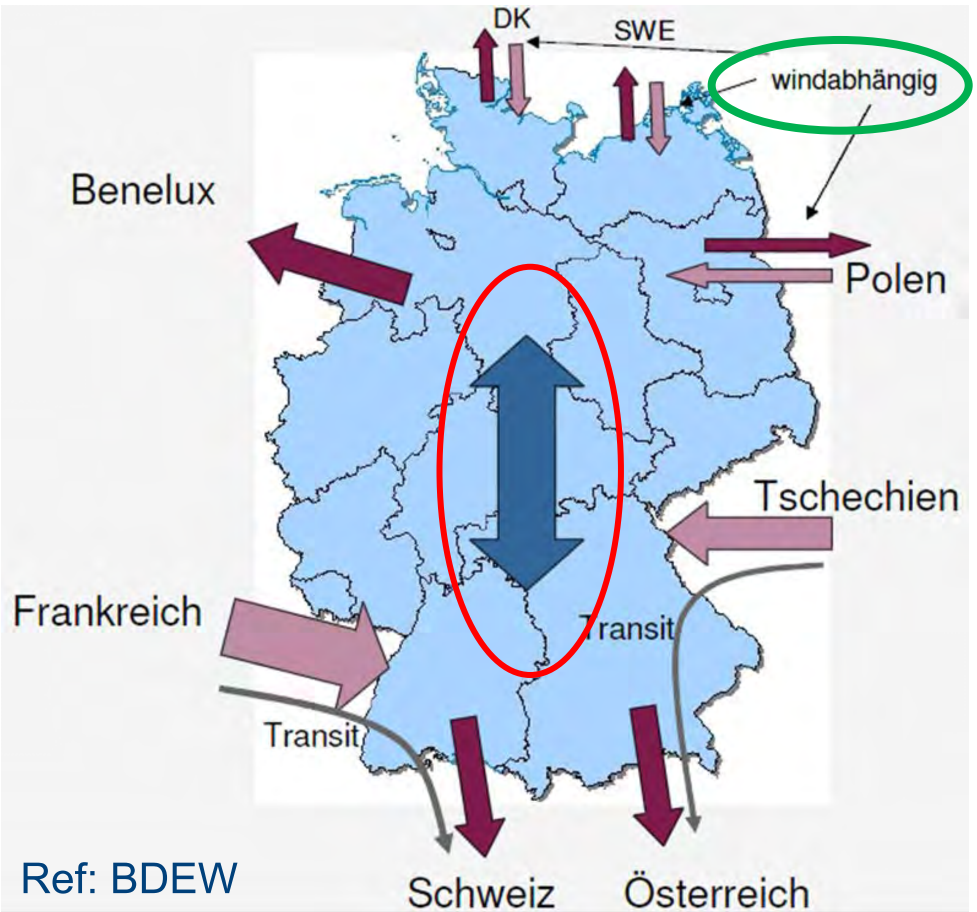
- Grids guide power flow from generation to consumption

- Electric power follows path of least resistance / impedance

- Transmission capacity high-voltage line:
  - Part needed for unexpected occurences
  - Must keep part for unintended flows (driven by electric resistance)
  - Remainder for actual commercial cross border transactions

# EU’s implementation – technical issues

## Unplanned flows (loop flows / transit flows)




Ref: BDEW

**Typical exchanges between Germany and neighboring countries**

Major problem in DE:
insufficient lines N → S

Wind in North
NPPs shut down in South
Industrial demand in South
PV in South

# EU’s implementation – technical issues

## Unplanned flows (loop flows / transit flows)

**Netzausbau: Insbesondere Nord-Süd-Trassen notwendig**

bdew
Energie. Wasser. Leben.

KKW-Abschaltungen verschärfen die Lastfluss-Situation


Ausbaustrecken gem. „dena I“

Abschaltungen Moratorium + KKW Brunsbüttel

Aktuell rd. 10% oder 80 km des Netzausbaus gemäß „dena I“ realisiert, weiterer Ausbaubedarf von rd. 3.600 km gem. „dena II“

**PERMITS !**

# EU’s implementation – technical issues

## Unplanned flows (loop flows / transit flows)

- **CEE Region**: DE→PL→CZ→AT→DE and DE→CZ→DE
- **CWE Region**: DE→NL→BE→FR→DE

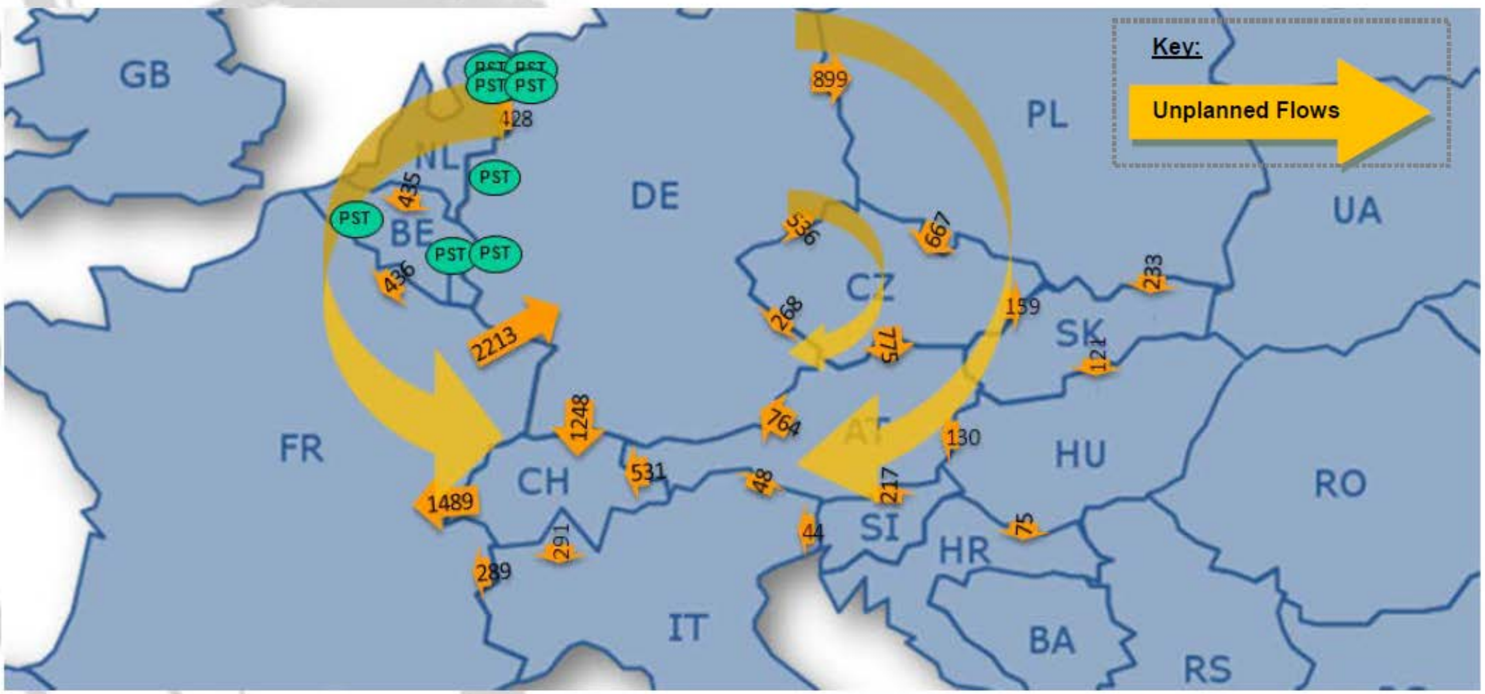



Figure 4. Average Unplanned Flows in Europe [MW], 01.2011–12.2012

Ref: CEPS et al, Jan 2013

# EU's implementation – technical issues

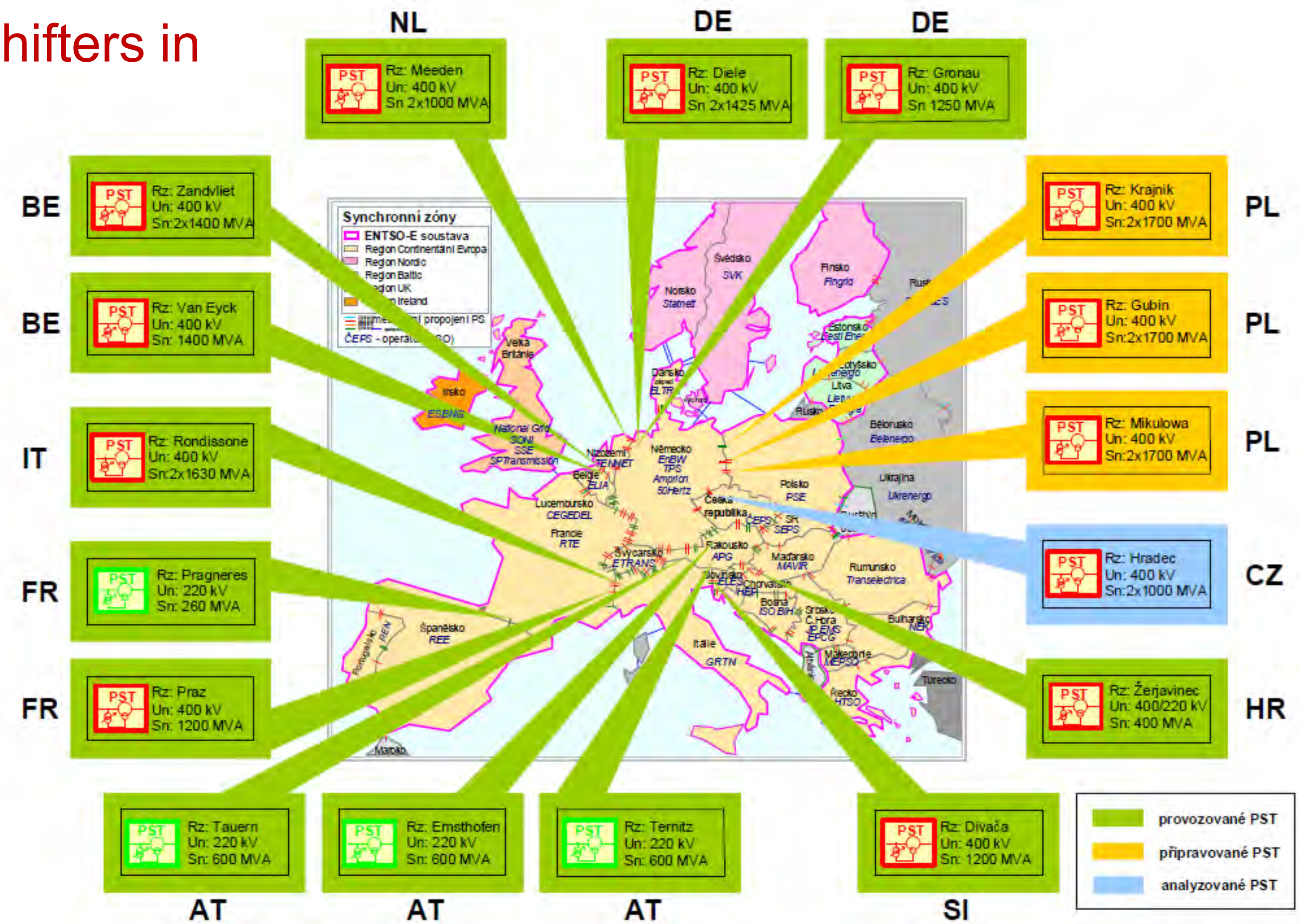
## Unplanned flows (loop flows / transit flows)

- Can be "avoided" via *phase-shift transformers*

  = a faucet/valve to "control" the flows (i.e., inhibit unplanned flows)
- But system becomes much more "nervous"...

# EU's implementation – technical issues

Phase shifters in Europe



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Source: Polish Energy Regulatory Office

# EU's implementation

## Issues / challenges / problems in the EU market

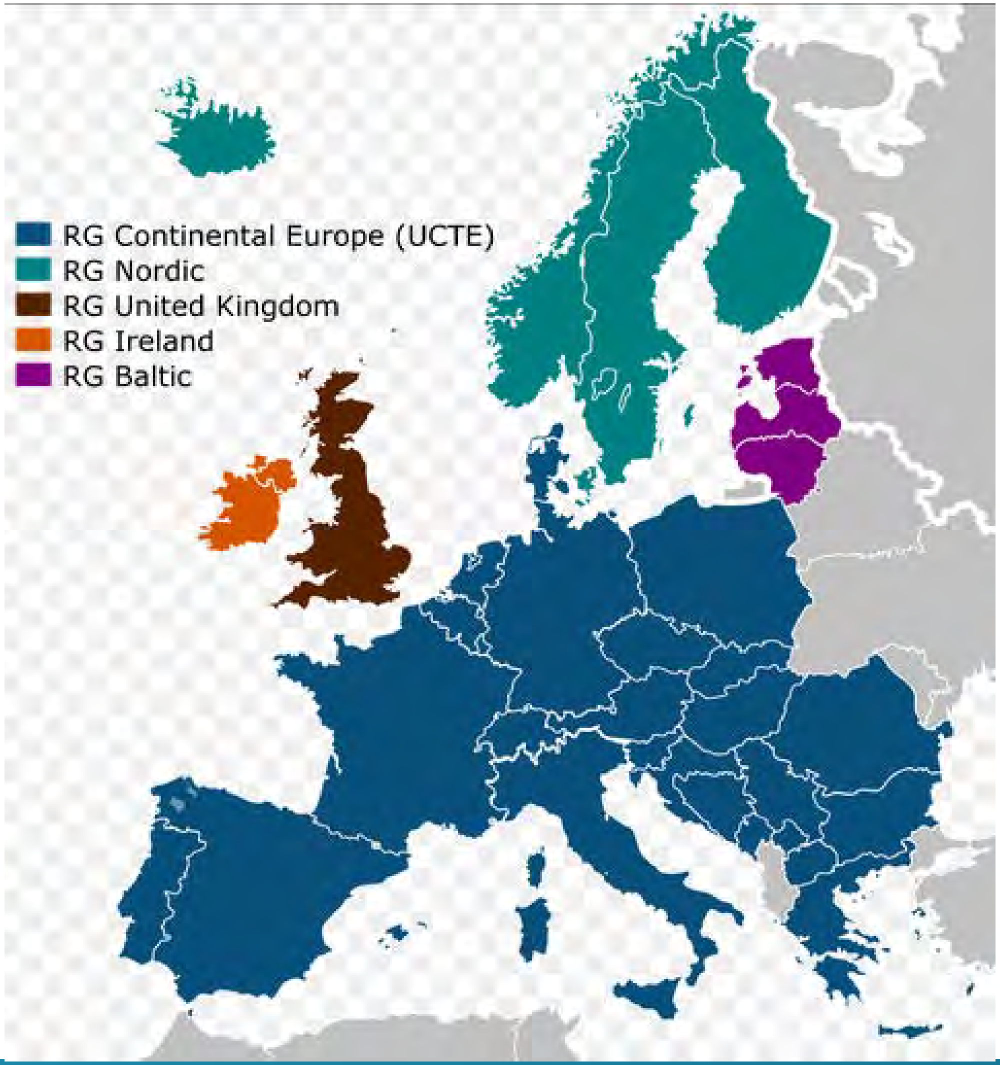
- Technical challenges
- Market-integration problems
- Consequences for the $CO_2$ emissions
- End-electricity prices for end consumers

# EU's implementation – market issues

- Common EU electricity market started in 1996,...then 2003, ...then 2009
- At present 'third package' being implemented
- Better European coordination through ENTSO-E, ACER
- Unbundling (generation, transmission, distribution, supply)
- "Alligned" grid codes...

- Market integration elements in place, was bearing fruits...

# Europe’s Synchronous Regions

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# Europe’s Market Coupling

## When will European electricity and gas markets be perfectly fluid?

- Despite remaining physical bottlenecks in electricity, **TSOs and Power Exchanges common actions** have improved electricity prices convergence:
  - **Trilateral market coupling (TLC)** from November 2006 between France, Belgium, and the Netherlands
  - **Coreso** (Regional Coordination Service Centre operational since February 2009 on the CWE* area)
  - **CWE* market coupling and ITVC**** since November 2010
- Gas market integration is slower but should progress

**Trading is becoming a European business offering synergies opportunities**

| | | |
|---|---|---|
| ■ | CWE* | Price coupling |
| ■ | AT | Price coupled to DE (no congestion) |
| ■ | UK | Price coupled to NL via BritNed |
| ■ | Nordics + EE | Price coupling |
| — | ITVC | Volume coupling CWE – Nordics |
| ■ | IT-SI | Price coupling |
| ■ | Mibel | Price coupling |
| ■ | CZ-SK | Price coupling |

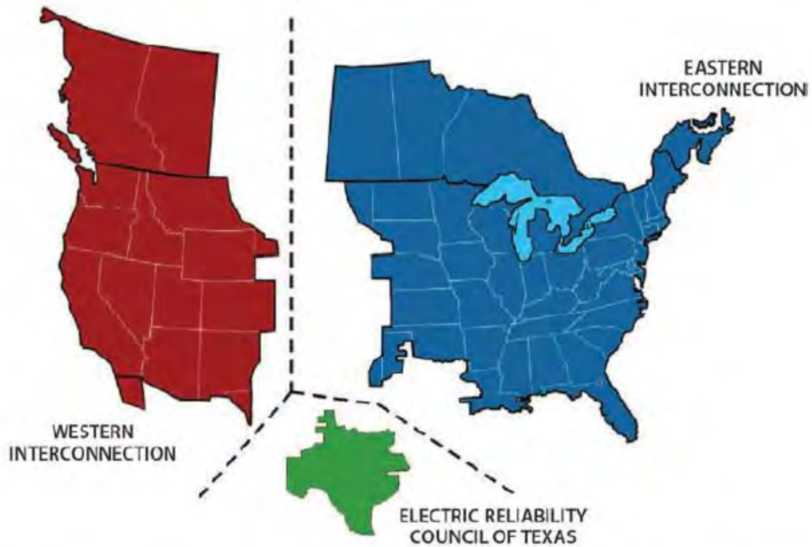
European power market coupling (current and future situation)


Source: ENTSO-E, EUROPEX, Energies 2050

*CWE: Central Western Europe; **ITVC: Interim Tight Volume Coupling

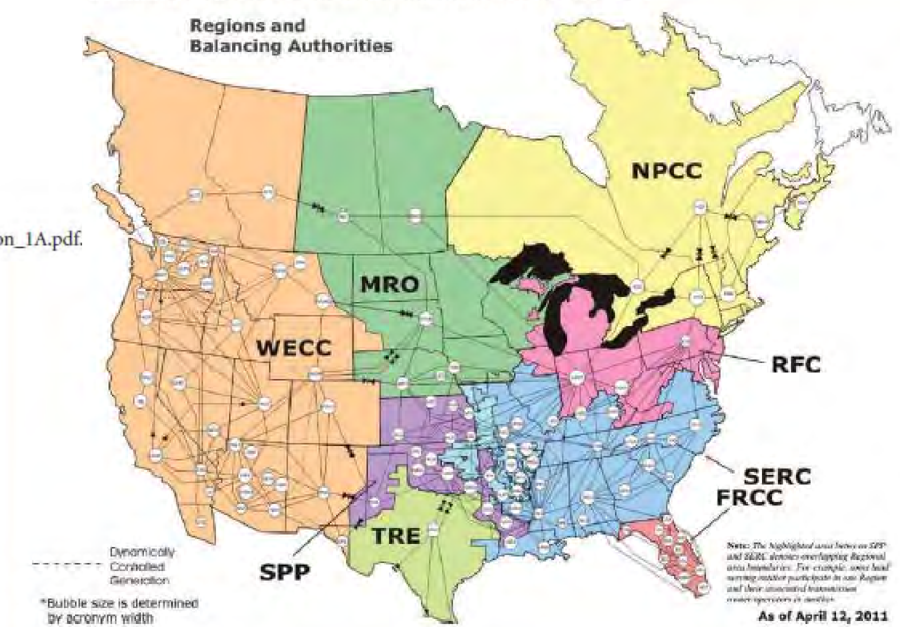
# Similar issues to US structure...

Synchronous regions in the US




Source: U.S. Department of Energy, http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/NERC_Interconnection_1A.pdf.

**Balancing Authorities in the North American Electric Grid, 2011**

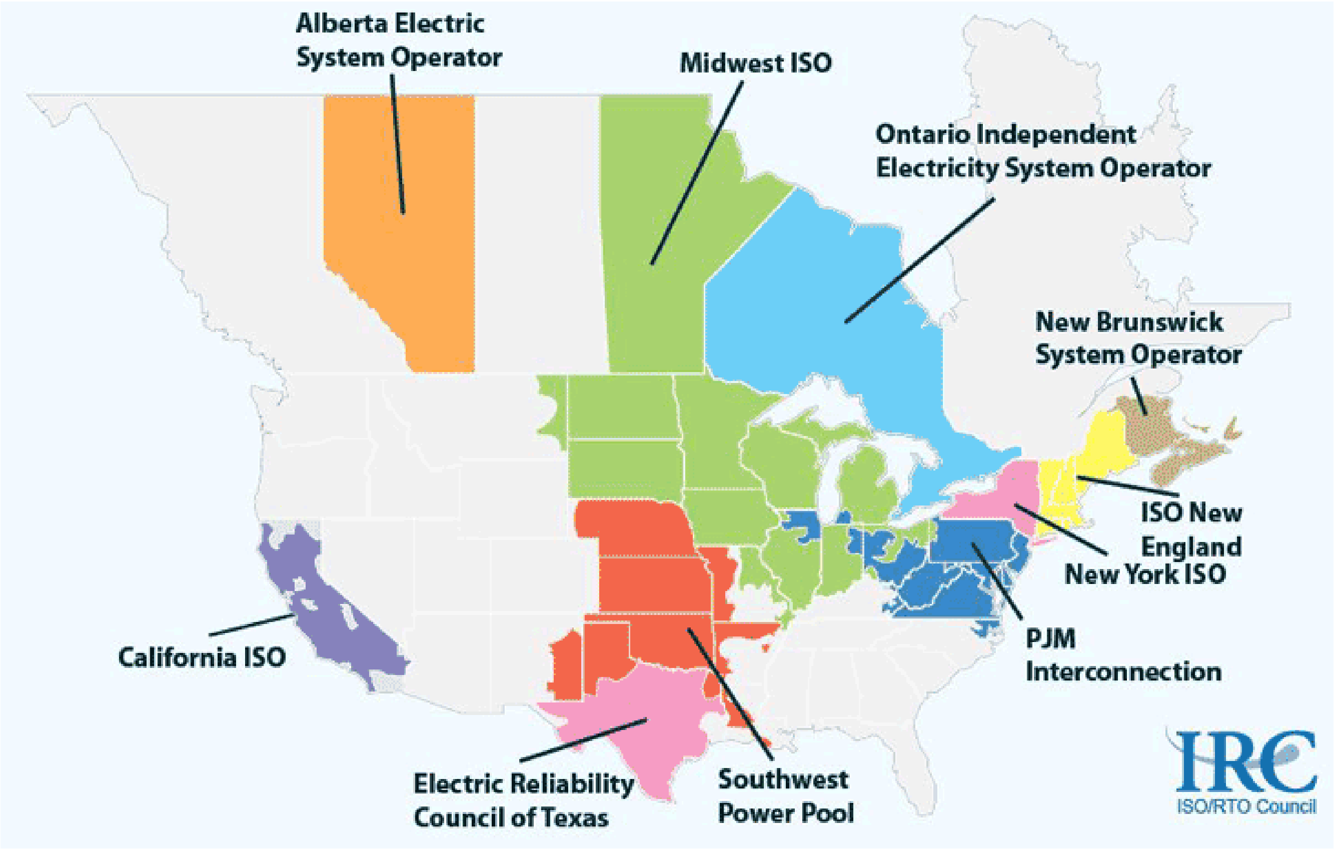



Source: North American Electric Reliability Corporation, http://www.nerc.com/docs/oc/rs/BubbleMap_2011-04-12.jpg

Note: FRCC = Florida Reliability Coordinating Council; MRO = Midwest Reliability Organization; NPCC = Northeast Power Coordinating Council; RFC = ReliabilityFirst Corporation; SERC = SERC Reliability Corporation; SPP = Southwest Power Pool; TRE = Texas Regional Entity; WECC = Western Electricity Coordinating Council.

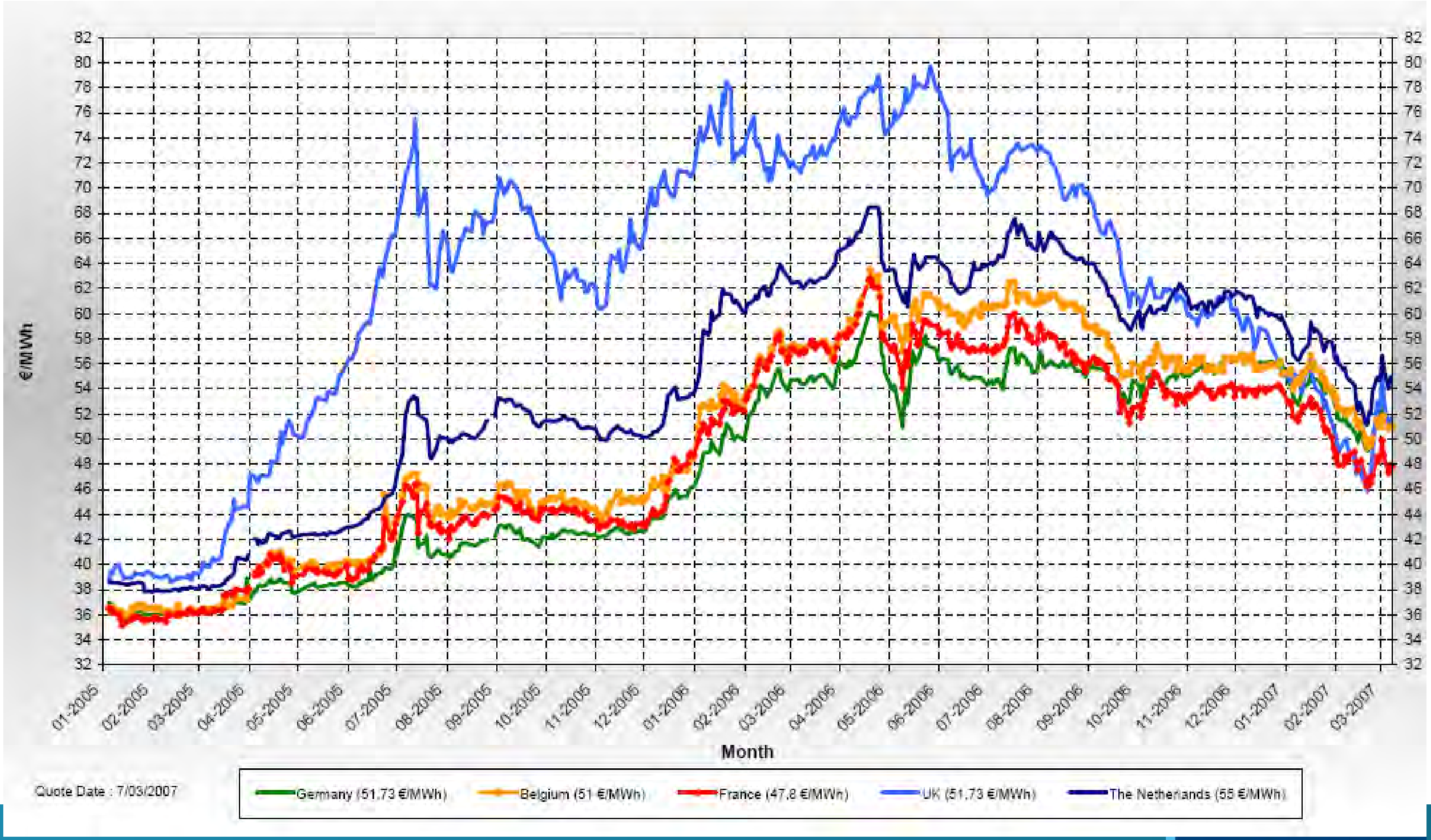
# Similar issues to US structure...

Regions with organized electricity markets



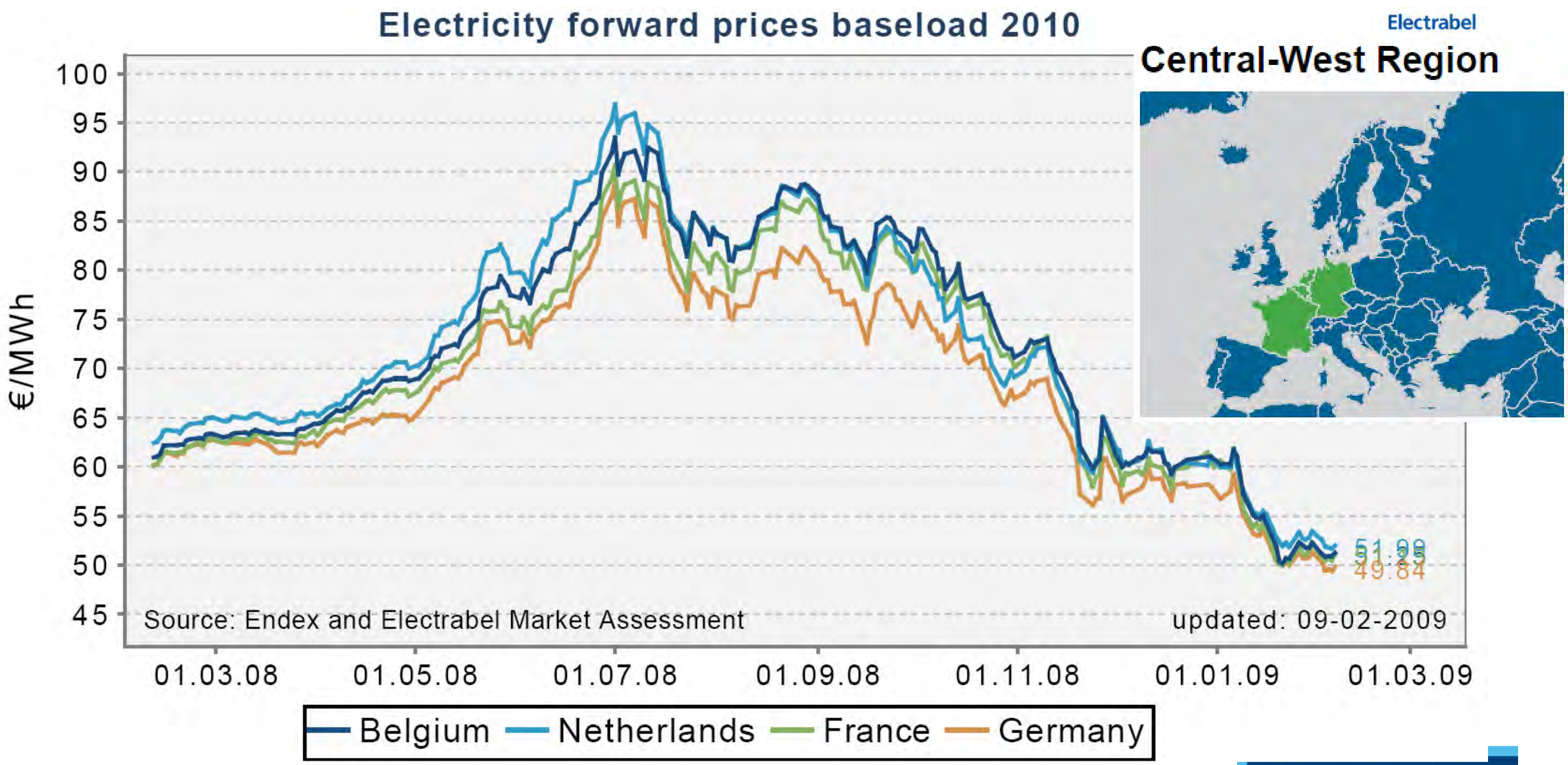
# EU’s implementation – market issues

## Convergence electricity prices point towards working market



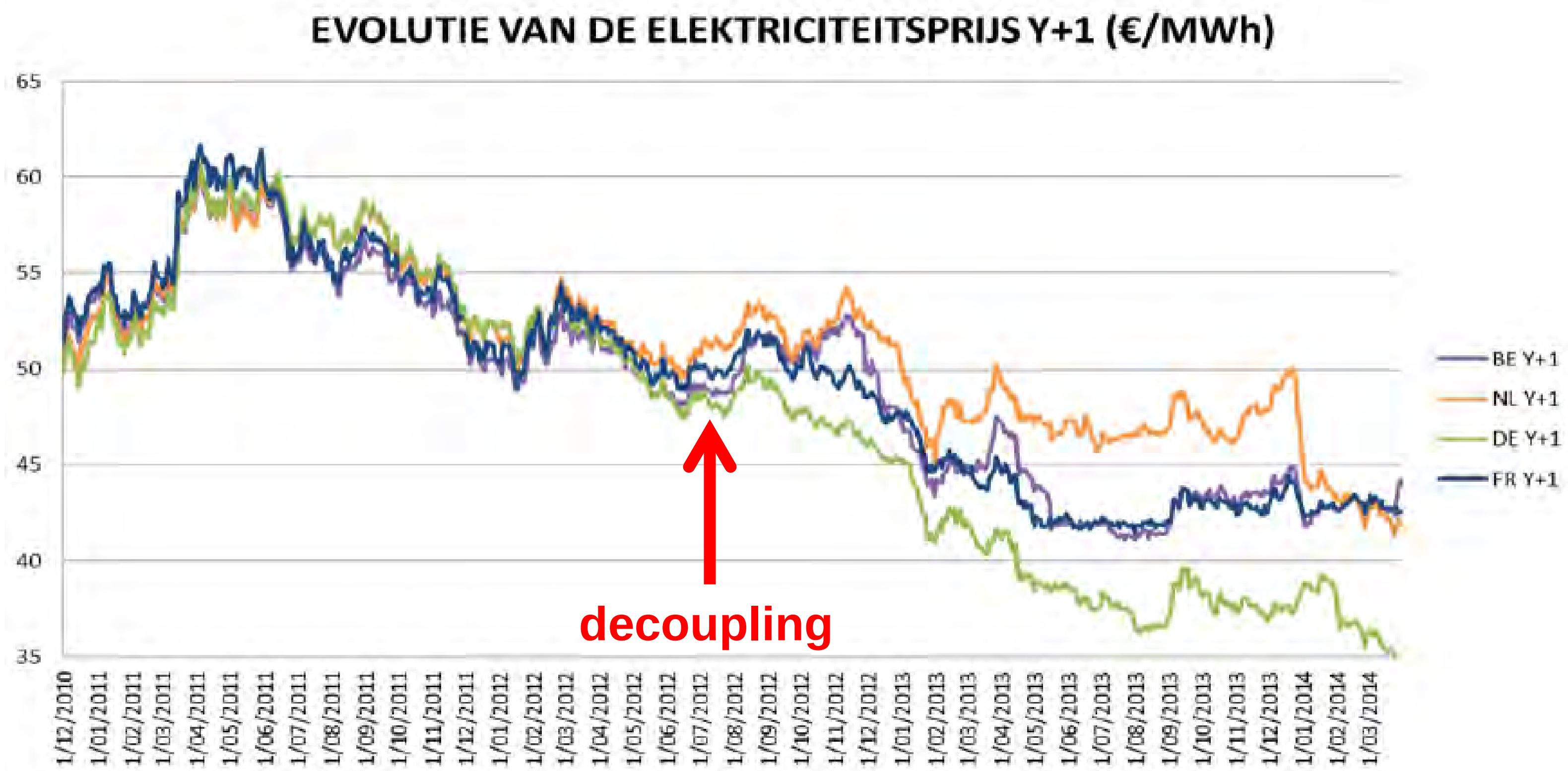
# EU’s implementation – market issues

**Convergence electricity prices point towards working market**



# EU's implementation – market issues

But ... Recent developments... !!!

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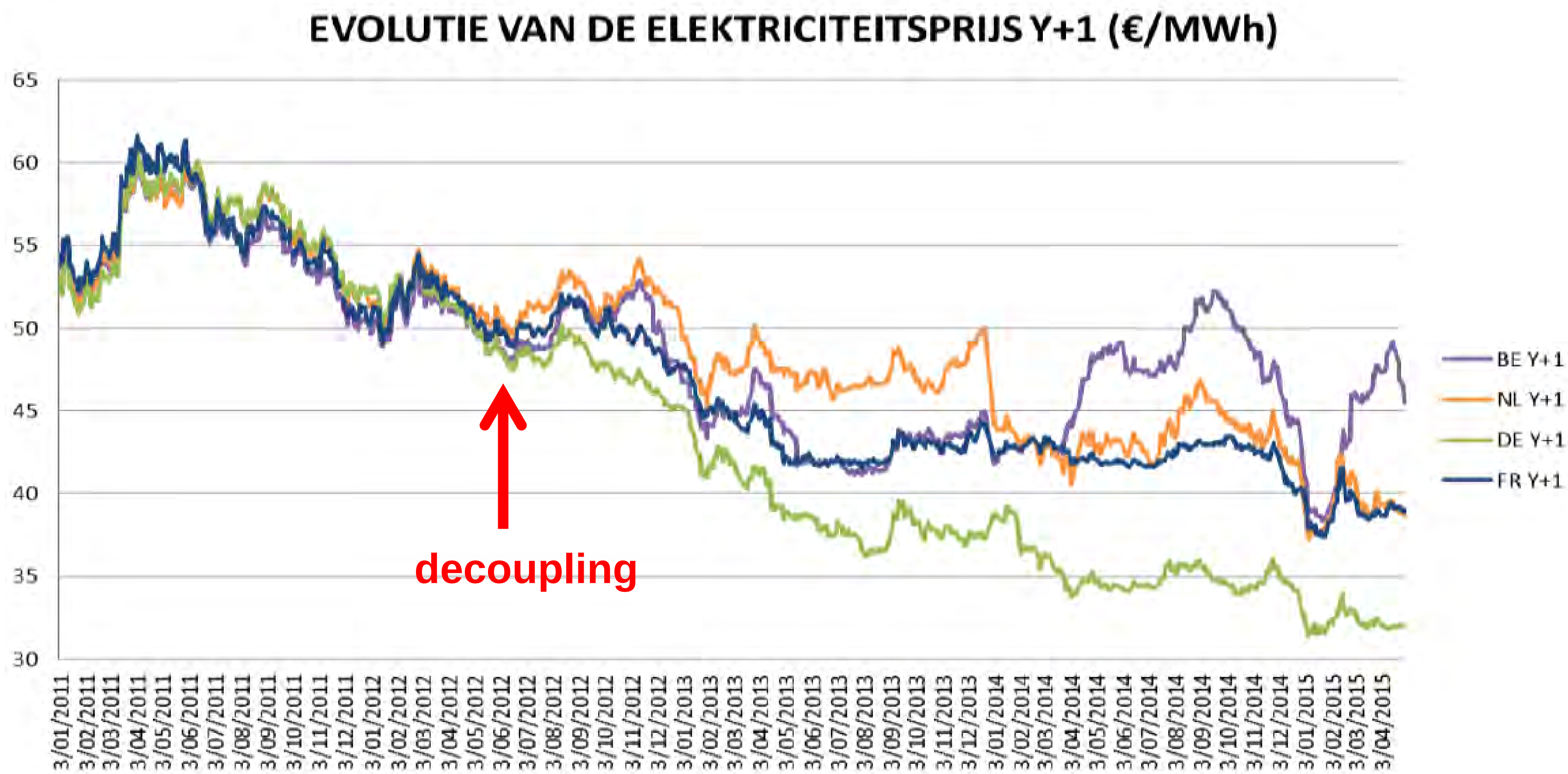
# EU's implementation – market issues

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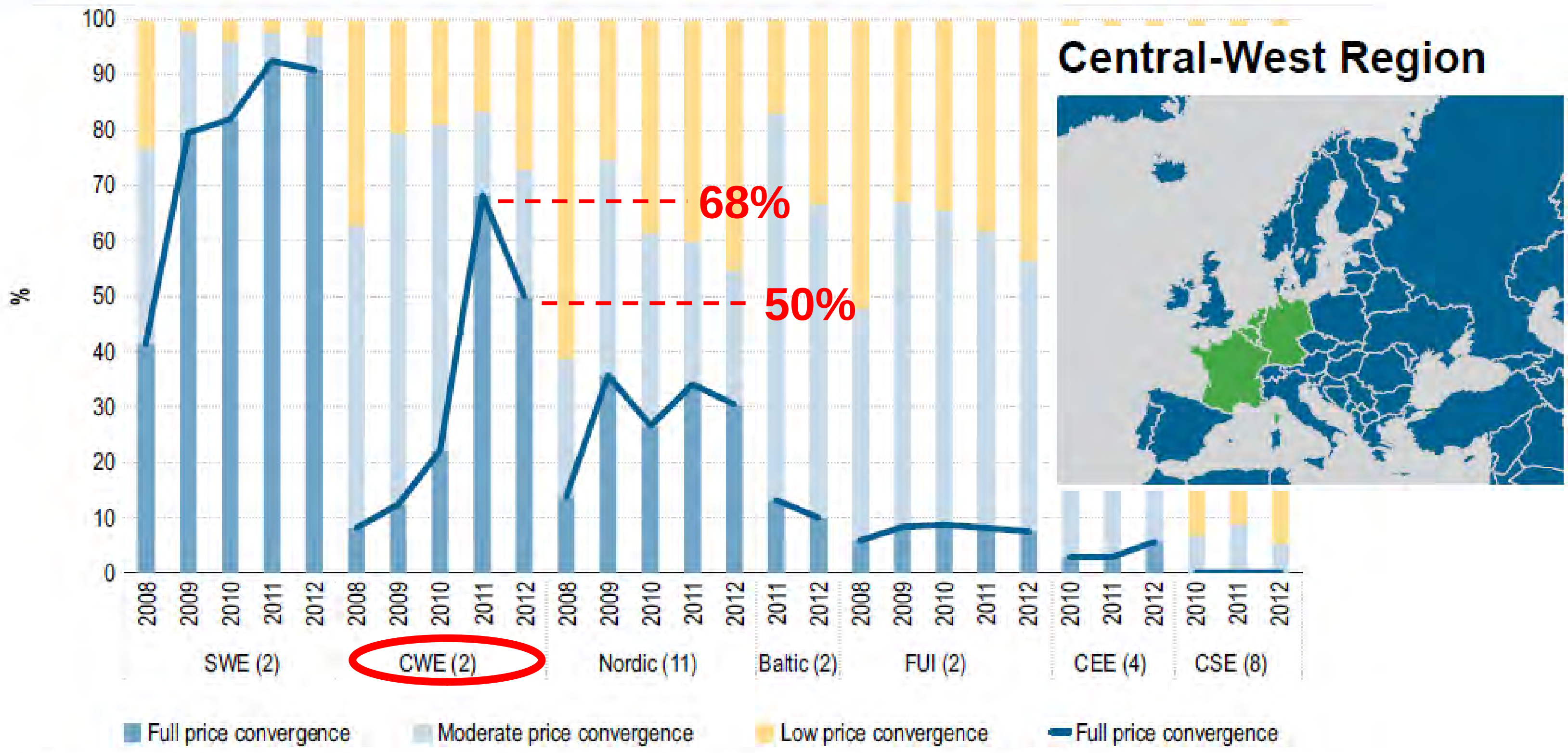
# EU's implementation – market issues

## But ... Recent developments... !!!

Figure 13: Price convergence in Europe by region (ranked) – 2008 to 2012 (%)

Source: ACER, 2013

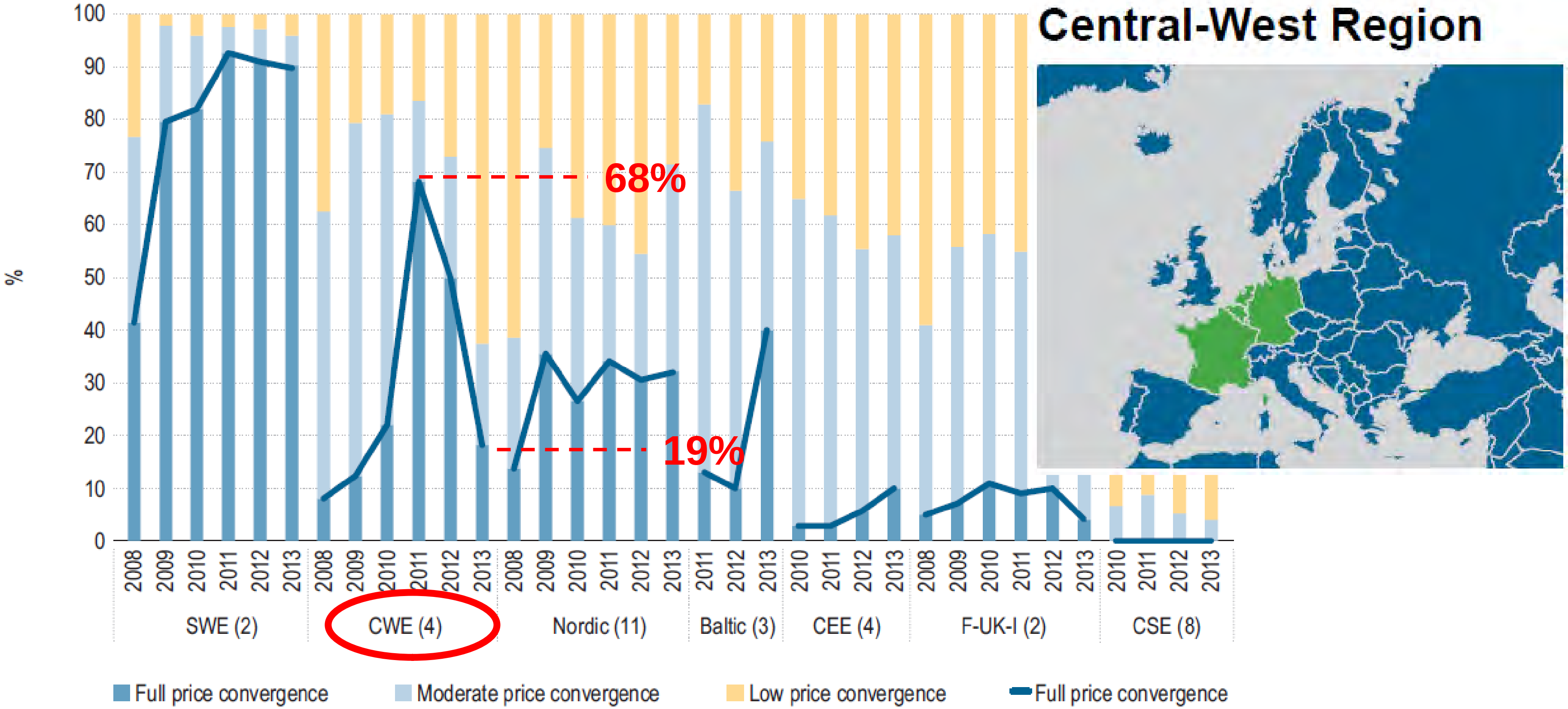



*Source: Platts, PXs and data provided by NRAs through the Electricity Regional Initiatives (ERI) (2013) and ACER calculations*

*Note: The numbers in brackets, e.g. SWE(2), refer to the number of bidding zones per region included in the calculations.*

# EU’s implementation – market issues

Figure 37: Price convergence in Europe by region (ranked) – 2008–2013 (% of hours)



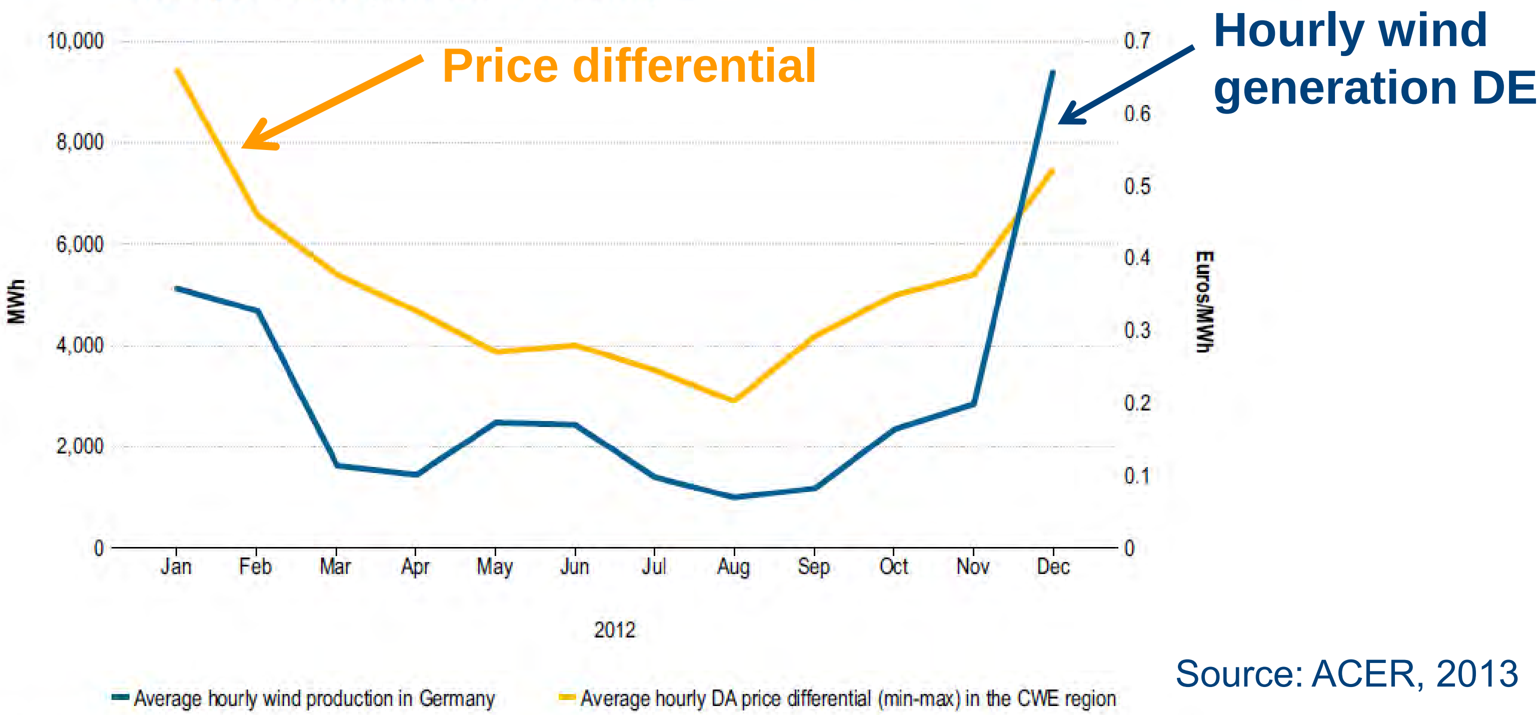

*Source: Platts, PXs and data provided by NRAs through the ERI (2014) and ACER calculations*

*Note: The numbers in brackets refers to the number of bidding zones per region included in the calculations.*

# EU's implementation – market issues

## But ... Recent developments... !!!

Figure 14: Monthly average hourly wind production in Germany compared to price differentials in the CWE region – 2012 (MWh and euros/MWh)



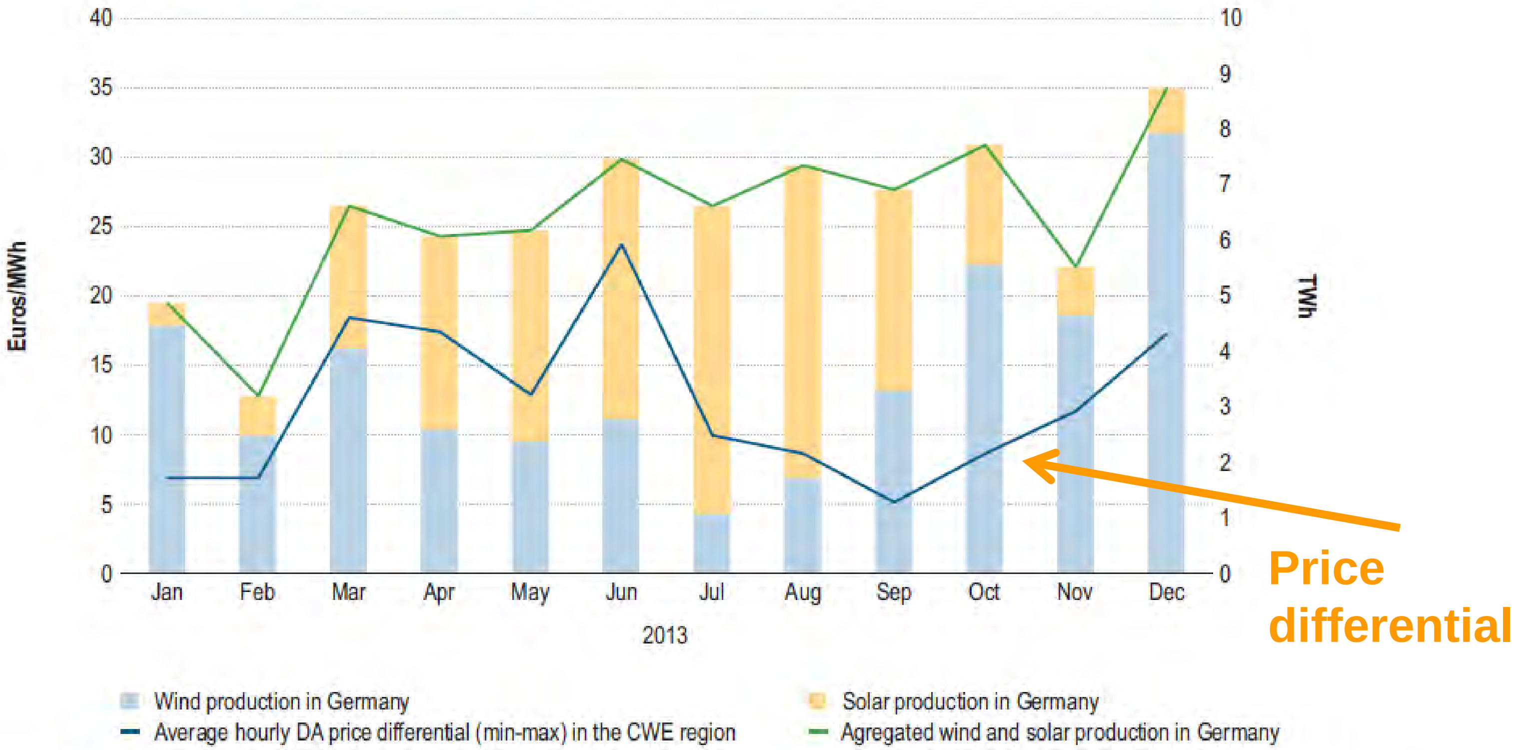

Source: ACER, 2013

*Source: Platts and German TSOs (2013) and ACER calculations*

*Note: The price differentials are calculated as the hourly difference between the maximum and minimum price of the bidding zones of the CWE region. In 2012, the lowest price was recorded in Germany for around 70% of the periods.*

# EU's implementation – market issues

Figure 38: Monthly aggregated wind and solar production in Germany compared to price differentials in the CWE region – 2013 (TWh and euros/MWh)




Source: Platts, ENTSO-E (2014) and ACER calculations

Note: The price differentials are calculated as the hourly difference between the maximum and minimum price of the bidding zones of the CWE region. In 2013, the lowest price was recorded in Germany for around 87% of the times.

Ref. ACER Annual Report 2014

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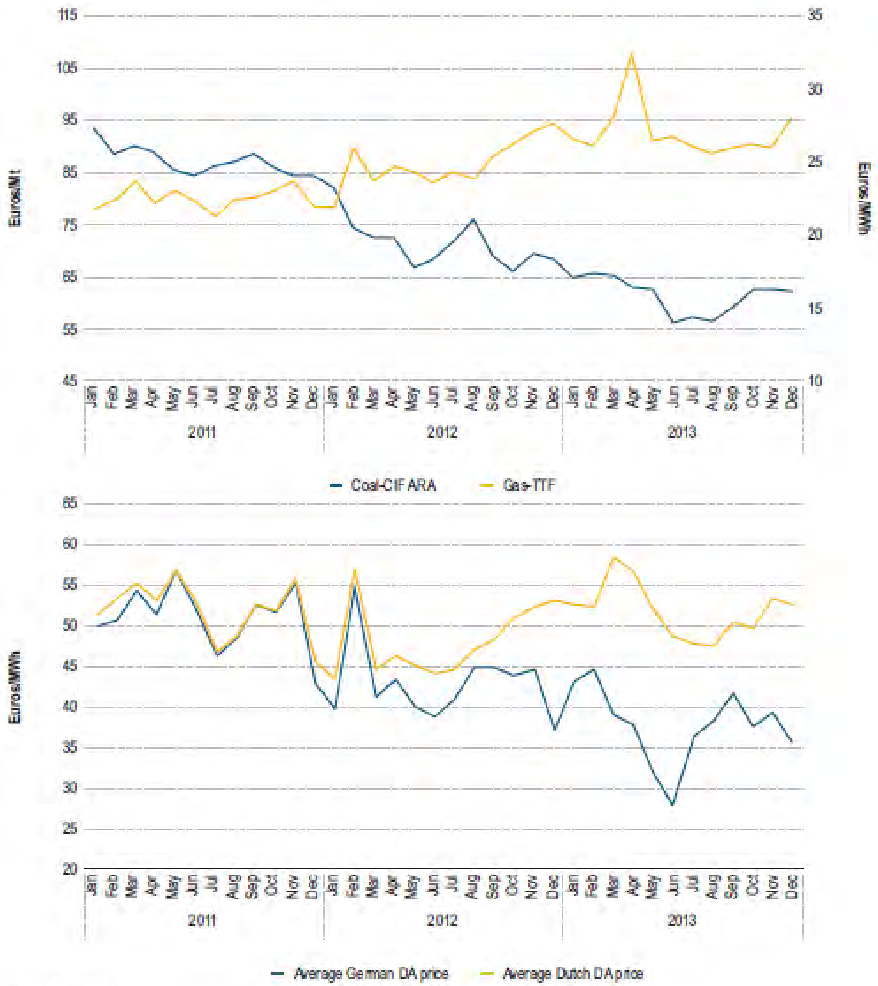
# EU’s implementation – market issues

Figure 39: Evolution of fuel (Coal-CIF ARA & Gas-TTF) and power prices (German and Dutch average day-ahead prices) – 2011–2013 (euros/Mt and euros/MWh)




Source: Platts (2014)

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# EU's implementation – market issues

But ... Recent developments... !!!

- *Decoupling prices* shows 'poorer' functioning of market
- *Lower* wholesale prices seem to be good news (?)
- But they lead to major problems for *owners/operators of thermal plants which are needed for balancing*!
- And ironically, end-consumer prices increase rather than decrease (to pay for the levies/subsidies)

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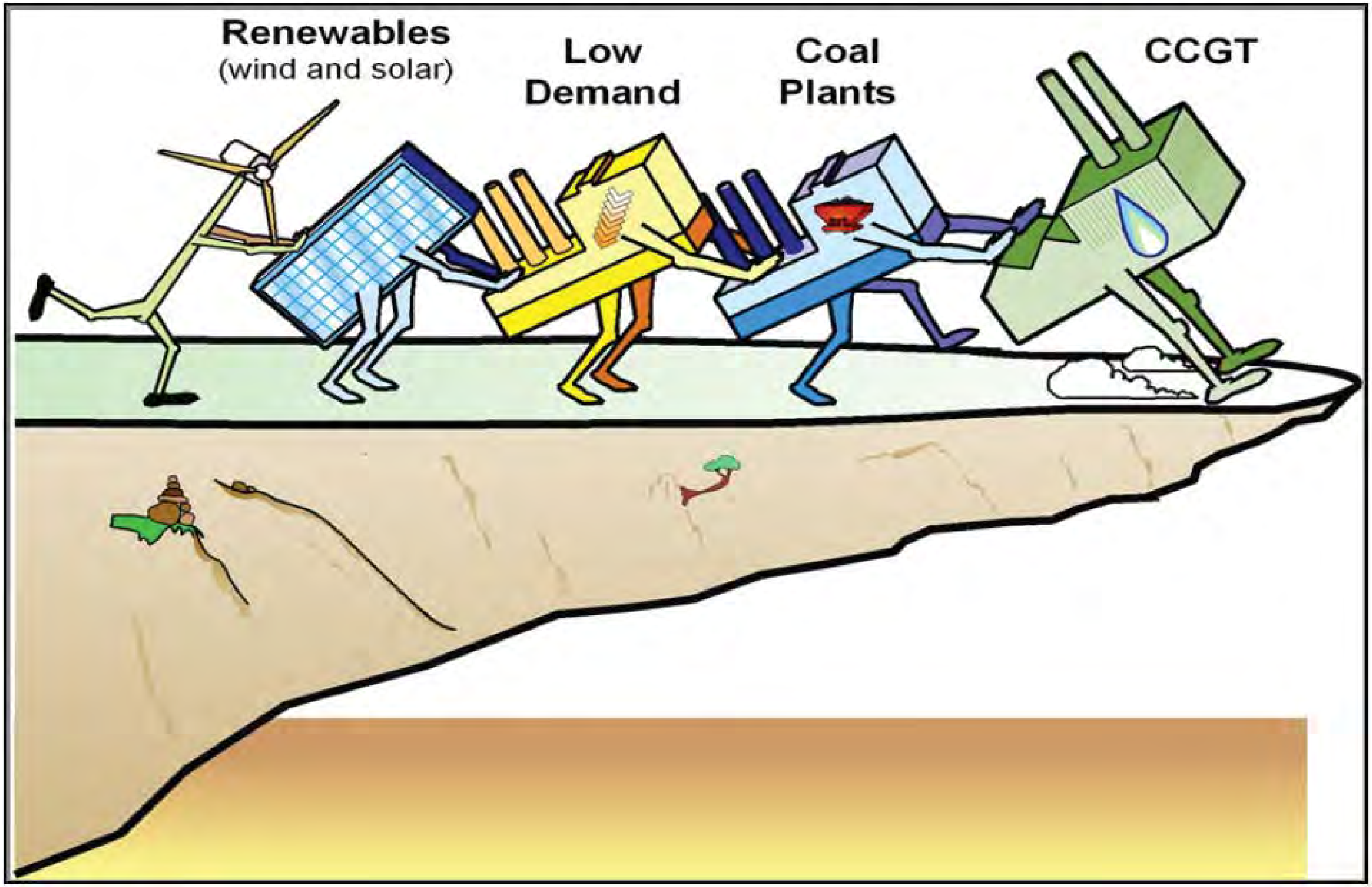
# EU's implementation – market issues

## But ... Recent developments... !!!

- These effects were not foreseen in "liberalized market design"...
- Due to massive injection of zero marginal cost generation (RES)
- Existing thermal plants are pushed out of merit order.
- But, due to low coal prices in Europe (high gas price in EU, low gas price in USA → coal cheaper, very low $CO_2$ penalty)
- Most efficient & flexible plants (CCGTs) are pushed out of merit order... Tendency for mothballing

# EU’s implementation – market issues



# EU's implementation – market issues

## But ... Recent developments... !!!

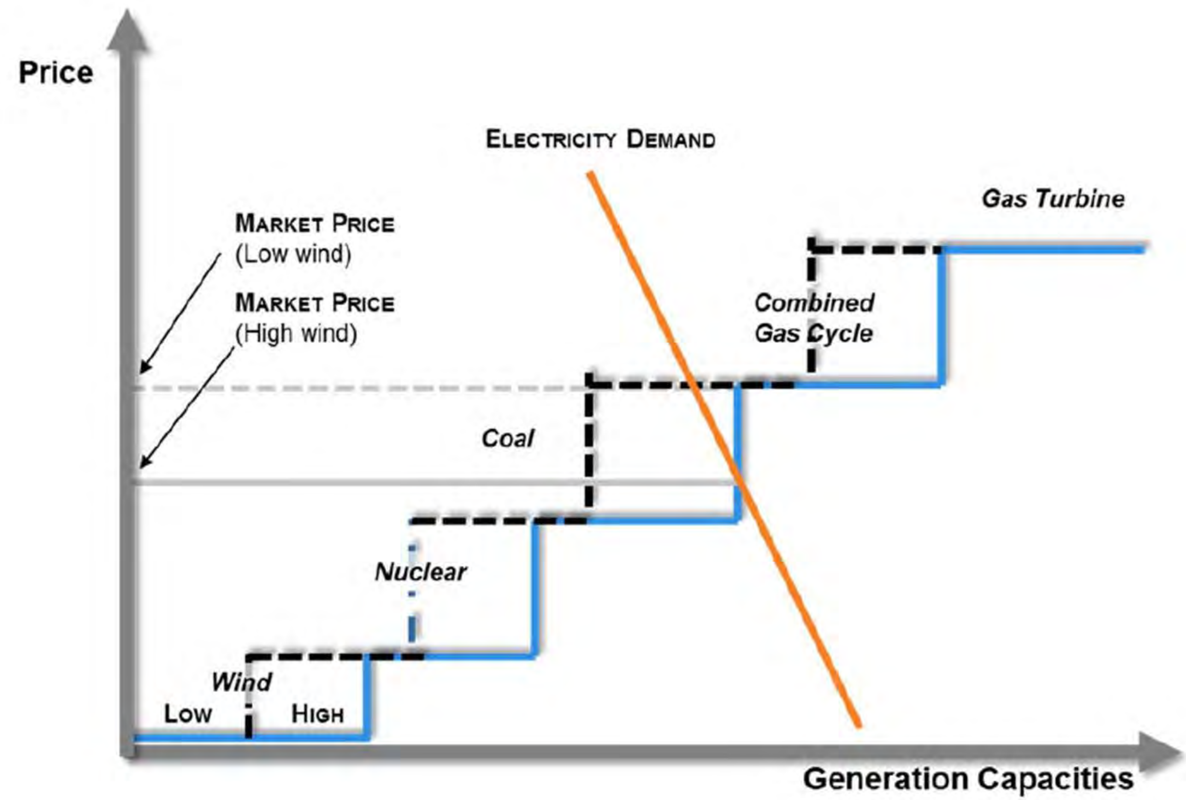
- Leads even to <u>negative</u> wholesale prices !!

- May need completely different philosophy whith massive RES, where 'holding' capacity ready is remunerated...

  → capacity remuneration mechanisms ??

# EU's implementation – market issues

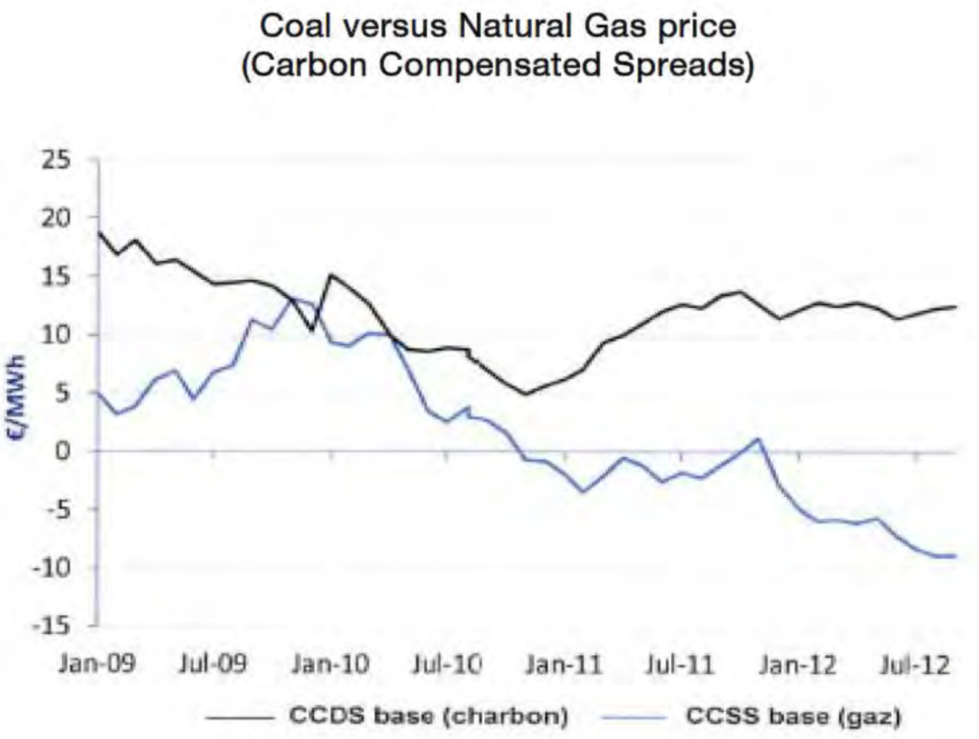
The merit order effect of RES




Ref: F. Roques in "The crisis of the European Electricity System" – FR 2014

# EU's implementation – market issues

## Prices too low for covering operational cost of gas plants




*Evolution of CDS and CSS between 2009 and 2012 – Source: GDF Suez*

**Spread = difference price & production cost = gross profit**

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# EU's implementation – market issues

## The "missing money problem" !!

- The most efficient plants (gas-fired combined cycles – CCGT) are pushed out of the merit order

→ their capacity factor becomes too low to recover investments

→ the prices are too low to cover operating costs

→ **many CCGTs are currently shut down and will be mothballed or shut down permanently!**

**→Risk: insufficient capacity (generation adequacy) to do the back up**

# EU's implementation – market issues

## Negative wholesale prices

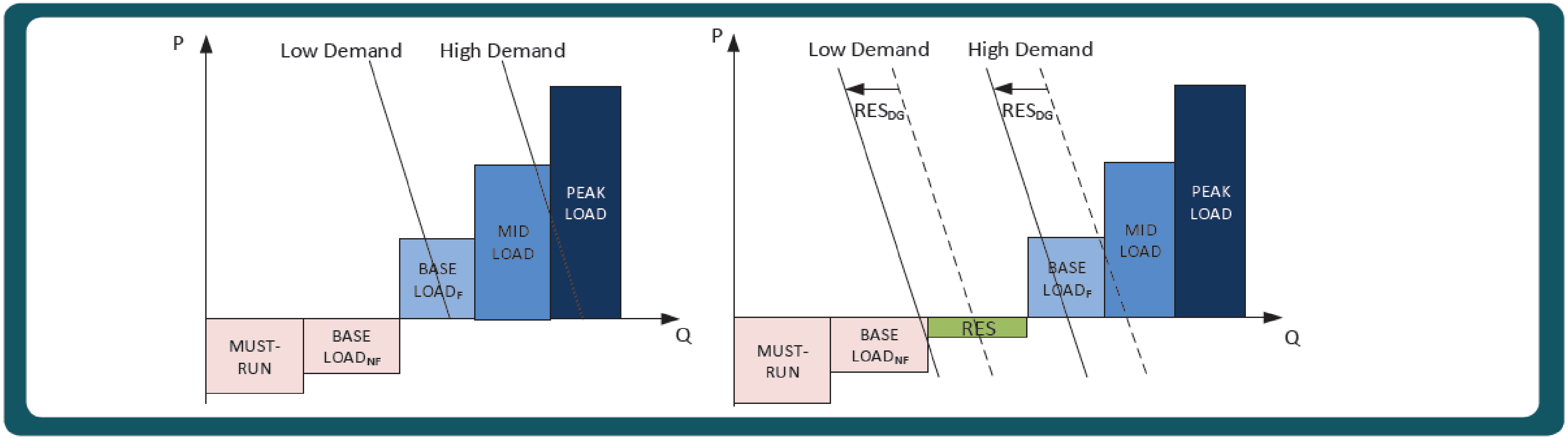


*Figure 2: Practical merit order without (left) and with renewable energy sources (right); $RES_{DG}$ expected renewable generation production of distributed nature; F flexible; NF non-flexible*

Ref: Factsheet 2014-1 KULv EI

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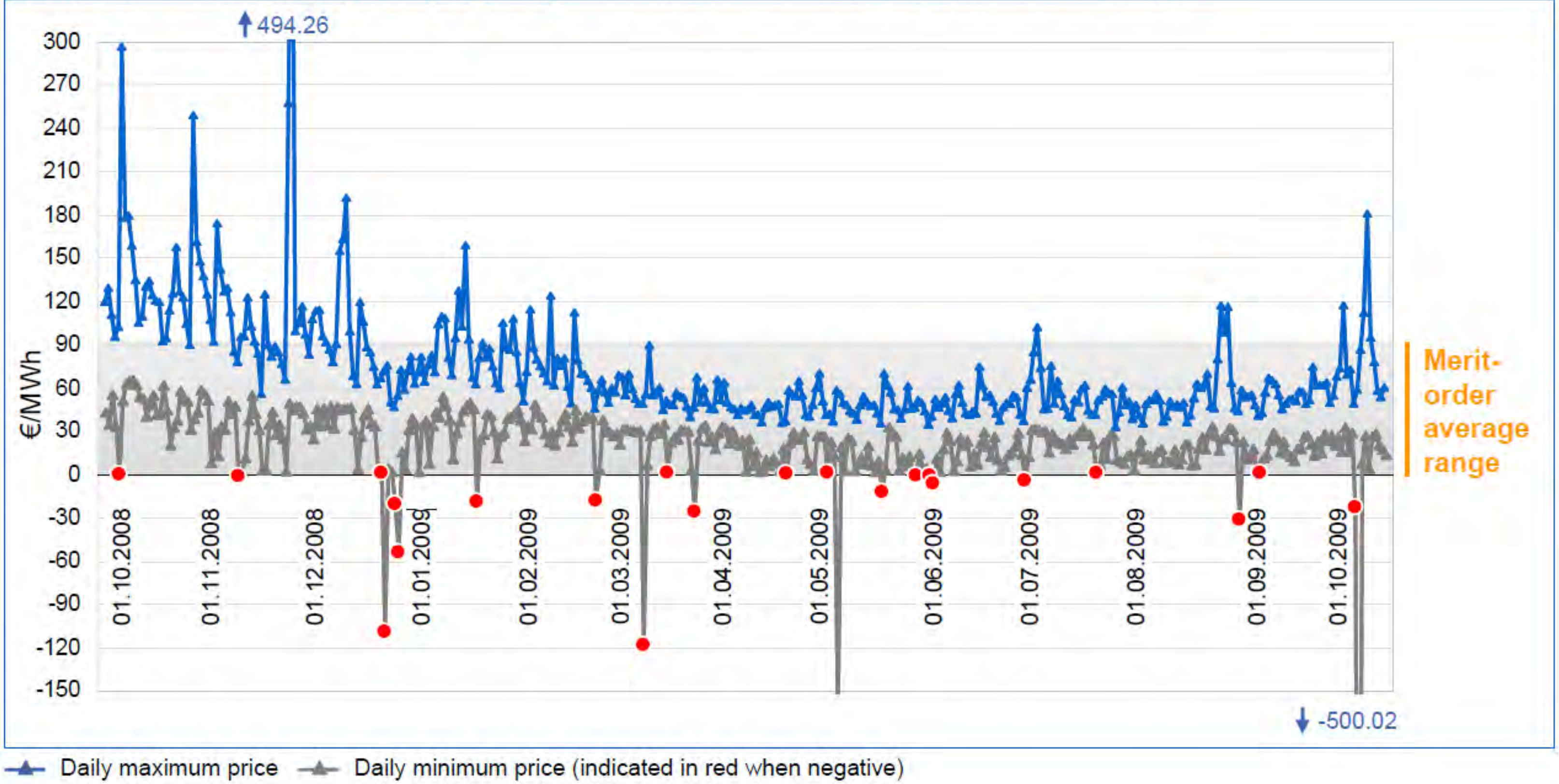
# EU's implementation – market issues

## Negative prices in Germany in period October 2008-October 2009

Growing proportion of renewables leads to higher price volatility. October 2008 to October 2009:
**60 hours** with negative prices; highest price reached: +€500/MWh, lowest -€500/MWh




Source: EEX spot prices.



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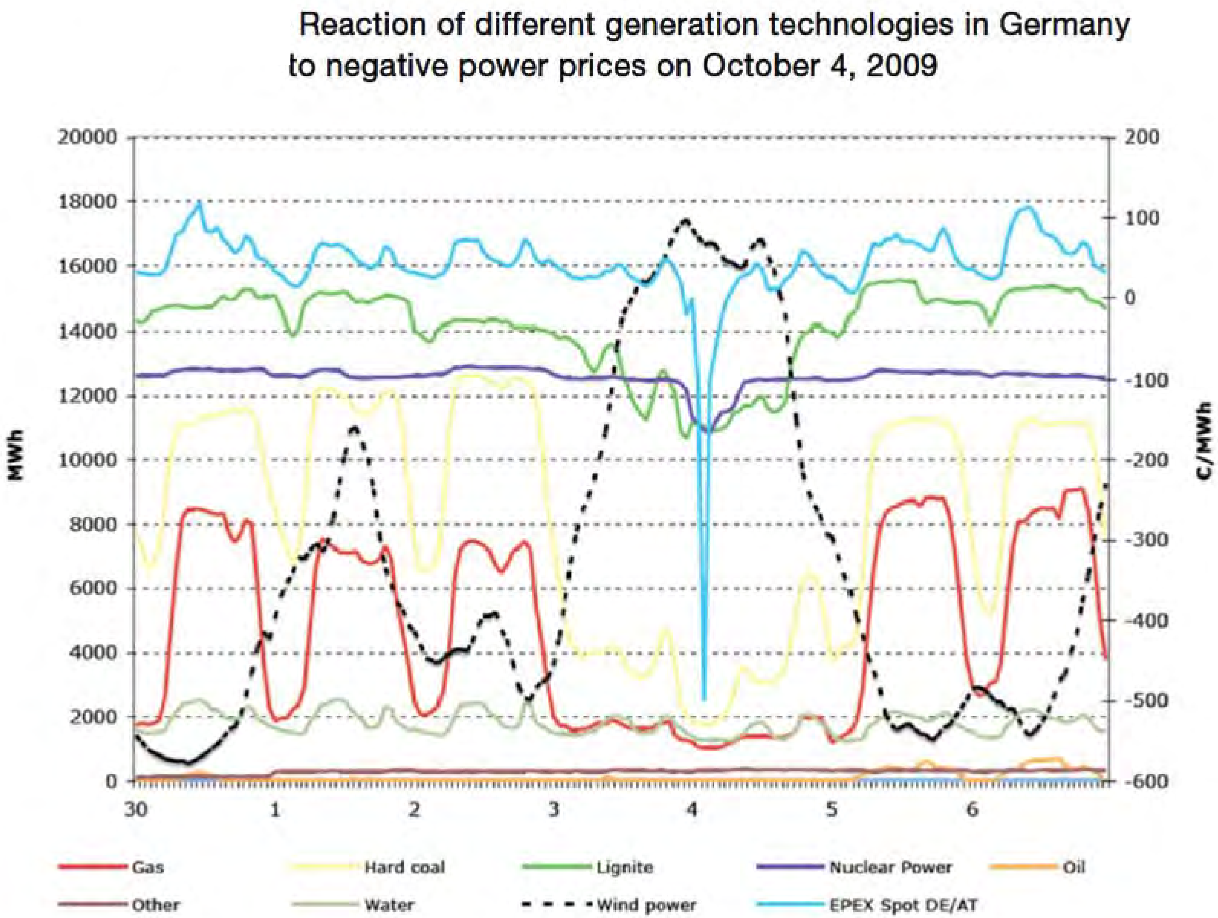
# Negative Wholesale Electrivity Prices




*Source: Vassilopoulos P. (2010) based on EEX Transparency and EPEX Spot data*

Ref: F. Roques in "The crisis of the European Electricity System" – FR 2014

# EU's implementation – market issues

Belgium: the "missing money problem" + nuclear phase out

**Recall:**

→**Risk: insufficient capacity (generation adequacy) to do the back up**

- In case of shortage, peak prices would skyrocket!
- But peak prices not high enough to compensate "losses"
- May need for **capacity remuneration mechanisms** unless unlimited peak prices are allowed ("energy only markets")

- In Belgium: combined with nuclear phase out...
- → "**Strategic Reserves**"

# EU's implementation

## Issues / challenges / problems in the EU market

- Technical challenges
- Market-integration problems
- Consequences for the $CO_2$ emissions
- End-electricity prices for end consumers

# A shared effort between sectors and MS

**GHG Target:**

**-20% compared to 1990**

**-14% compared to 2005**

**EU ETS**

**-21% compared to 2005**

**Non ETS sectors**

**-10% compared to 2005**

**27 Member State targets, stretching from -20% to +20%**

# European Energy Policy - *EU ETS*

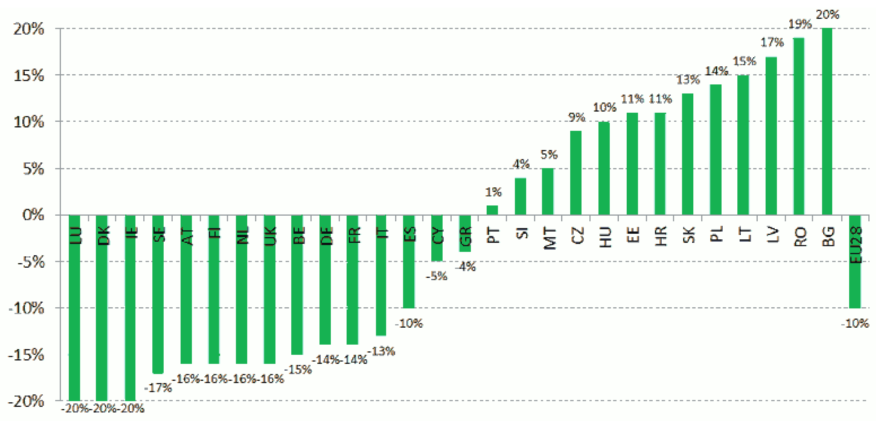
-20% GHG wrt 1990 = -14% GHG wrt 2005

## Emission Trading Scheme (ETS)

- -21% GHG compared to 2005
- ~45% GHG, ~50% $CO_2$
- one EU-wide system for heavy industries
  - o power and heat sector
  - o energy intensive industrial sectors
  - o aviation (from 2012, within ETS)
- cap-and-trade system

## Effort Sharing Decision

- -10% GHG compared to 2005
- ~55% GHG, ~50% $CO_2$
- Member State targets for small emitters

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# European Energy Policy - *EU ETS*

- As of January 1st 2005, EU has started **EU Emission Trading Scheme (EU ETS)**
- For each ton of $CO_2$ emission, allowance must be submitted
  - Can be traded on a market
- So-called “Cap and Trade” system: Amounts emitted limited but price varies

  ↔ $CO_2$ tax fixes price, but emissions unknown
- Not between countries but between companies!

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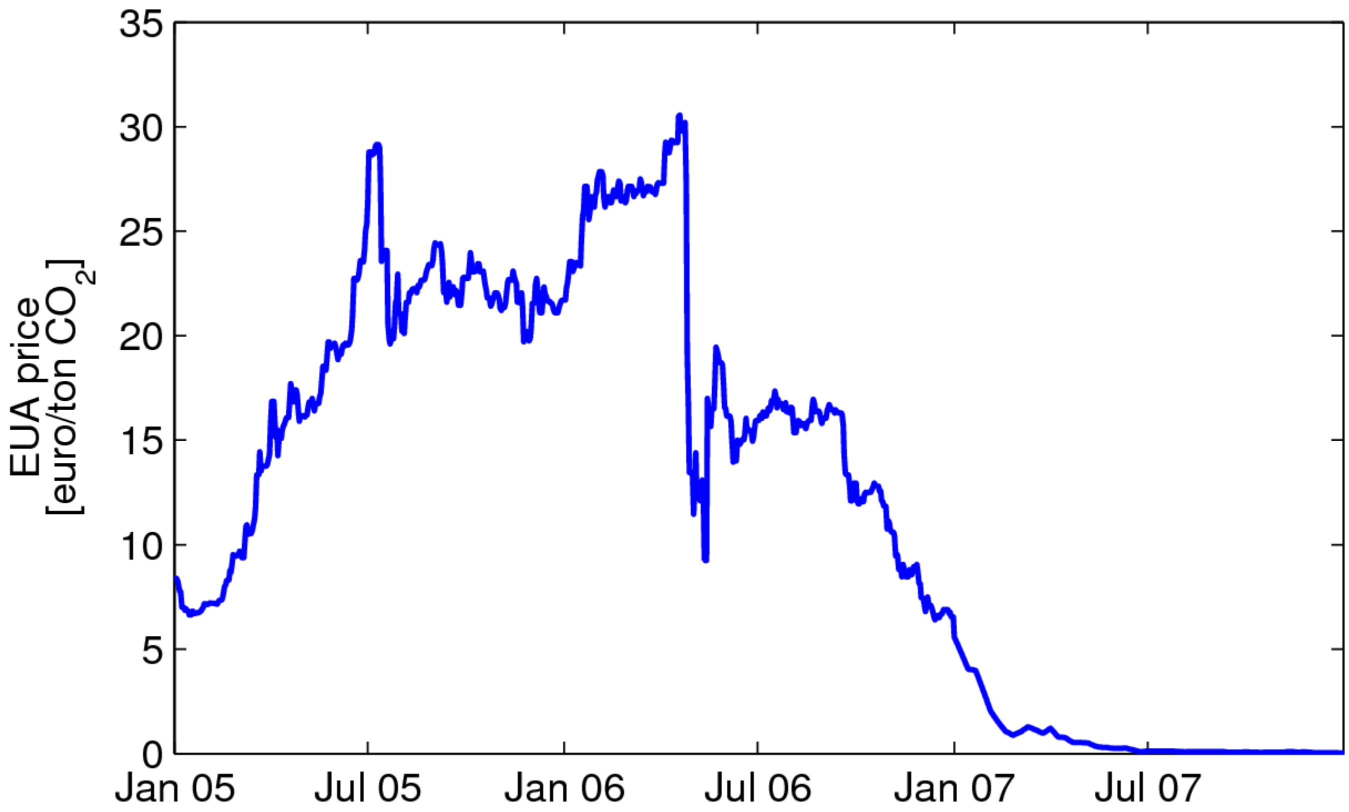
# European Energy Policy - *EU ETS*

- EU ETS price - First Phase (2005 - 2007)

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# European Energy Policy - *EU ETS*

- EU ETS price – Second Phase (2008 - 2012)

# European Energy Policy - *EU ETS*

- EU ETS price – Second and Third


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# European Energy Policy - *EU ETS*

- EU ETS price – Third Phase (2013 till early 2015)


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# EU's implementation

## Consequences for the $CO_2$ emissions

- Very low prices for $CO_2$ emission permits ("allowances")
- Due to
  - economic crisis (less $CO_2$ emissions) in 2008-2014
  - "banking" of allowances from phase 2
  - Inflow of international credits
  - massive injection RES with priority access → reduces demand for fossil generation → reduces demand for $CO_2$ allowances → lower $CO_2$ prices

    *i.e., highly subsidized RES effectively **subsidize cheap coal** by keeping the $CO_2$ penalties low !!*

# EU's implementation

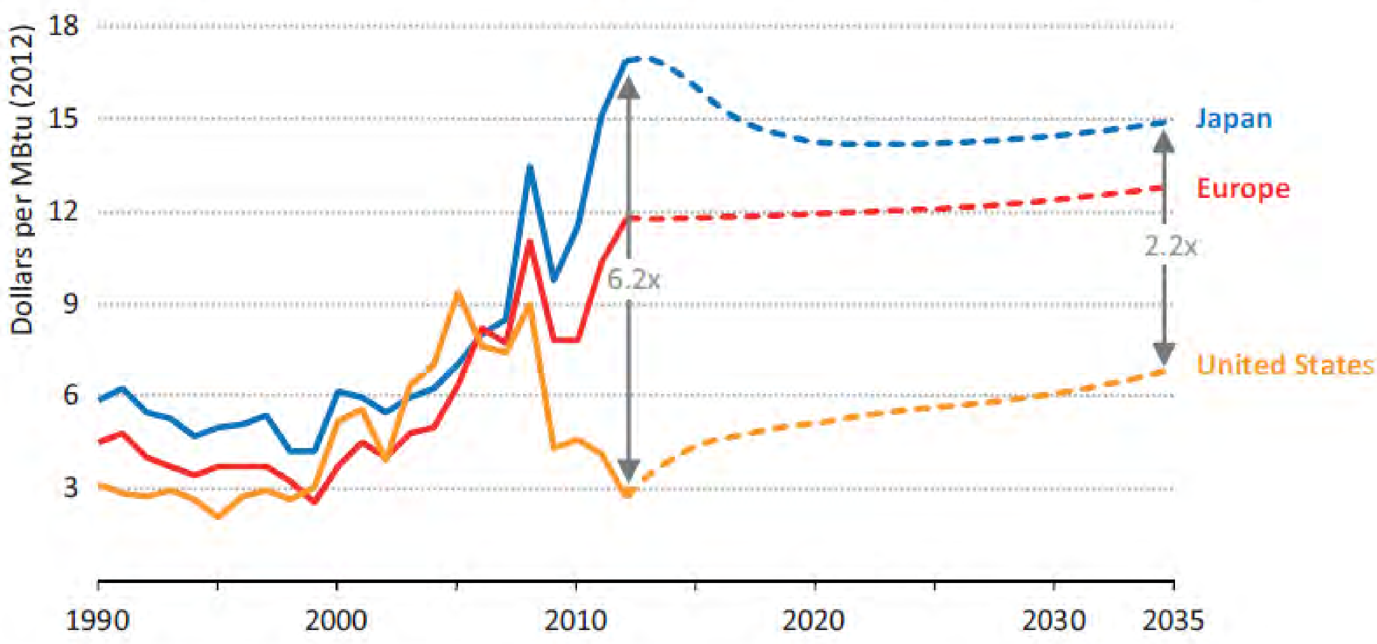
- Consequences of shale gas in US for $CO_2$ emissions in DE

- System effect due to low gas prices in USA – shale gas
- Gas extremely cheap in the USA

# EU's implementation

## Consequences of shale gas in US for $CO_2$ emissions in DE

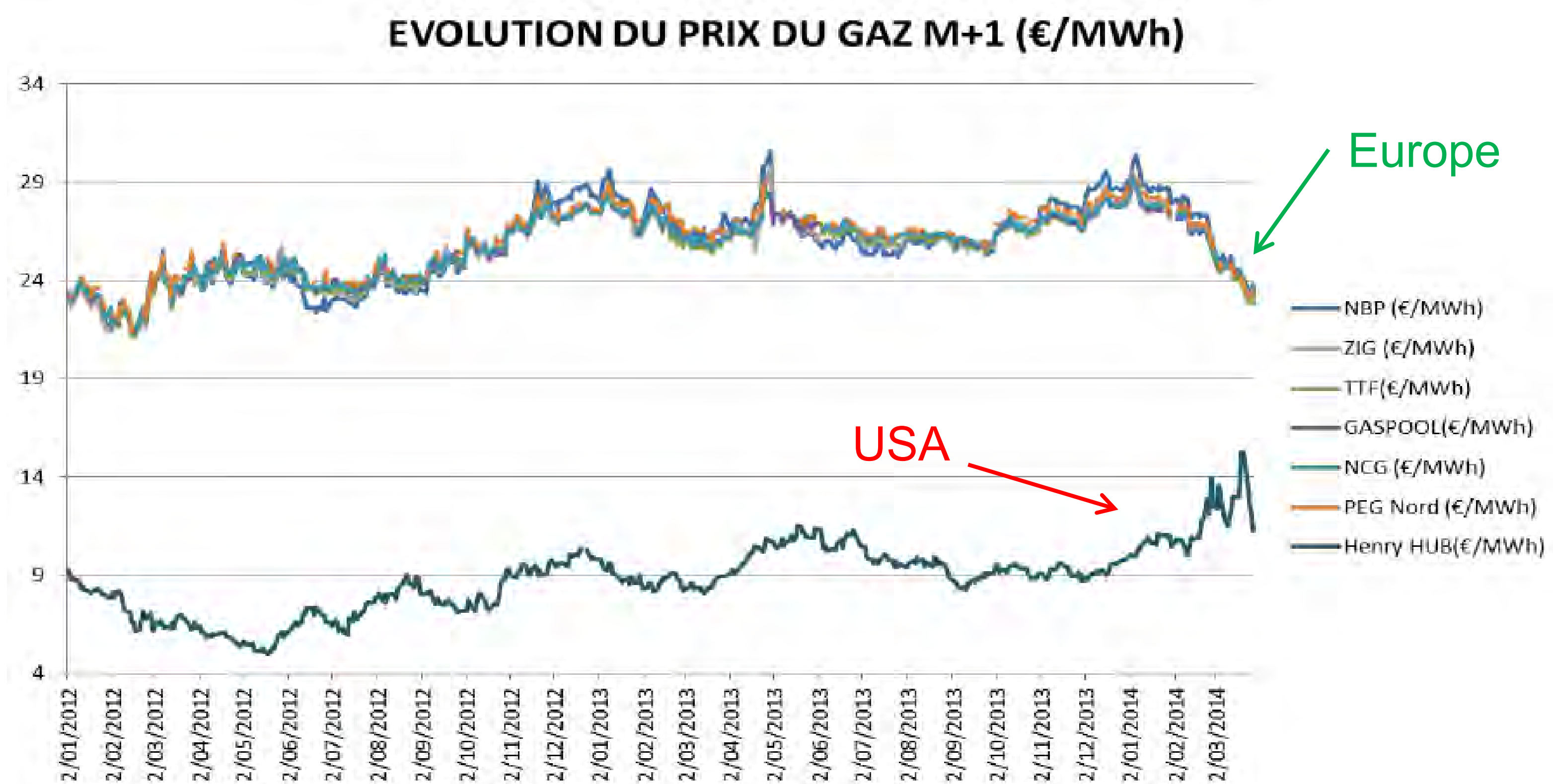
**Figure 1.3 ▷** Natural gas prices by region in the New Policies Scenario




IEA WEO November 2013

# EU's implementation

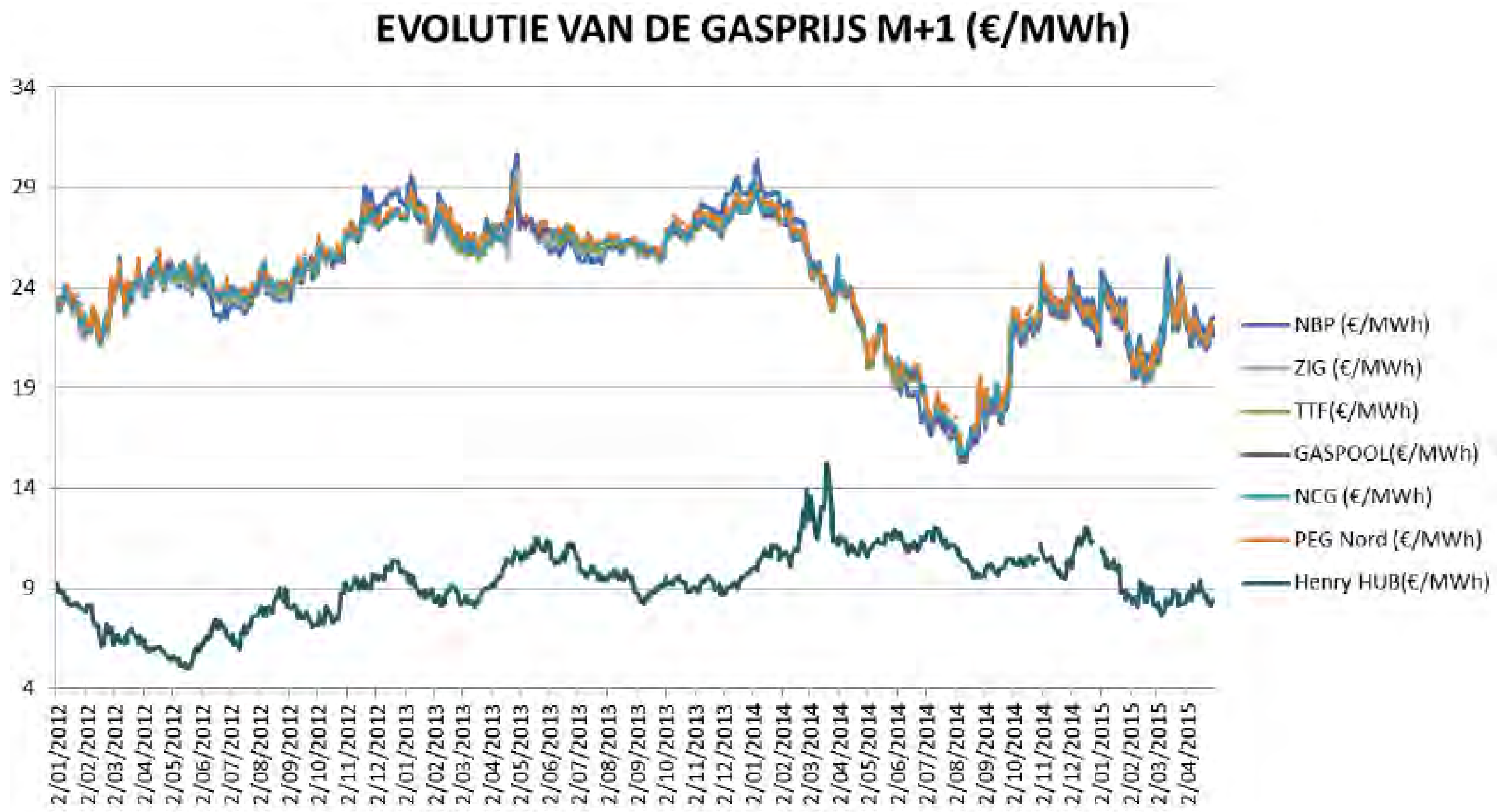
## Consequences of shale gas in US for $CO_2$ emissions in DE




Source: CREG, 2014

# EU's implementation

## Consequences of shale gas in US for $CO_2$ emissions in DE




Source: CREG, 2015

# EU's implementation

## Consequences of shale gas in US for $CO_2$ emissions in DE

- System effect due to low gas prices in USA – shale gas
- Gas extremely cheap in the USA
- Gas pushes coal out of merit order in USA
- US coal demand decreased
- Lower coal prices
- USA coal offered to world market ... shipped to Germany
- Cheap US coal used in German coal fired plants

→ German $CO_2$ emissions electricity generation have gone up!

- But does not matter in EU since ETS, only price increase EUAs
- **In mean time: world emissions $CO_2$ up up up**

# EU's implementation

## Issues / challenges / problems in the EU market

- Technical challenges
- Market-integration problems
- Consequences for the $CO_2$ emissions
- End-electricity prices for end consumers

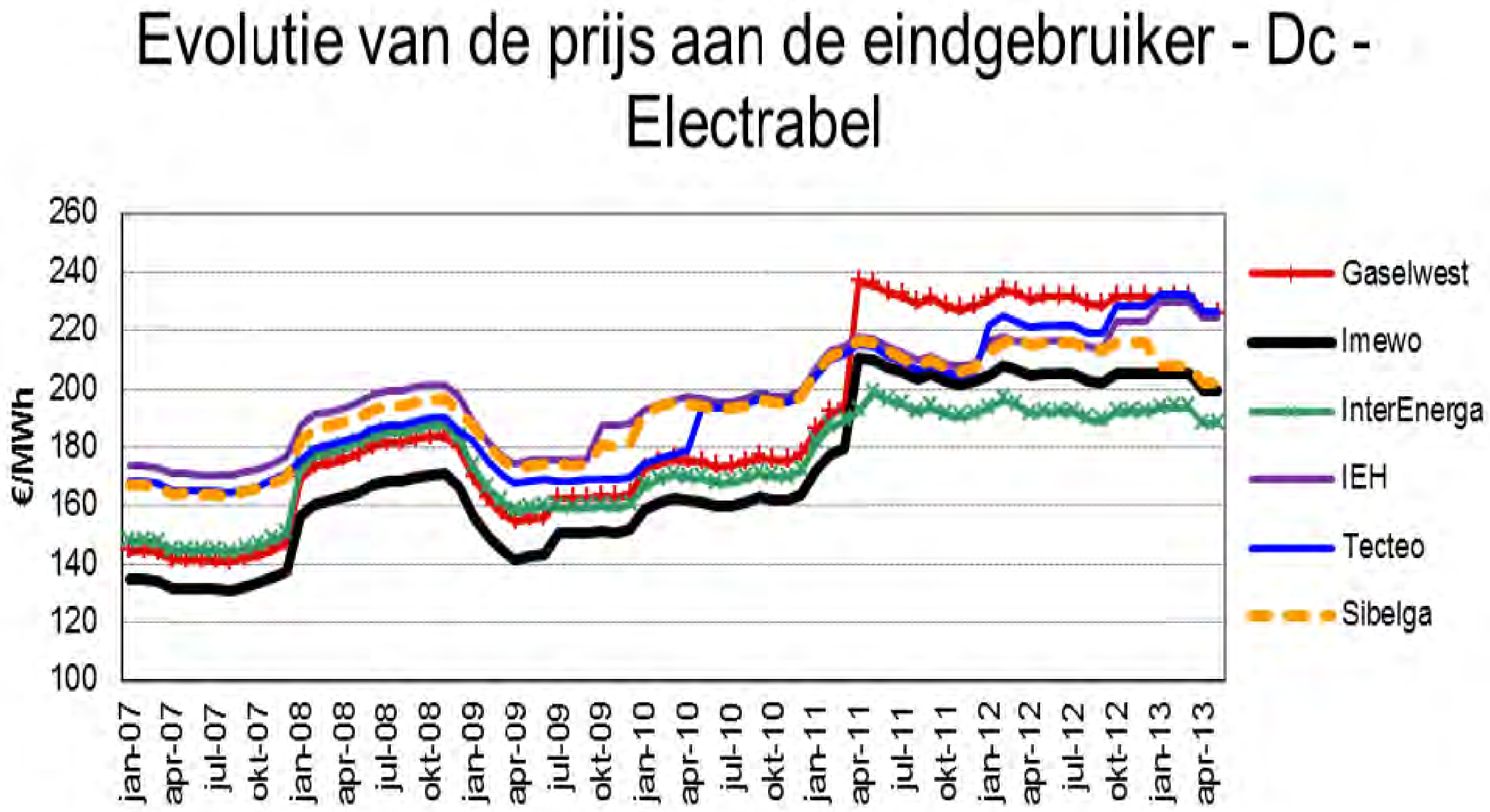
# Decomposition of energy retail prices BE
## Electricity

- Consider following consumers *(following CREG report)*
  - o Household ("Dc")
    - Electricity 3,500 kWh/y
  - o Professional consumers
    - Electricity 160,000 kWh/y, low voltage ("Ic")
    - Electricity 160,000 kWh/y, medium voltage ("Ic1")

- Evolution of price from January 2007 till May 2013

# Decomposition of energy retail prices BE
## Electricity

- Evolution of final price – domestic consumer




Source: CREG, 2013



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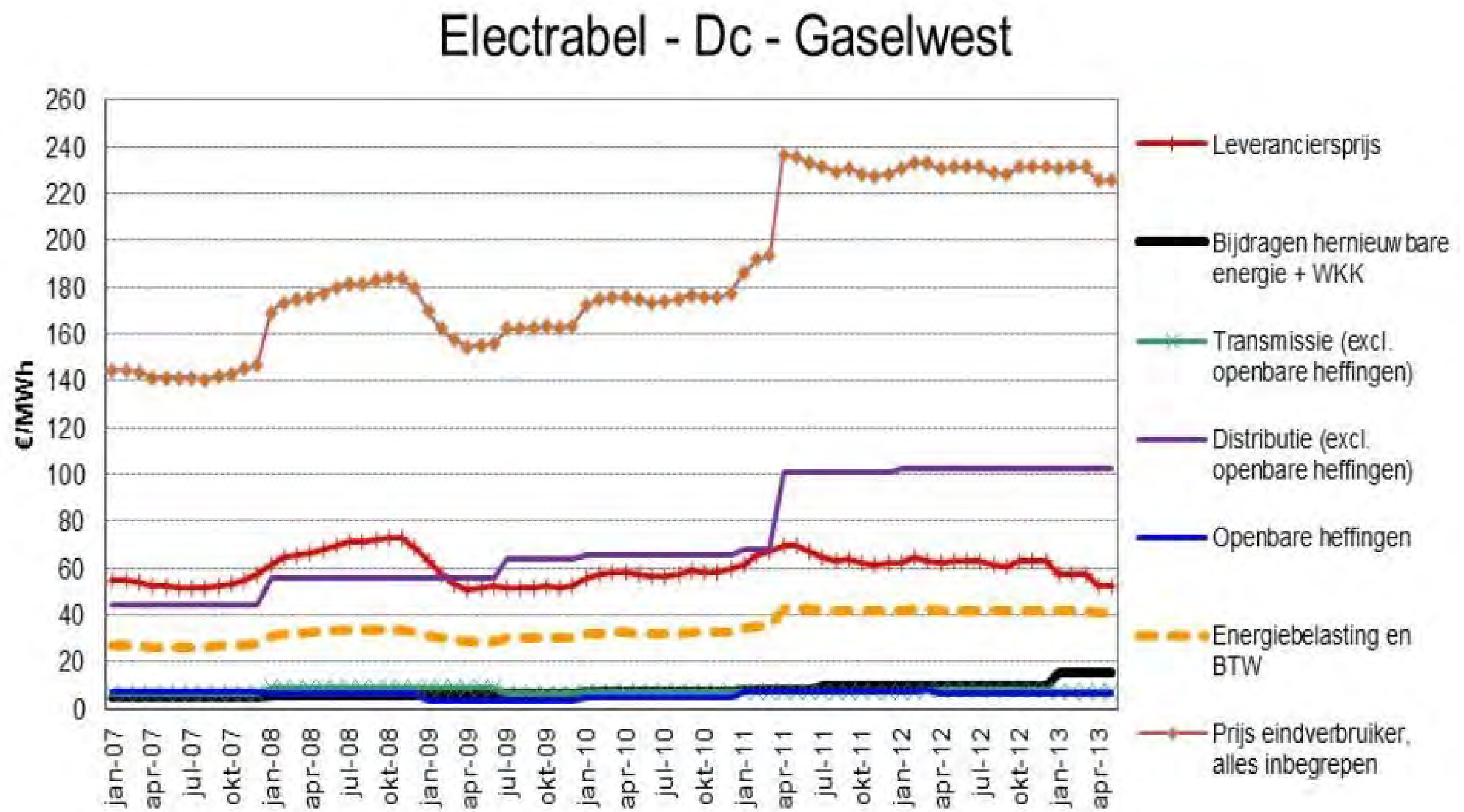
# Decomposition of energy retail prices BE
## Electricity

- Composition of final price
  - Energy price
  - Transmission
  - Distribution
  - Public levies
  - Contribution RES and CHP
  - Energy taxes and VAT

# Decomposition of energy retail prices BE
## Electricity

- Composition of final price – domestic consumer




Source: CREG, 2013



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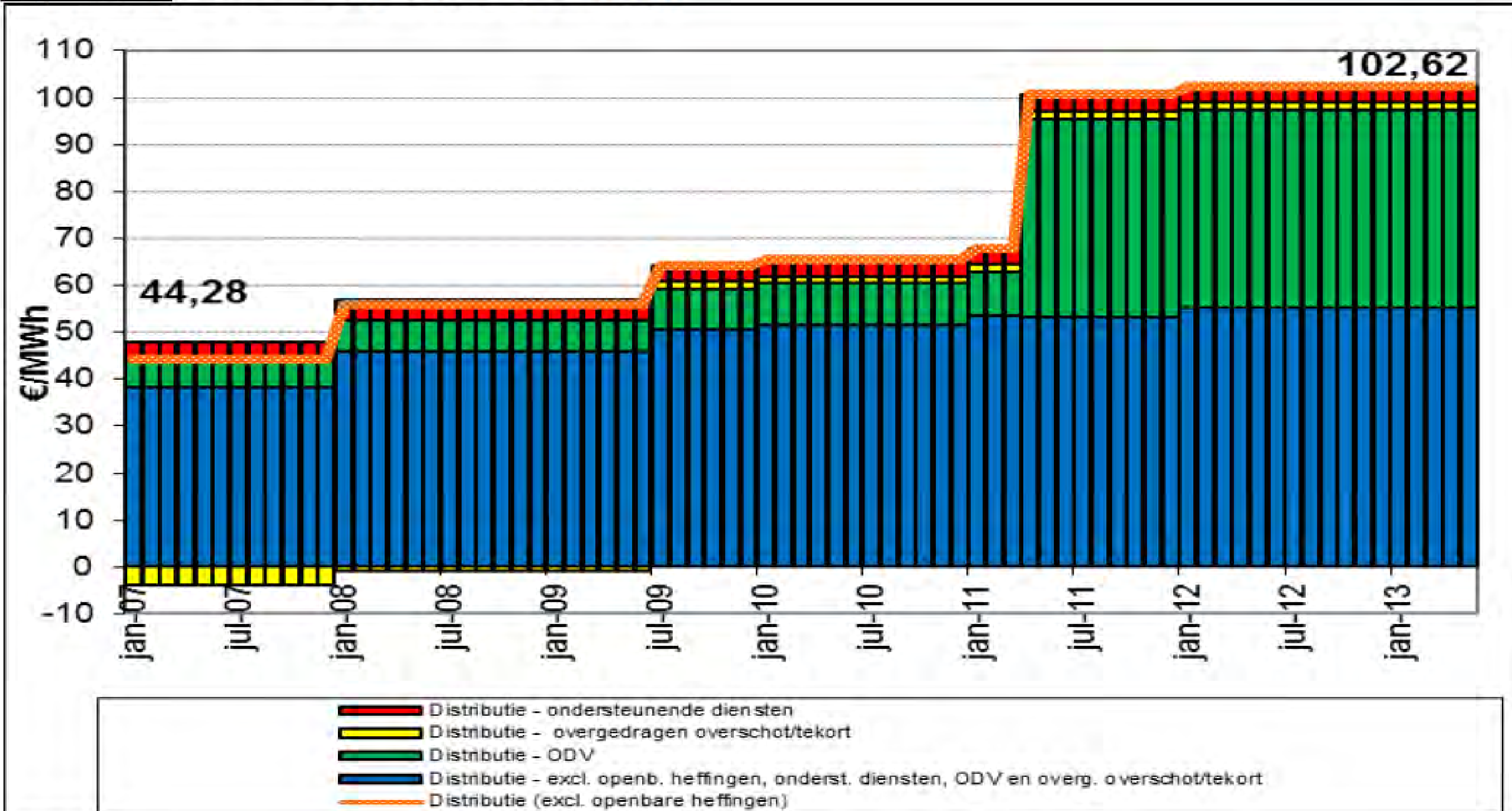
# Decomposition of energy retail prices BE
## Electricity

- Evolution and composition distribution tariff

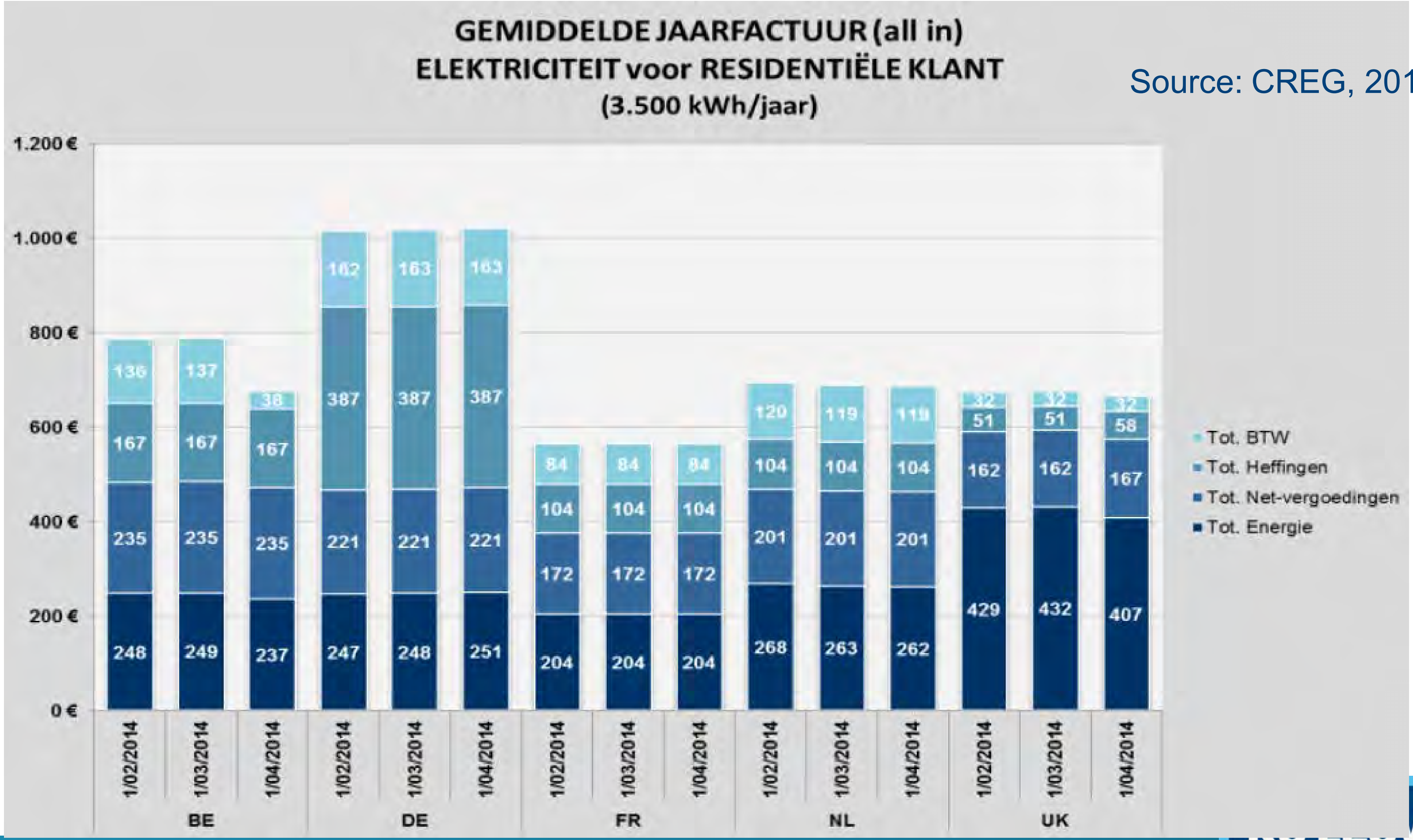
Source: CREG, 2013

Figuur 6.1. – **Dc – Gaselwest - €/MWh**



# International positioning
## Electricity prices

- Comparison neighboring countries – domestic consumer

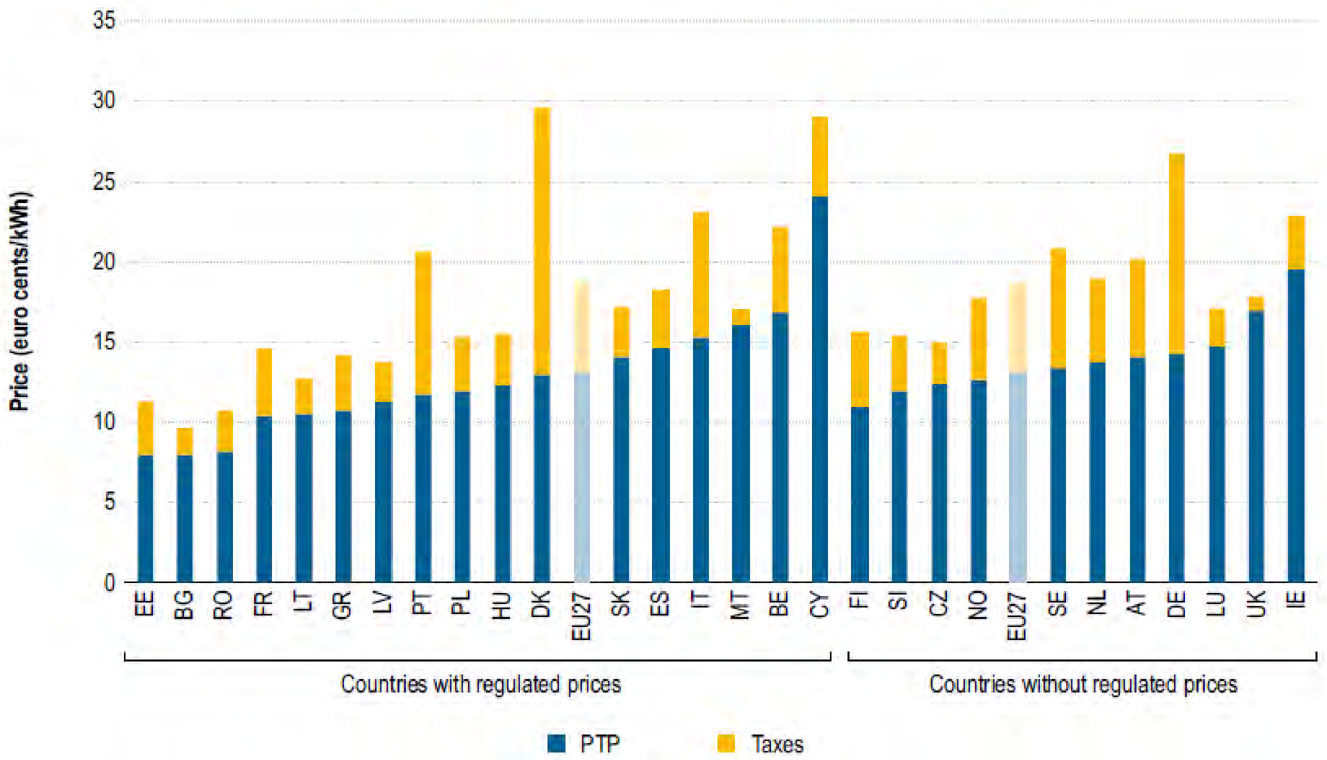



Source: CREG, 2014

# International positioning
## Electricity prices

- EU comparison – domestic consumer

Figure 3: Electricity POTP and PTP for households – Europe – 2012 (euro cents/kWh)



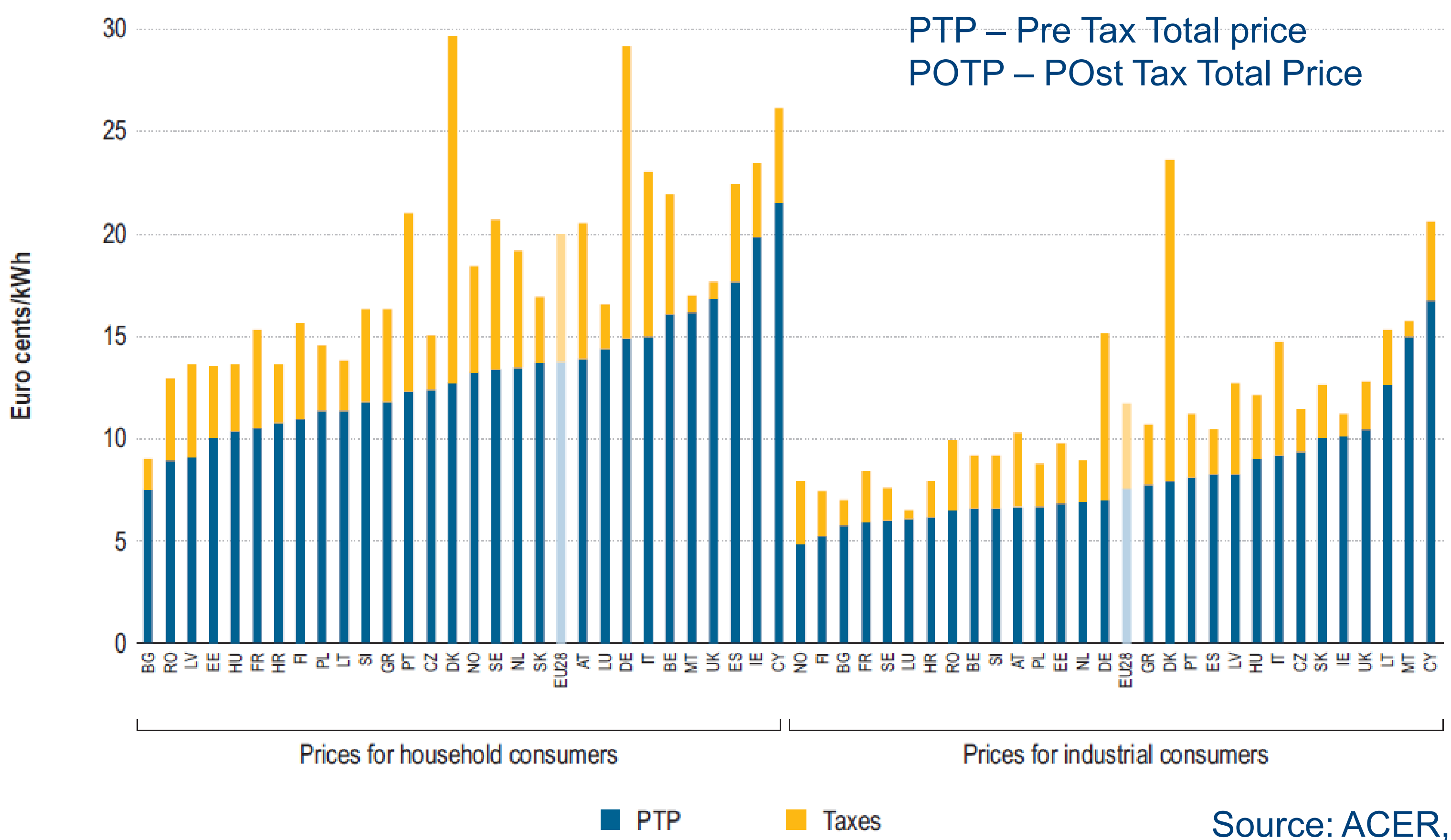

Source: ACER, 2013

*Source: ACER, based on Eurostat (25/5/2013), DC: 2,500-5,000kWh*

*Note: Within each group, MSs are ranked according to the PTP level.*

# International positioning
## Electricity

Figure 4: Electricity POTP and PTP[19] for households and industry – Europe – 2013 (euro cents/kWh)




Source: ACER, 2014

*Source: Eurostat (10/7/2014) and ACER calculations*

*Note: Consumption bands: DC: 2,500-5,000 kWh (households) and IE: 20,000 MWh-70,000 MWh (industry). Within each group, MSs are ranked according to PTP.*

# Solutions? Energy System Integration

- Electric power sector is ***driving force*** for dramatic change due to massive RES injection
  - Intermittent
  - Overcapacity
  - Electricity difficult to store
  - Zero marginal cost PV and wind
- Interaction with the transportation sector (V2G/G2V – PHEV)
- Effects also in the gas sector
  - Fluctuating gas demand in CCGTs due to RES
  - But gas can be useful storage intermediary (P2G)

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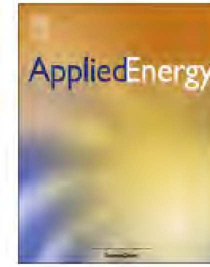
# Solutions? Energy System Integration

Contents lists available at ScienceDirect

Applied Energy

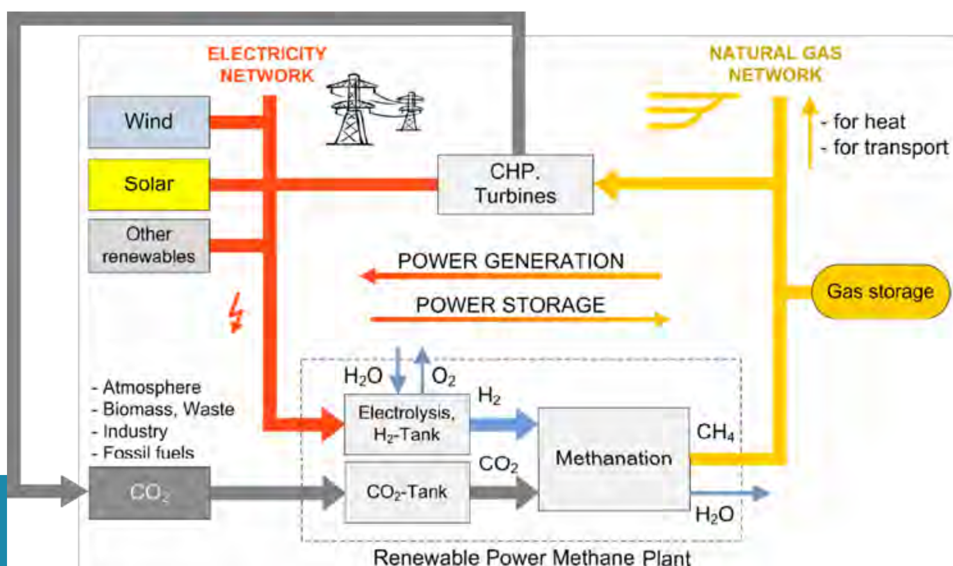
journal homepage: www.elsevier.com/locate/apenergy




## Impact of unpredictable renewables on gas-balancing design in Europe

Nico Keyaerts, Erik Delarue, Yannick Rombauts, William D'haeseleer *

*University of Leuven (KU Leuven) Energy Institute, TME Branch (Applied Mechanics and Energy Conversion), Celestijnenlaan 300A, P.O. Box 2421, B-3001 Leuven, Belgium*

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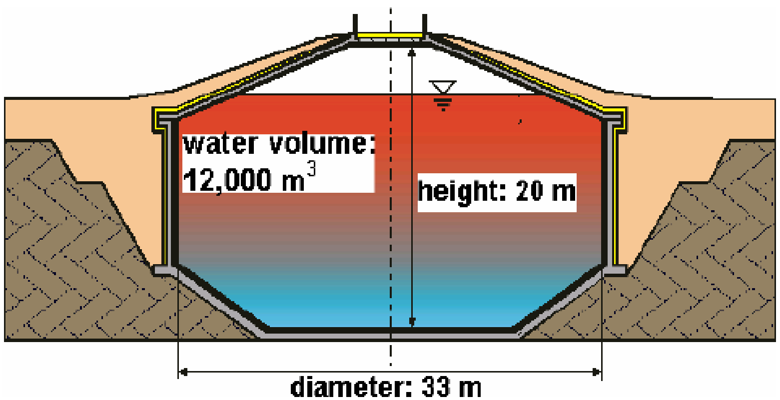
# Solutions? Energy System Integration

- Good opportunities in heating sector

# ESI in Thermal Sector

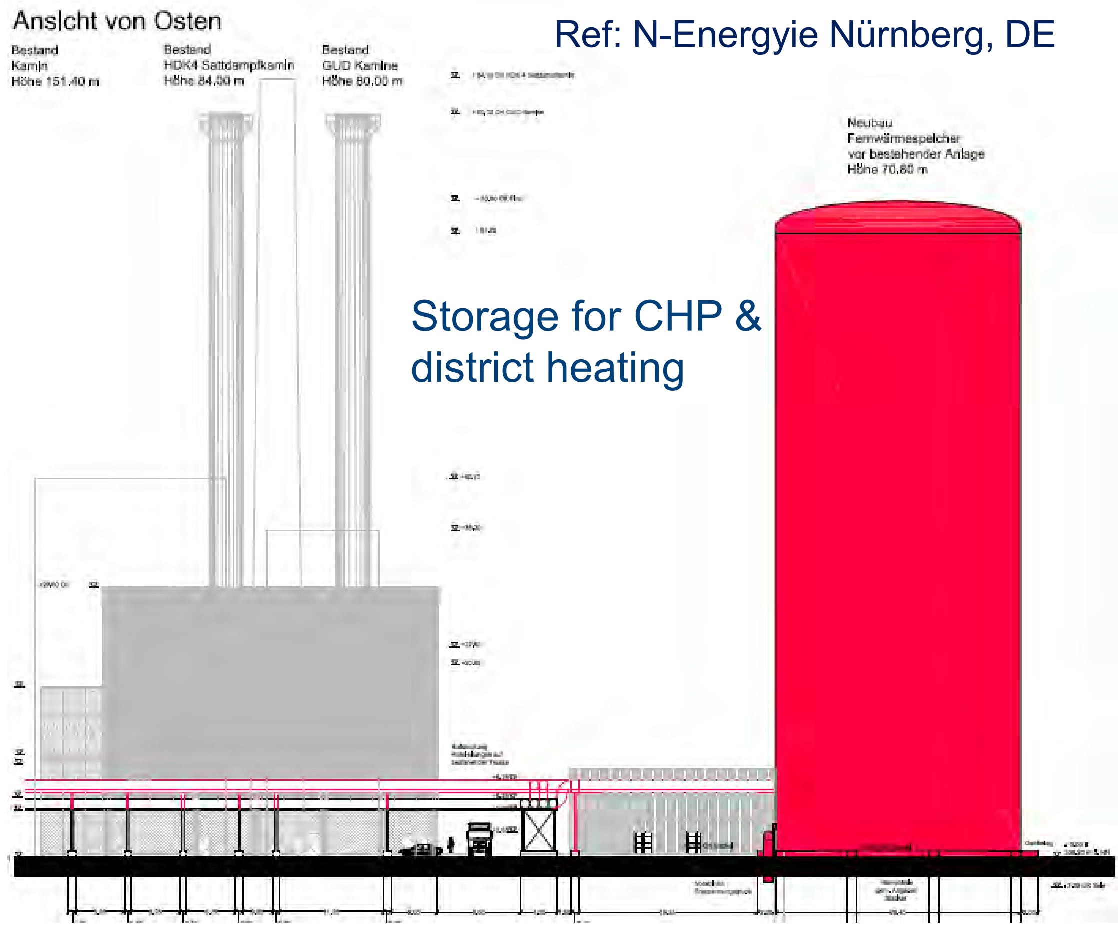
**Thermal storage in hot water**

Originally:
seasonal hot water storage




Ref: Solites, DE

Ref: N-Energyie Nürnberg, DE




Storage for CHP & district heating

**Can be used to dump superfluous electric energy**
**→ "electric boilers" – used in Denmark!**

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# ESI in Thermal Sector

## Thermal Storage via Electric Heating
## Virtual Electricity Storage via ADR

| | Electricity demand (TWh) | Share in total residential water heating (%) |
|---|---|---|
| Australia | 28 | 41 |
| Canada | 63 | 23 |
| France | 51 | 40 |
| Germany | 84 | 27 |
| Ireland | 6 | 32 |
| Italy | 29 | 26 |
| Japan | 161 | 14 |
| Netherlands | 17 | 13 |
| Spain | 48 | 10 |
| United Kingdom | 80 | 9 |
| United States | 542 | 23 |

IEA, ETP 2014

# ESI in Thermal Sector

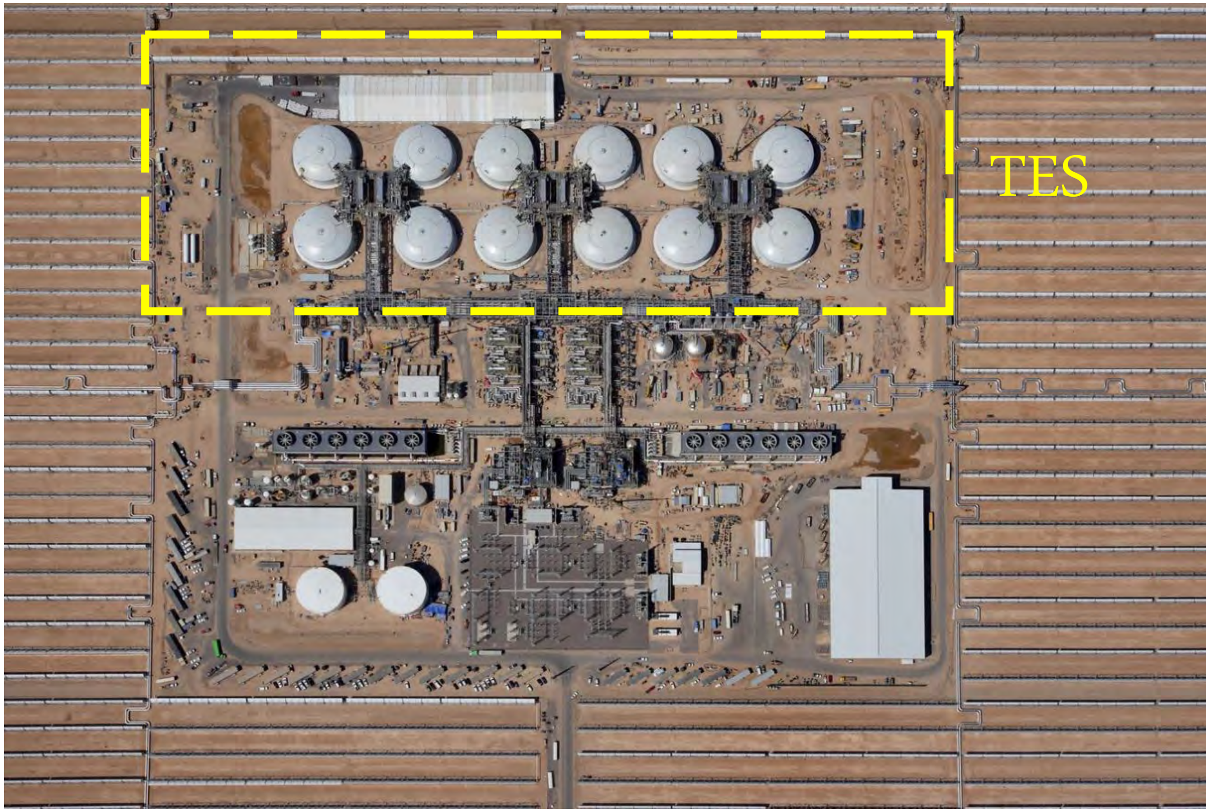
## *Virtual Electricity Storage via ADR*

→ *Thermal storage in buildings through* ***Heat Pumps*** *(HP)*

- Can be considered as an electricity ‘dump’
- But thermal mass of building acts as a thermal buffer
- Can shift with electric power delivery to HP
- Is effectively a virtual electricity storage (via **ADR**)

# Other Thermal Storage in Electric Apps

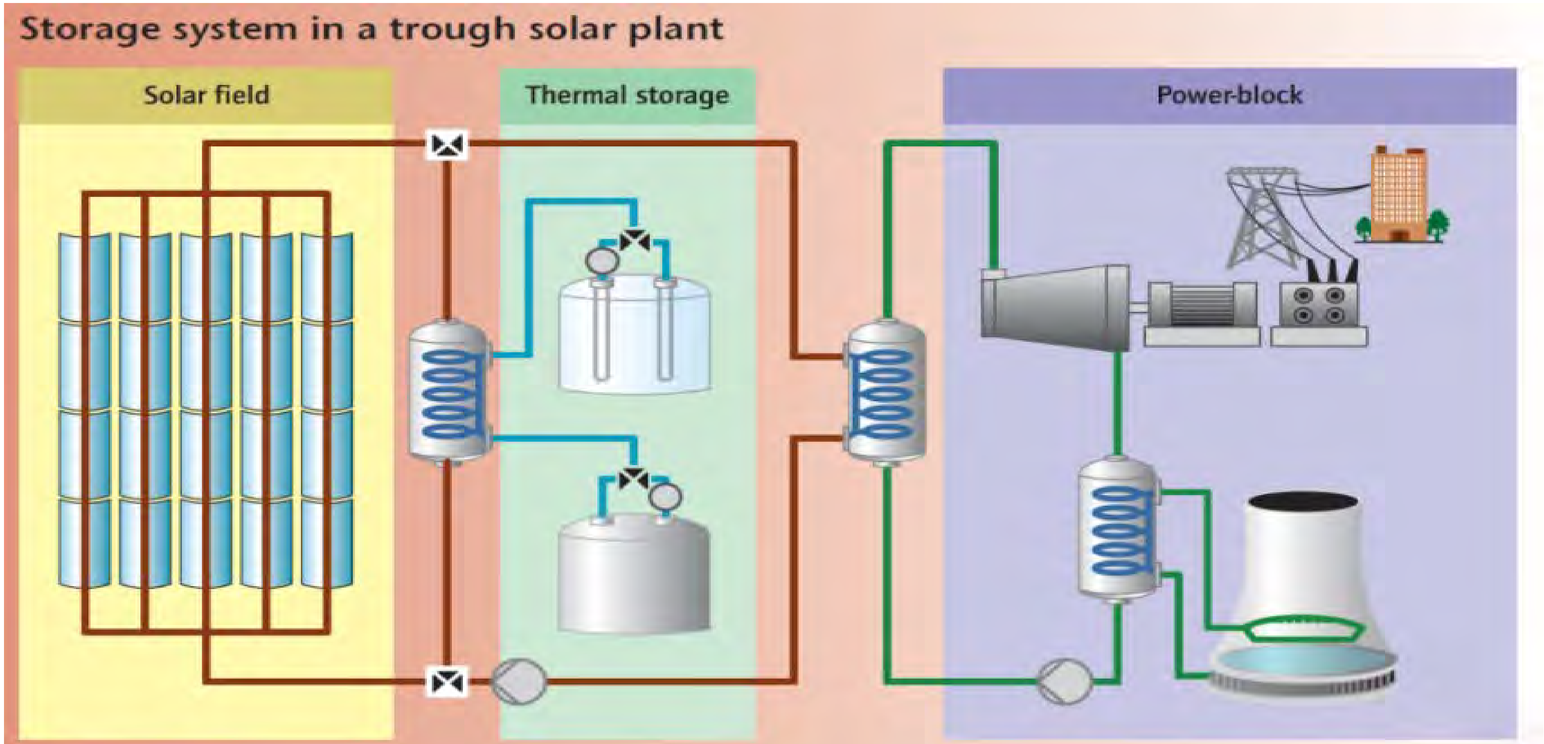
# High-Temperature Storage for CSP




- **Thermal Energy Storage (TES): 6 hours of full load operation**
  - **2-tank, indirect, molten-salt TES**
  - **Six parallel TES trains**

# High-Temperature Storage for CSP

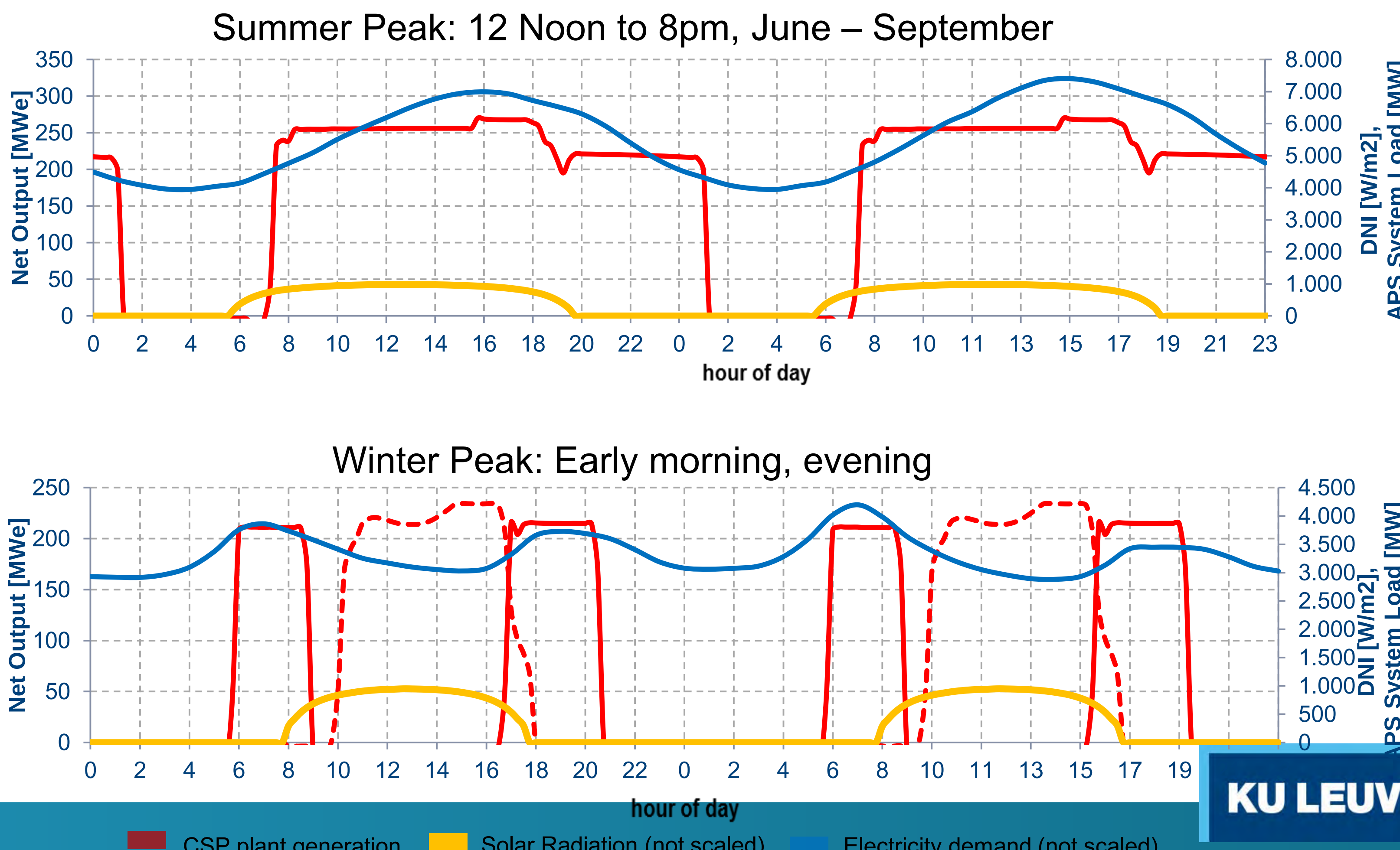
Basic set up of power plant with molten salt storage. Ref. [IEA, 2010]




This graph shows how storage works in a CSP plant. Excess heat collected in the solar field is sent to the heat exchanger and warms the molten salts going from the cold tank to the hot tank. When needed, the heat from the hot tank can be returned to the heat transfer fluid and sent to the steam generator.

*Source:* SolarMillennium.

# **Storage allows improved operational flexibility to meet utility peak loads.** Arizona Public Service system peaks:



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# Batteries – Cost Evolution

nature climate change

LETTERS

PUBLISHED ONLINE: 23 MARCH 2015 | DOI: 10.1038/NCLIMATE2564

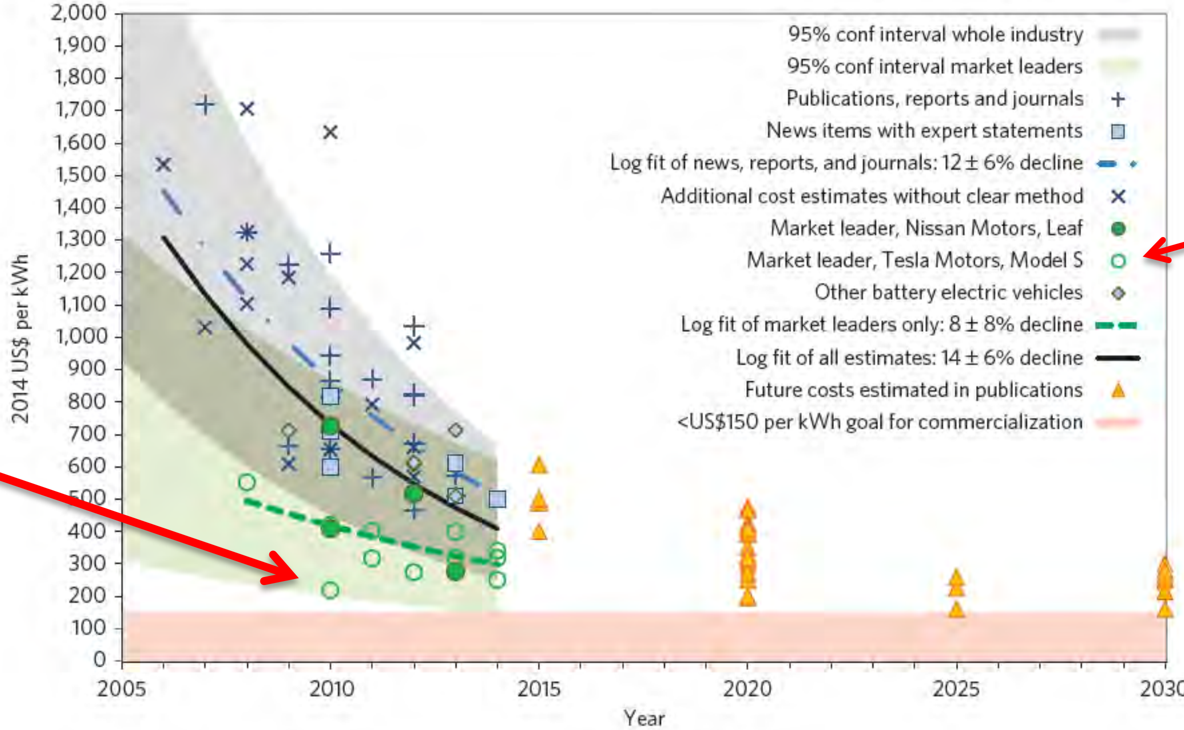


**Figure 1 | Cost of Li-ion battery packs in BEV.** Data are from multiple types of sources and trace both reported cost for the industry and costs for market-leading manufactures. If costs reach US$150 per kWh this is commonly considered as the point of commercialization of BEV.

# Battery Revolution of Tesla?


**TESLA**

**Powerwall** = similar to wall boiler
- for the home -

7 kWh unit
3,000 \$ ~ 2,700 €

10 kWh unit
3,500 \$ ~ 3,100 €

**Powerpacks** for industrial applications
Packs of 100 kWh

# Battery Revolution of Tesla?


- Giga Li-ion factory near Reno, NV

- Mass scale manufacturing

- Open-access patents

- What if the Chinese take over like for PV?

- Could lead to dramatic cost reductions

- Tesla's battery manufacturing might be temporary

But Musk & Tesla may be the winners in the EV market!

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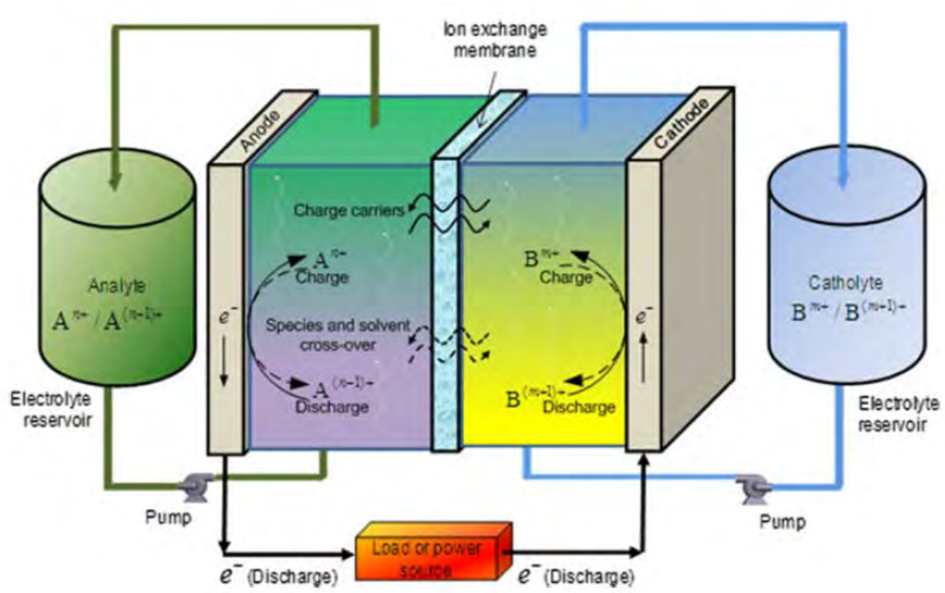
# Battery Revolution?

- Tesla may see breakthough in CA, USA
- Grid independence feasible? But perhaps also installing back-up gasoline/diesel engine generators... (?)
- Situation in NW Europe and other places in US is different from CA, AZ, NV... since other weather conditions – grid connection almost centainly needed
- But cheap local batteries may drastically change market behavior & participation
- Interesting combination with EV and PHEVs (G2V & V2G)

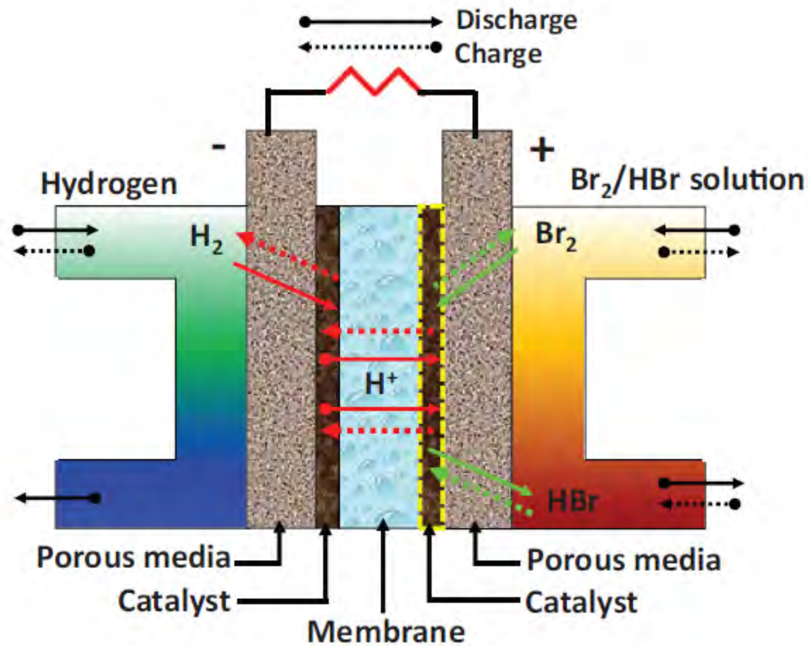
# (Redox-)Flow Batteries




Weber et al, RFB: a review, J. Appl Electrochem 41, 2011

Recent revival after sleeping mode

Cho et al, J. Electrochem Soc. 159, 2012




<u>Advantage</u>:
**power** (area electrode) **and energy** (volume vessels) **are decoupled!**

Commercially available include Vanadium, Zink Bromide, Polysulphide Bromide

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# Important research issues ESI

- ESI is not only technical – strongly affected by policy choices, market design, regulation!
- Policy switches & regulatory uncertainty are “killing circumstances” for efficient ESI
- But well meant policy measures can lead to “nightmares” since neglecting feedback effects of system integration

# Important research issues ESI

RENEWABLE ENERGY WORLD.COM

Friday, July 24, 2015

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**Will California Allow Rooftop Solar to Meet its RPS?**

Christopher Minott
Jul 17, 2015

When California legislators vote to increase the state's renewable energy portfolio standard to 50 percent by 2030, will rooftop solar count toward the total?

Many will be surprised to learn that rooftop solar doesn't currently count toward utility companies quota requirements.

And many others will be surprised to learn that utility companies are aligned with rooftop solar installers on the issue. Both believe rooftop solar should count toward California's ambitious new renewable energy portfolio standard if legislators do as they are expected and increase the standard from 33 percent by 2020 to 50 percent by 2030.

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# Important research issues ESI

## Important research issues:

- Correct estimate of system costs / Methodology?
- Interaction of targets (RES, efficiency, $CO_2$ reduction) – cfr 20-20-20
- What kind of subsidies: feed-in, CFD, investment support, certificates?
- Is net metering for e.g., rooftop PV justified? What are the system consequences? How about the efficiency paradox?
- What is an appropriate grid-connection cost for prosumers? / how about “emergency power” – at what cost?
- What may be the role of electricity storage (batteries, renew $CH_4$)?
- How responsive is electric-power demand (ADR)?
- What kind of market structure & tools are “optimal”?
  - Auctions?
  - Energy-only markets (exchanges)
  - Capacity remuneration mechanisms?
  - Playing field for aggregators? / Role of service providers (ESCOs)?

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# Conclusions

- The challenges on energy provision are daunting
  - SoS
  - Environment (mostly $CO_2$)
  - Affordability
- Many uncertainties...

- Energy issue is very complicated because interactions
  → more need to study the system effects

- **Important <u>research</u> activity on all aspects influencing energy system integration is required!**

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Energy
Ville

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