Energy trends – Smart Grids
where power meets intelligence

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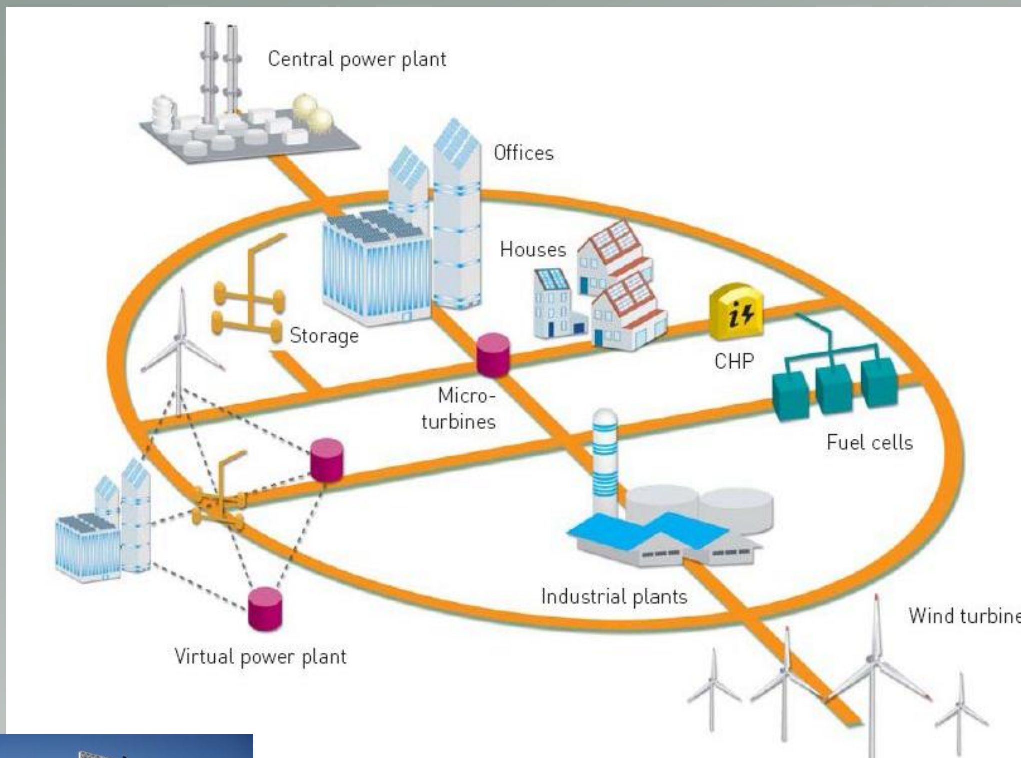
Smart Grids Vision

Multi-directional ‘flows’



Central & dispersed sources

SMARTGRIDS

End user real time
Information & participation

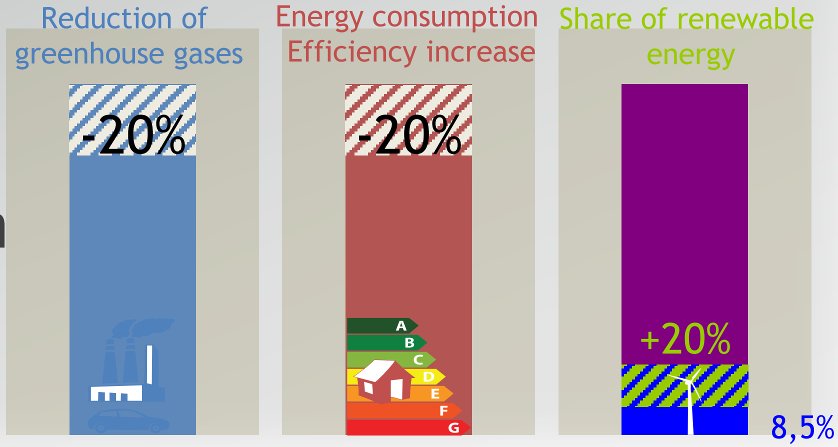
Seamless integration
of new applications

Central & dispersed
intelligence

Smart materials and
power
electronics

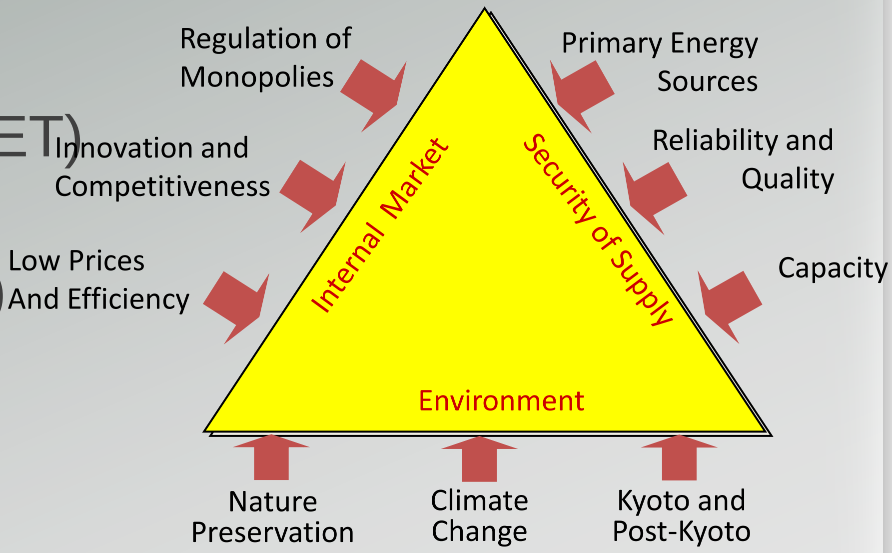
Directorate-General for Energy

- Decarbonised European Economy: Five Priorities towards 2020 - 2050
  - Create grass-roots demand for ***energy saving*** equipment and services
  - Improve ***investment conditions*** in low-carbon energy and replacements of generating capacity and networks
  - Keep leadership in having world renowned ***renewable energy*** companies and ***research*** institutions
  - Reassuring a safe, secure, reliable ***energy system***
  - Strengthening the dimension of the internal ***market***



Directorate-General for Energy

- Three Agencies
  - ACER: Agency for the Cooperation of Energy Regulators
  - EACI: Executive Agency for Competitiveness & Innovation
  - ESA: Euratom Supply Agency
- Actions
  - ***Technology & Innovation*** (SET)
  - ***Infrastructure*** (EEGI)
  - ***Renewable energy*** (NER300)
  - ***Research*** (EERA, ERA Net+)
  - …
- Stakeholders
  - Industrial Partners (Eurelectric)
  - System Operators (e-DSO, ENTSO-E)



Source: European Commission of Energy, website

Technology & Innovation

- SET-plan
  - Accelerating development and deployment of cost-effective ***low carbon technologies***
  - Industrial Initiative with large scale pilot projects
  - Themes:
    - Wind, Solar
    - Nuclear
    - CCS
    - Bio-energy
    - Green Cars
    - Fuel cells
    - Hydrogen
    - Smart Cities
    - Electricity Grids
    - Sustainable Energy

SET-plan

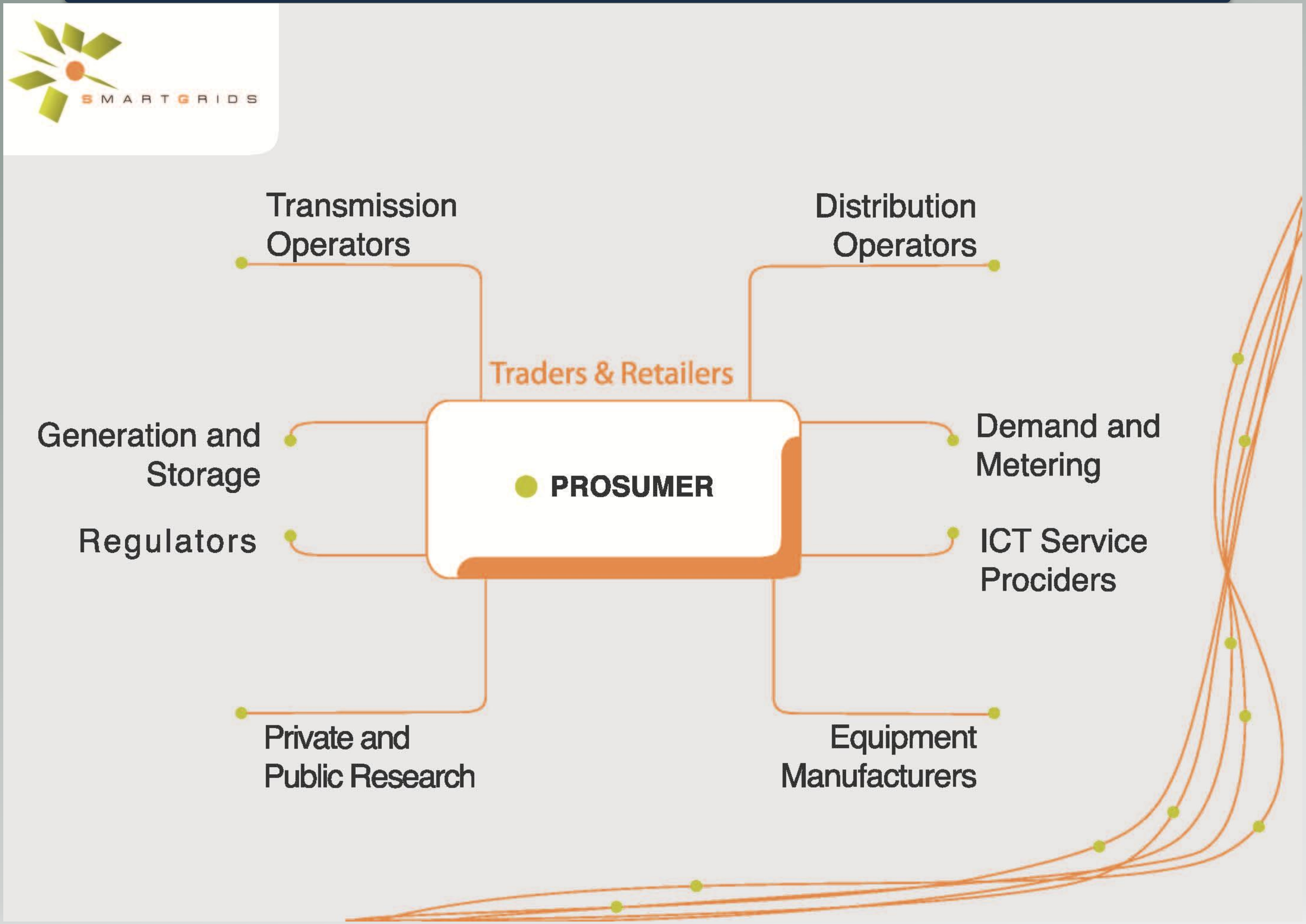
Industry	Research	Education	Financing
EII	EERA	EIT	ERA-NET
European Industrial Initiative	European Energy Research Alliance	European Institute of Innovation & Technology	European Research Area
		KIC	

Infrastructure

- The European Electricity Grid Initiative (EEGI)
  - Accelerating development and deployment of ***electricity networks*** capable of handling the massive deployment of renewable and decentralised energy sources as proposed by the SET-plan
  - Initiative of the System Operators (EDSO, ENTSOE)
  - Theme:
    - Active Smart Grid
      - TWENTIES, PEGASE, REALISEGRID
    - New Market Rules
      - OPTIMATE
    - Intelligent Metering

Source: The European Electricity Grid initiative, Roadmap 2010-18 and Detailed Implementation Plan 2010-12, 25th May 2010 [online]

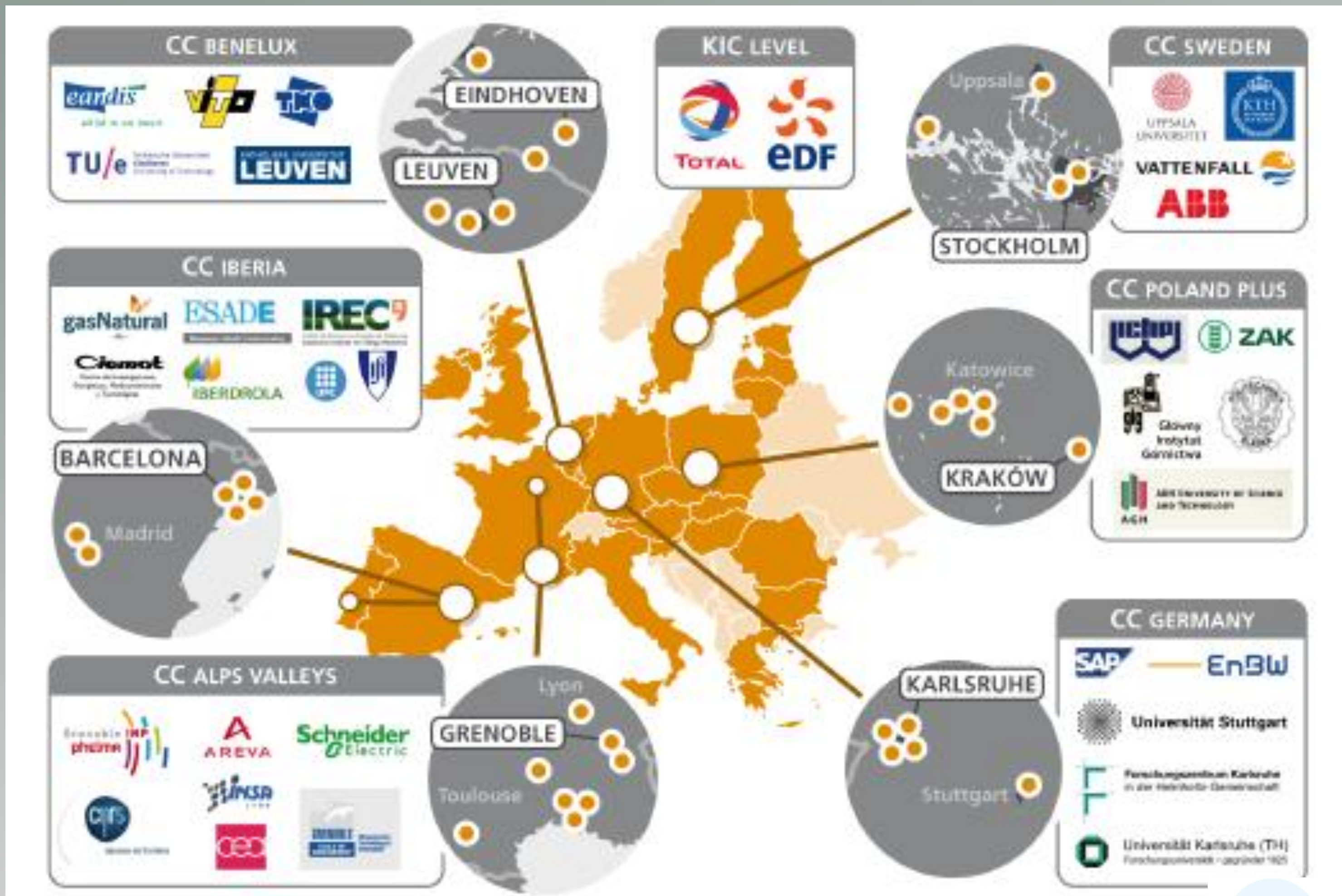
Infrastructure



Renewable Energy

- NER300
  - Subsidises installations of innovative ***renewable energy*** technologies and Carbon Capture and Storage
  - 300 million allowances in the New Entrants' Reserve of the European Emissions Trading Scheme
  - Themes
    - Innovative Renewable Energy
      - Biofuels, solar, wind, geothermal, hydro, ocean, ...
    - Grid Integration
    - Carbon Capture Storage

Research & Education

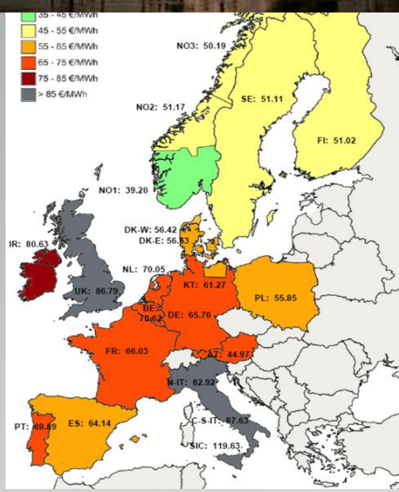


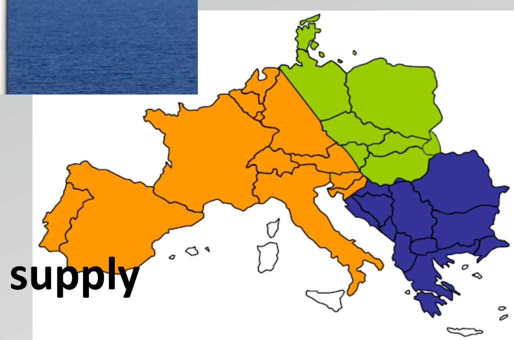
European Institute of Innovation & Technology

Triangular challenge: Climate-Market-Security of Supply

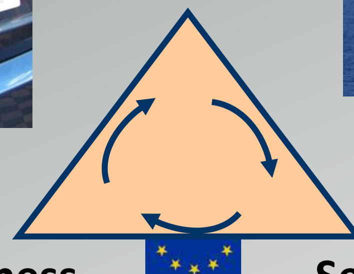
One European policy…

three goals that have to converge simultaneously!!



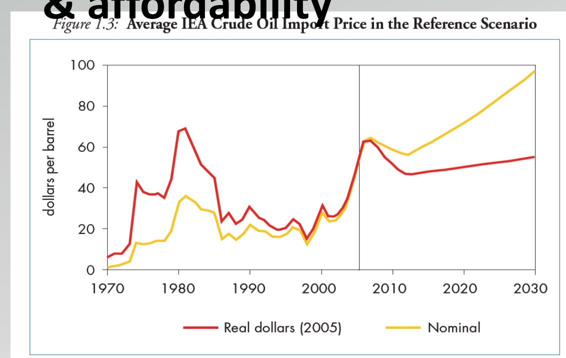


Sustainability



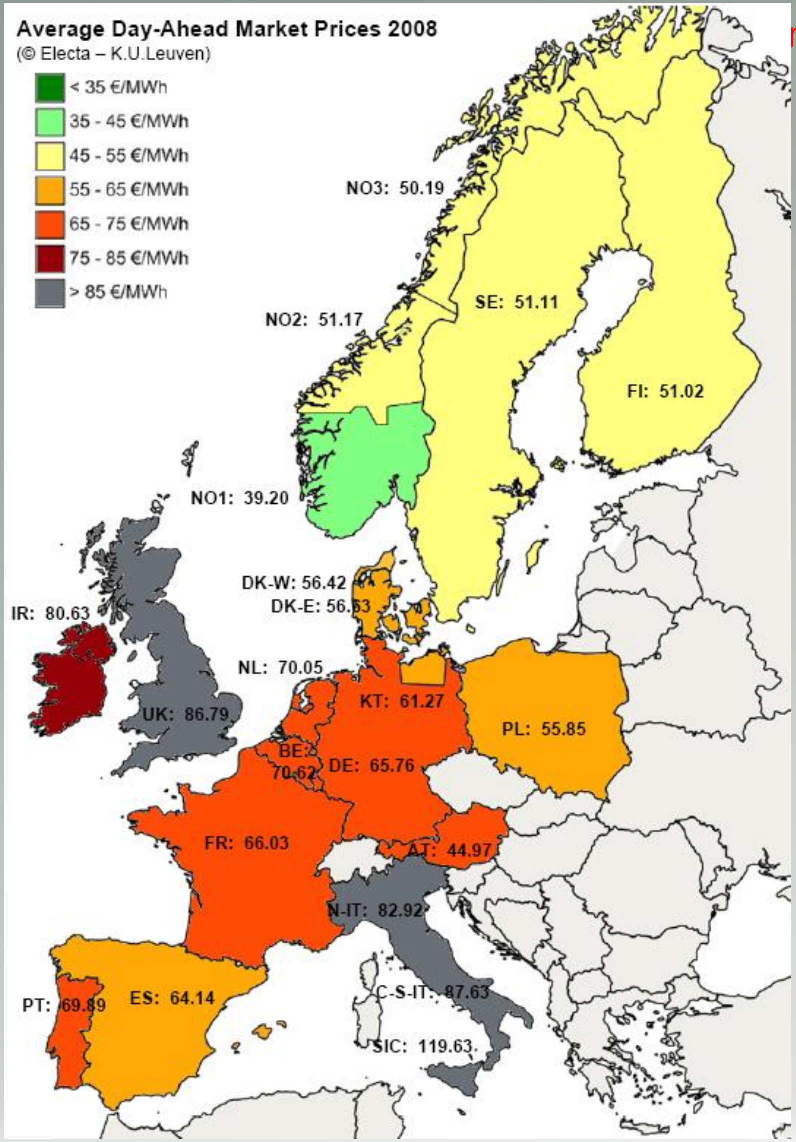
Competitiveness & affordability

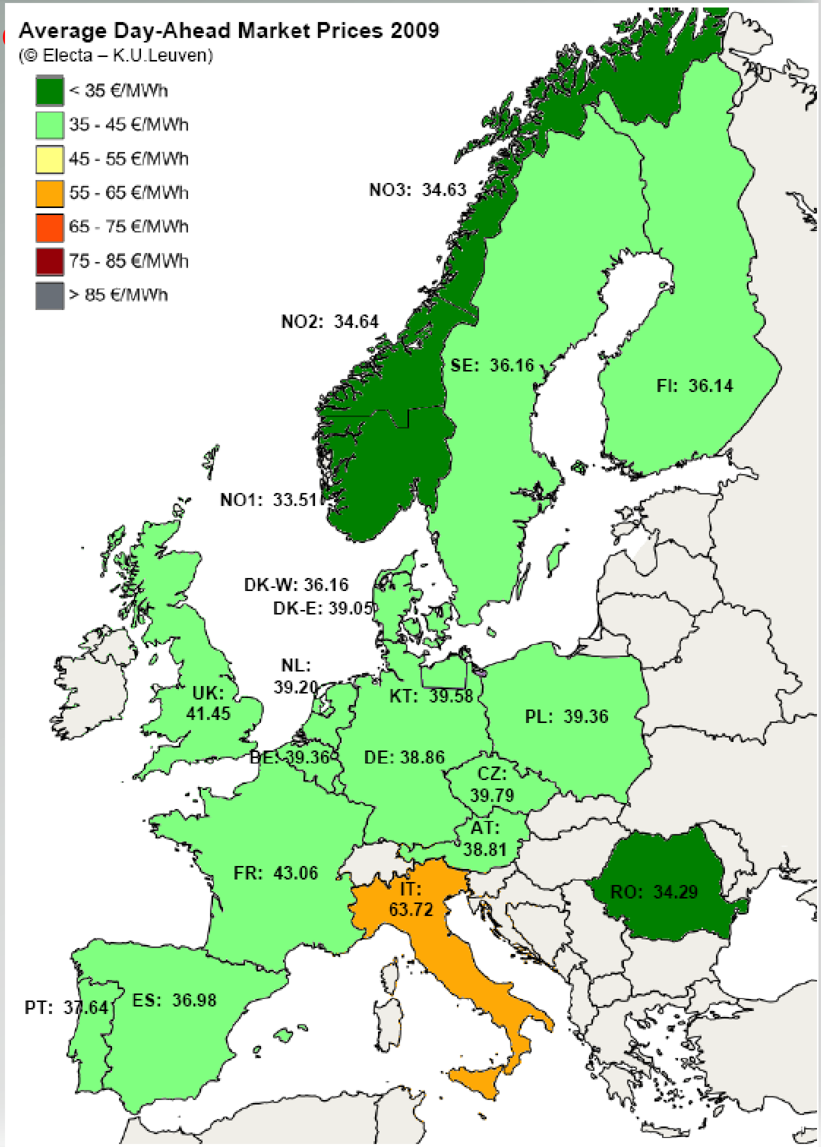
Security of supply



Competitiveness & Affordability

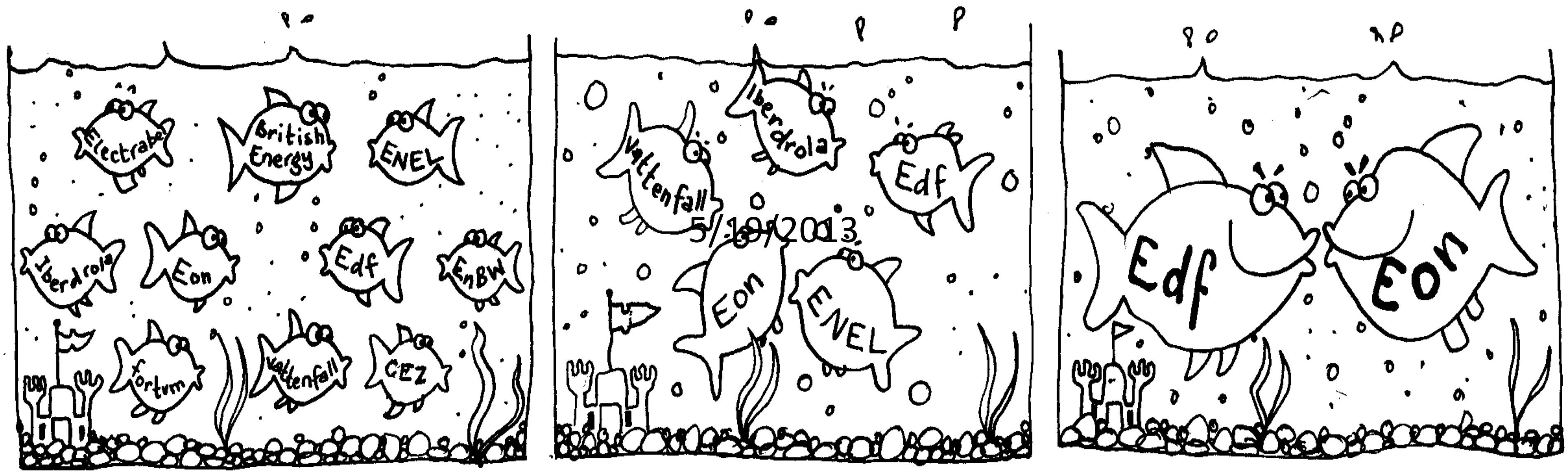
mand in times





Competitiveness & Affordability

EU market building slower than industry consolidation?



5/19/2013

Big fish, small pond

Sustainability

Desertec

One of several concepts in bringing sustainable energy sources to Europe, but the main ideas in different concepts are:

- Offshore Wind from the North
- Solar energy from the South
- Hydro from Scandinavia and the Alps

PHEV

- Decrease dependency on fossil fuels and (volatile and/or high) oil prices
- Limit greenhouse gas emissions in transportation via sustainable electricity production

Security of supply
examples of short term issues

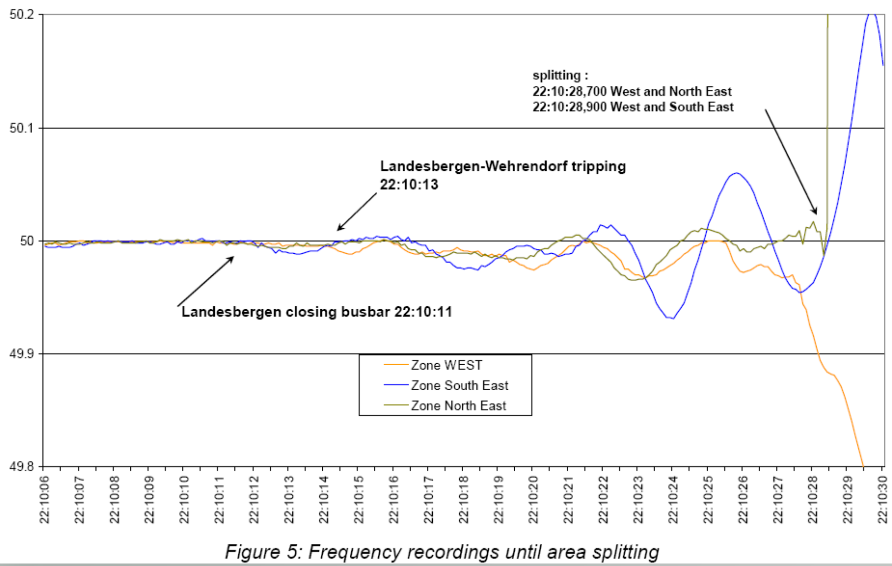
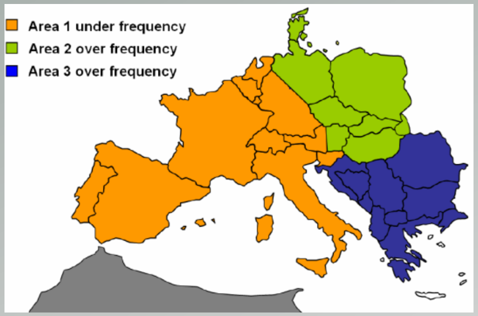


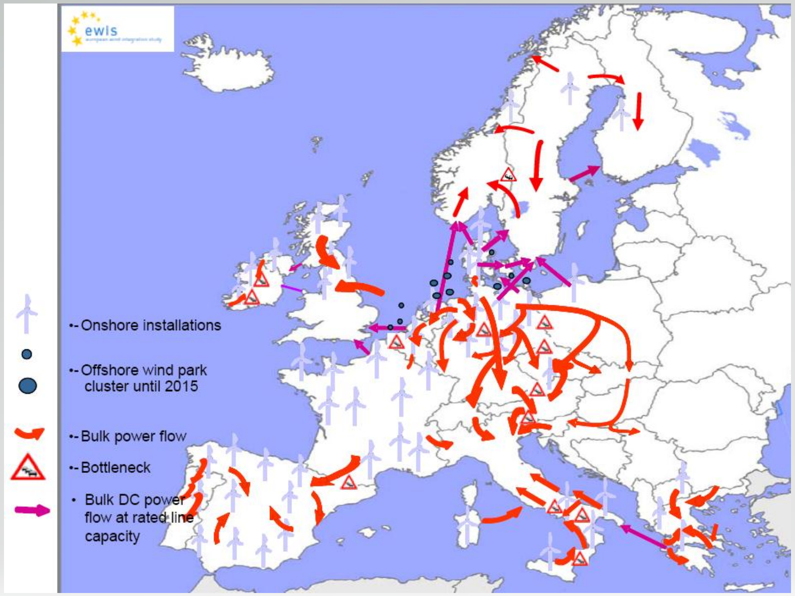
Figure 5: Frequency recordings until area splitting

Disturbance of 4 November 2006

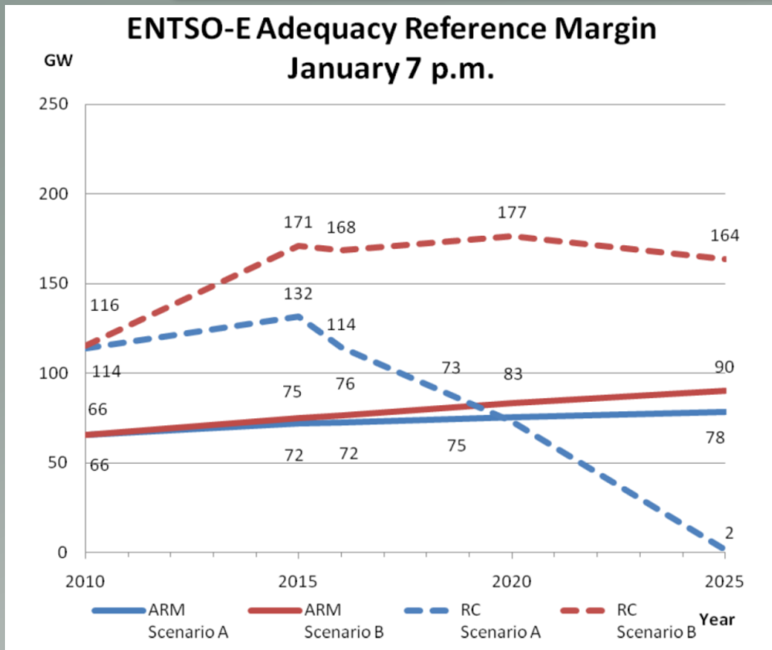


European Wind Integration Study

2015 Physical Power Flow Patterns
(High Wind North)



Security of supply
examples of long term issues



Generation adequacy

ARM: Adequacy Reference Margin

RC: Remaining Capacity

Overall European pictures looks ok, but

- Think of lead times
- Regional demand-supply balances are also important

Diversify primary energy resources

Nabucco natural gas pipeline

An example of diversifying natural gas supply

CO_2 neutral electric energy supply

- Target:

CO_2 neutral electric energy supply in Europe by 2050

- Objective behind:

Keep global temperature rise below 2°C above pre-industrial level

CO_2 neutral electric energy supply

Impossible?

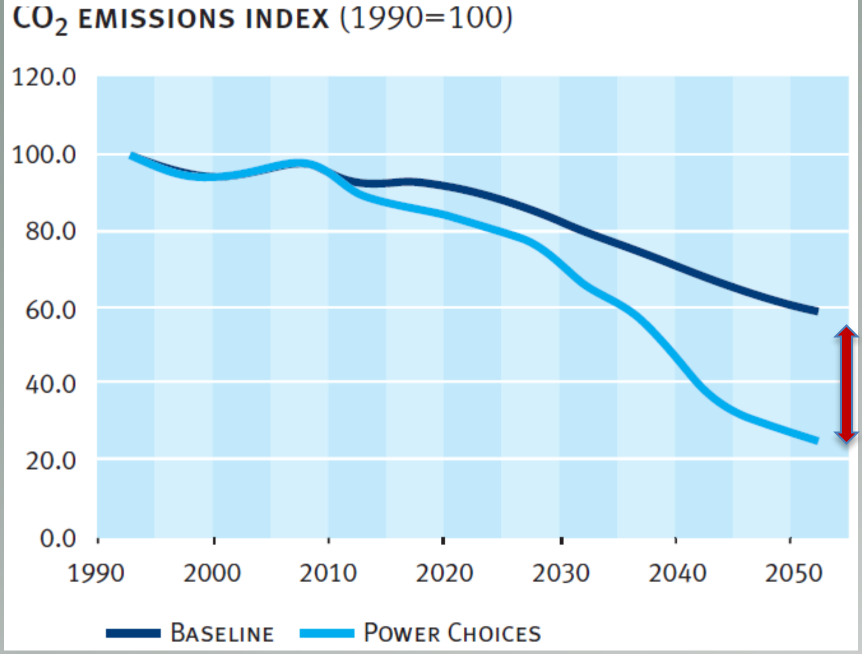
CO_2 neutral electric energy supply

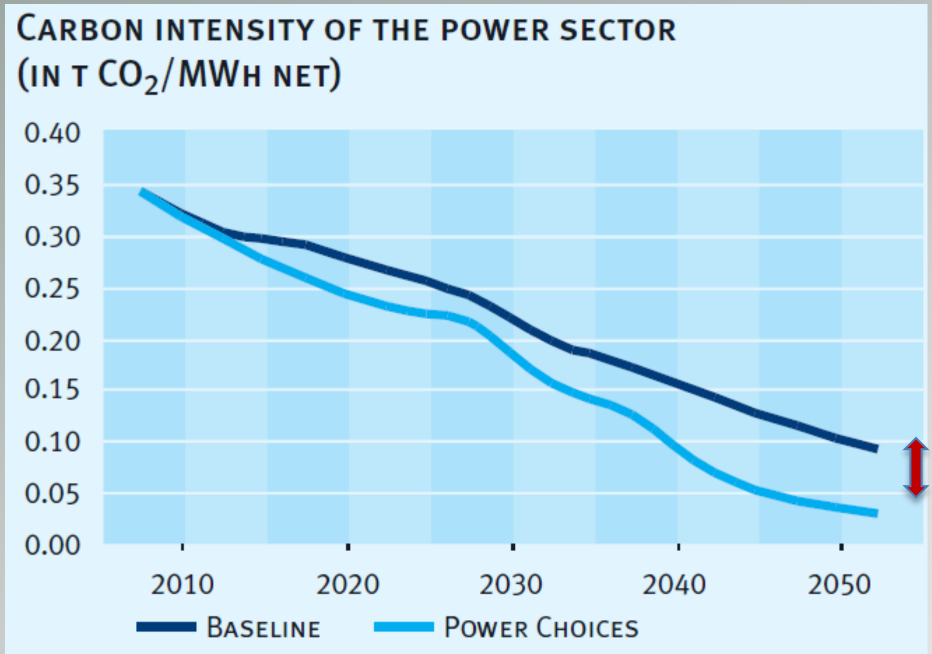
- Study using the PRIMES energy model:

  "Power Choices - Pathways to Carbon-Neutral Electricity in Europe by 2050"

- Baseline
  - Meeting 2020 CO_2 targets
  - Nuclear phase-out
  - Electricity does **not** become major transport fuel towards 2050
- Power choices scenario
  - 75% CO2 emission reduction target for entire economy by 2050
  - Carbon market for all sectors
  - Standards energy efficiency
  - Facilitate intelligent grids
  - Electricity **becomes** major transport fuel towards 2050

CO_2 neutral electric energy supply





- "Power Choices" scenario shows promising CO_2 emission reduction benefits

CO_2 neutral electric energy supply

Generation-side

- Energy efficiency
- Nuclear
- CCS
- Renewables

Demand-side

- Energy efficiency & Intelligent consumption
  - Residential
    - Smart appliances
    - Intelligent heating/cooling
    - insulation
  - Transportation
    - Electric vehicles

	2007	2020	2030	2050
Wind	56	180	288.5	462
Hydro[1]	102	120	148	194
PV	4.9	150	397	962
Biomass	20.5	50	58	100
Geothermal	1.4	4	21.7	77
CSP	0.011	15	43.4	96
Ocean	-	2.5	8.6	65
Total RES-E capacity (GW)	185	521.5	965.2	1,956

EREC: RE-thinking 2050

Required paradigm shift on the demand-side

CO_2 neutral electric energy supply

- Key outcome
  - Carbon-neutral power in Europe by 2050 is **achievable**
  - The major CO_2 reduction in the power sector occurs during 2025 to 2040
  - All power generation options and policies to foster **energy efficiency**, are all needed simultaneously
  - A paradigm-shift is needed on the demand side: **intelligent electricity systems** should replace direct use of fossil fuels
  - The Power Choices scenario minimizes energy import dependency

CO_2 neutral electric energy supply

- Policy recommendation
  - International agreement on climate change needed to
    - Reach emissions at least cost
    - Internalize cost of emissions in all sectors
  - Facilitate the electrification of road transport and spatial heating & cooling
  - Encourage public acceptance of modern energy infrastructure, especially grids, onshore wind and CO_2 - storage sites

CO_2 neutral electric energy supply

CO_2 neutral electric energy supply

- The vision of the power industry
  - European Electricity Sector CEOs Declaration 18 March 2009
    - ACHIEVE a carbon-neutral power supply in Europe by 2050
    - DELIVER power cost-efficiently and reliably through an integrated electricity market
    - PROMOTE energy efficiency and electricity use as solutions to mitigate climate change

How will the future grid look like?

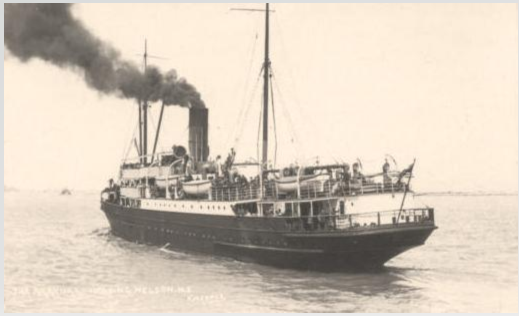
Can we manage by stretching the current 380 kV grid to its limits?

"Stretching" was successful for trains

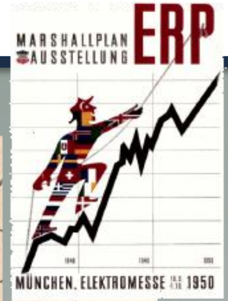
Or do we need a new overlay grid, a new paradigm?

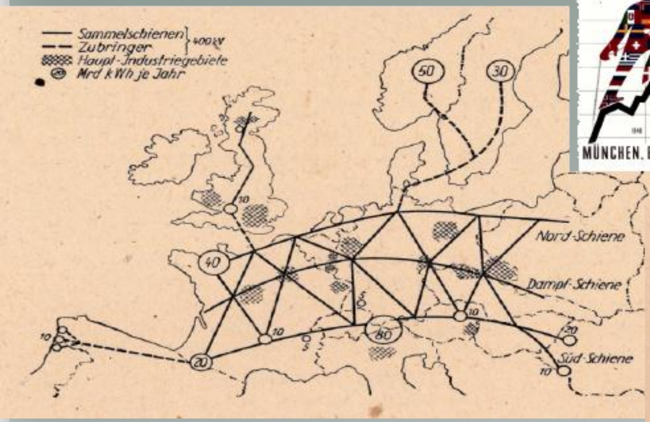
Be aware of the "sailing ship syndrome"…

We must accept the limits of today's situation

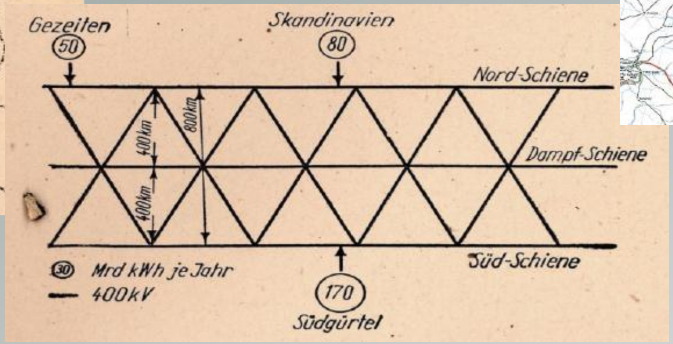


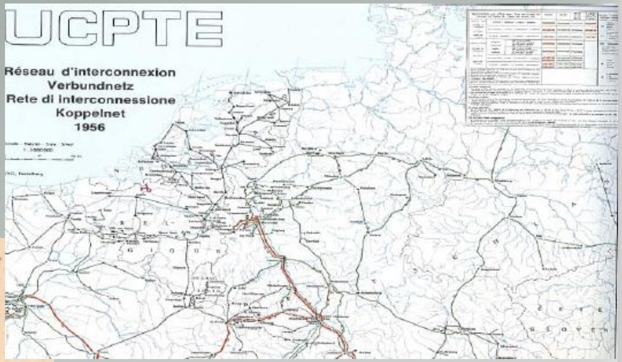
Back to the future





1948

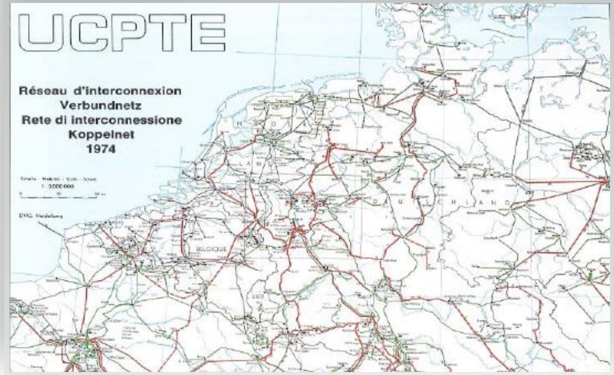




1956

A renewed grid vision?

1974

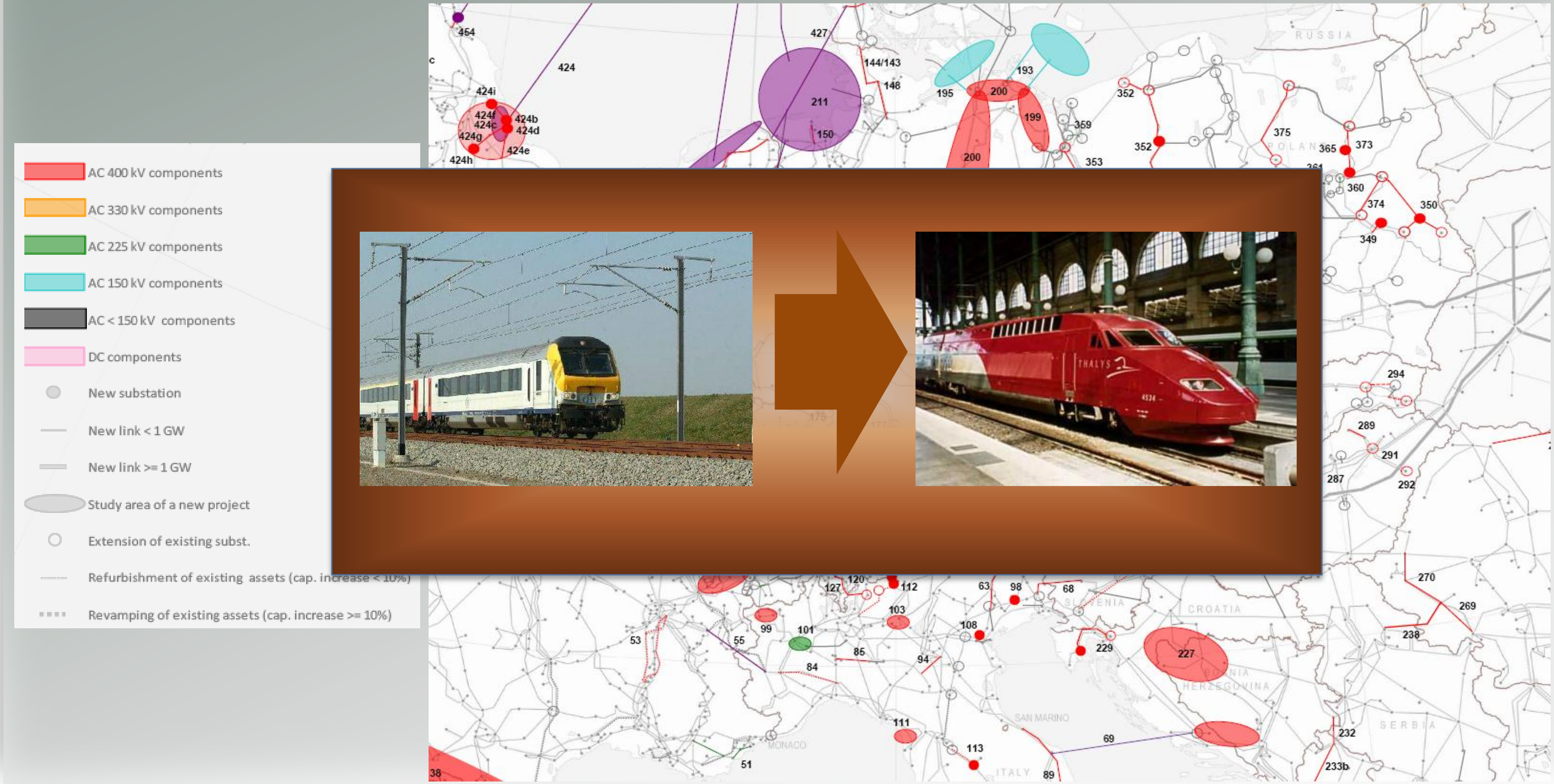


2008

2020
2050
…
?

Stretching: ENTSO-E's TYNDP

Excerpt from ENTSO-E's Map of Pan-European Projects 2020-2050



Stretching: ENTSO-E's TYNDP

However, ENTSO-E does acknowledge the potential of "supergrid" concepts!

Supergrid

Technological issues

- Technical feasibility of existing transmission concepts
- Proper technology;
  - AC, DC (also reliable multi-terminal solutions) and mixed
  - OHL / cables / etc
- Power quality / Level of SoS
- Voltage level / EMF
- Upgrade of existing HV lines to UHV AC/DC
- Technological improvements
- Electricity storage
- Power reserve margin
- Level of reliability

Economical/financial issues

- Different generation and load scenarios
- Cost/benefit (business case) of scenarios
- Electricity prices
- Financial demand per scenario
- Realization and ownership of the Supergrid
- European funding
- Potential investors

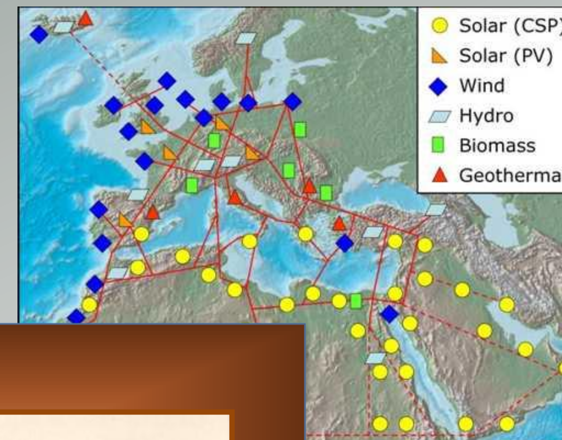
Political/sociopolitical issues

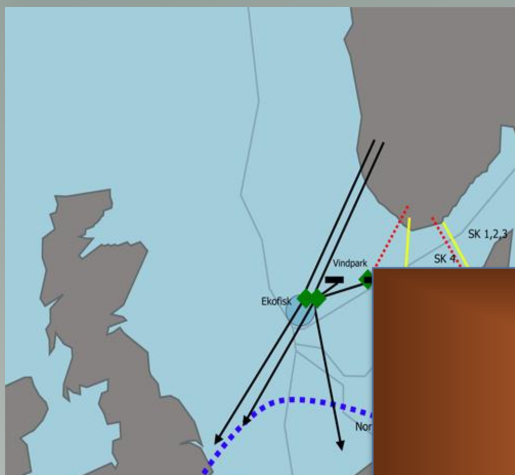
- Legal and regulatory framework
- Social acceptance / Public support of the Supergrid
- Permitting processes, harmonization of national rules
- European policy on Demand Side Management
- New areas to be incorporated; e.g. MENA, Russia, Nordic
- Political stability of regions
- Risk of terrorists attacks

Source: ENTSO-E, TYNDP (June, 2010)

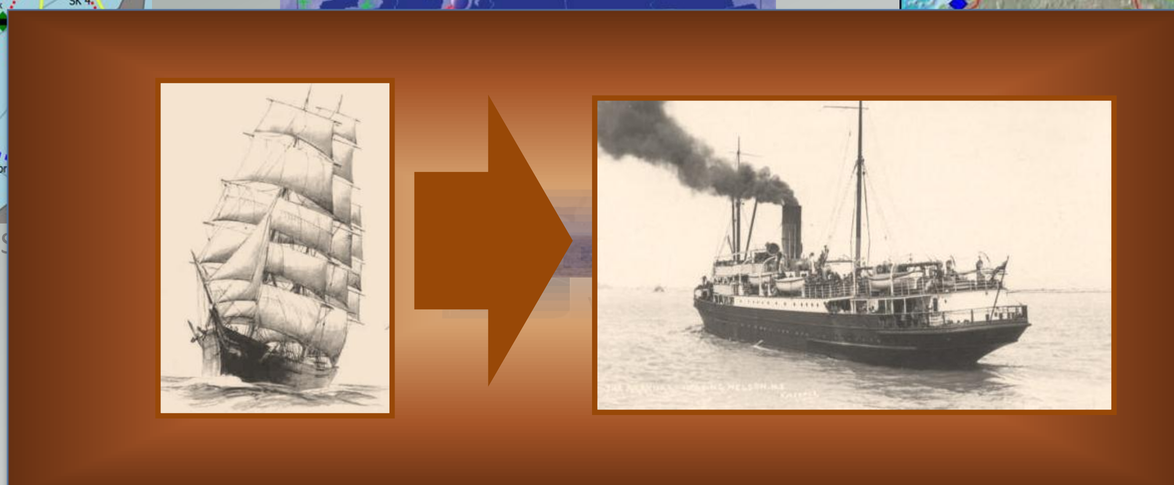
New paradigm: Some suggestions

DLR





Offshore Grid Proposal by S
(Source Statnett, 2008)



Czisch

Offshore Grid examined in the
Greenpeace study
(Source: Woyte et al, 2008)

HVDC
more than just a point to point connection?

- DC power transmission is not new
  - ‘War of Currents’ (1880): AC (Westinghouse) vs. DC (Edison)

- HVDC: High Voltage Direct Current
  - First HVDC link operational in 1954 (Gotland, Sweden)
- Two technologies
  - Current Source Converter (CSC) technology
  - Voltage Source Converter (VSC) technology

State-of-the-art

Existing

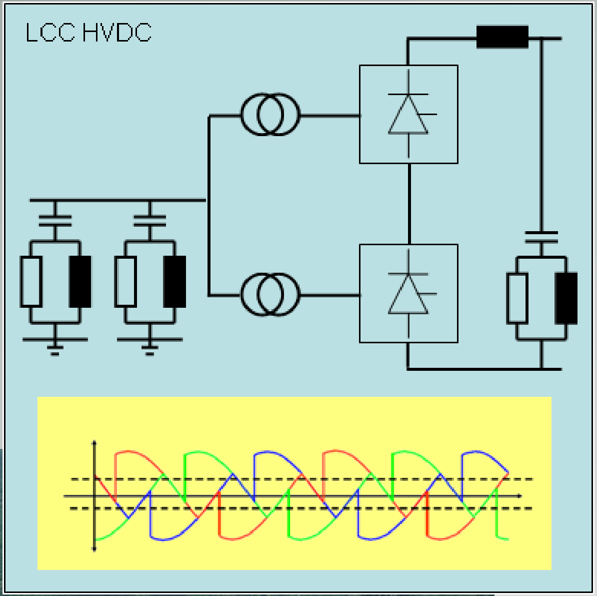
- CSC HVDC
  - 6300 MW
  - ±600 kV DC
  - 785 km + 805 km
- VSC HVDC
  - 350 MW
  - ±150 kV DC
  - 180 km

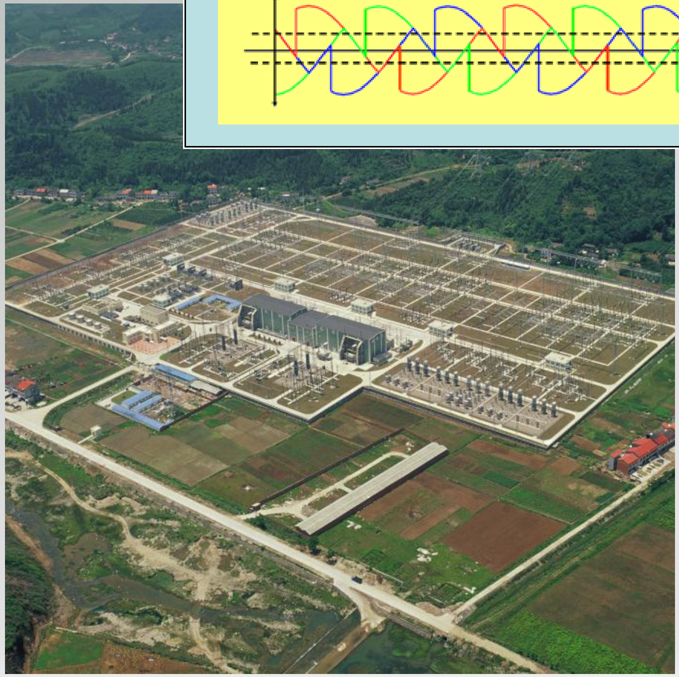
Currently possible

- CSC HVDC
  - 6400 MW
  - ±800 kV DC
  - 2000 km
- VSC HVDC
  - 1100 MW
  - 350 kV DC

CSC HVDC

- Steady increase in ratings
  - Shanghai-Xiangjiaba (2011): 800 kV; 6,4 GW; 2071 km
- Large filter requirements
  - footprint
- Strong AC grid required
  - Problems to connect at weak connection points
- Not viable for offshore applications
  - Rely on the AC grid voltage for commutation

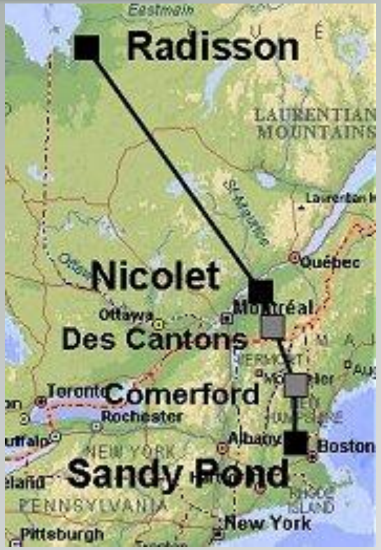


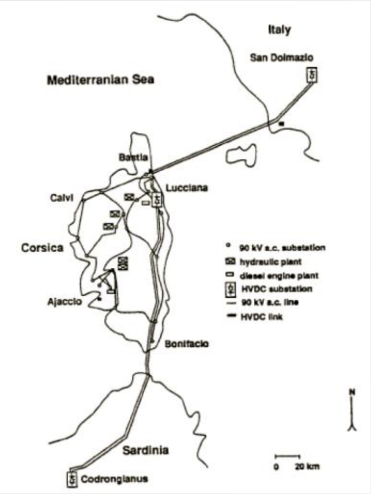


CSC HVDC – Multi-terminal

- Limited experience
  - Only two ‘pseudo-multi-terminal’ links exist
- Hydro Québec - New England (1992)
  - Extended to 3-terminal
  - Originally planned: 5-terminal but cancelled
  - Fixed direction of power
- Mainland Italy-Corsica-Sardinia (1992)
  - 1965: monopolar between mainland and Sardinia
  - 1987: converter added in Corsica
  - 1990: mercury arc replaced by thyristors
  - 1992: second pole added
- General multi-terminal CSC HVDC operation is not feasible

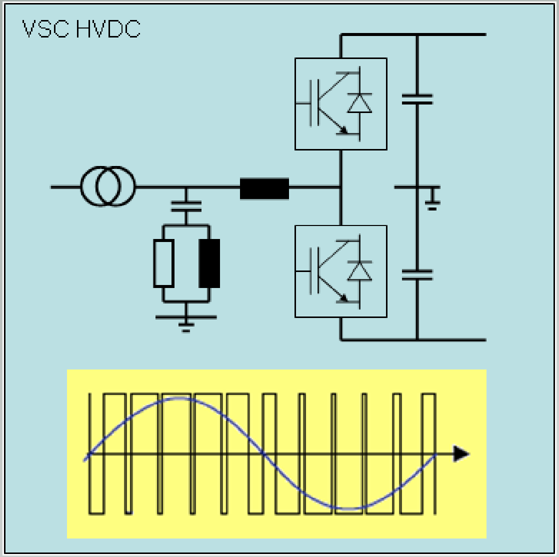
→ CSC for offshore multi-terminal HVDC is a dead end …





VSC HVDC

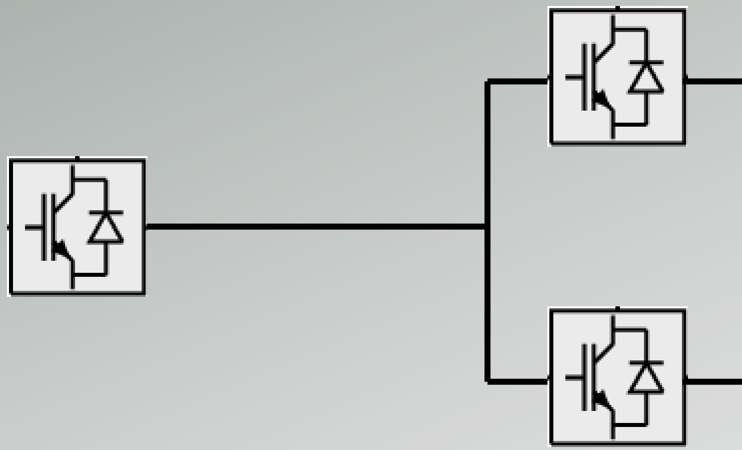
- New concept based on switches with turn-off capability

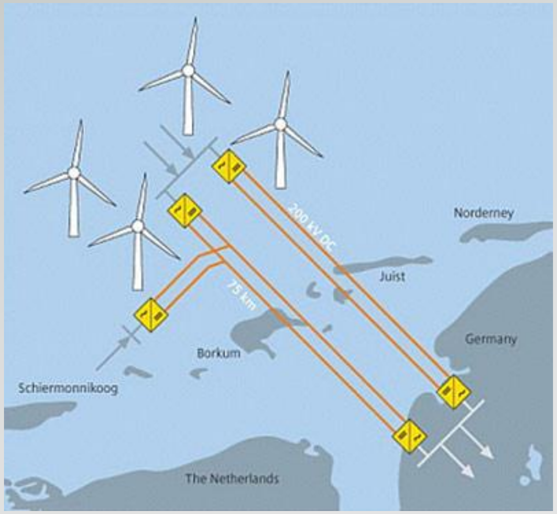


- Characteristics:
  - No voltage source needed to commutate
  - Very fast
  - Very flexible: independent active and reactive power control
  - Less filters → reduced footprint

VSC HVDC – Multi-terminal

- VSC HVDC only developed for point-to-point, but…
- …looks very promising for MTDC
  - Converter's DC side has constant voltage → converters can be easily connected to DC network.
- Extension to 'pseudo-multi-terminal' systems straightforward: e.g. star-connections





VSC HVDC – offshore applications

- Modified design

- Troll (2005)
  - First offshore HVDC converter
  - 40 MW, 70 km from shore
  - Oil-platform

- Borwin alpha (2010)
  - First offshore HVDC converter for wind power
  - 400 MW
  - 200 km

VSC HVDC – wind applications

- No cable length issues
- Wind farms are independent of power system
  - Do not need to run on main/fixed frequency
- Multiple wind farms can be connected to offshore grids
- This could lead to a ‘supergrid’ …

HVDC
Conclusions & future challenges

- CSC HVDC
  - Stretching not possible
    - Too large
    - Grid voltage needed
- VSC HVDC
  - Stretching possible
    - Small footprint
    - Passive grid operation
    - Technical characteristics suited to wind applications
    - Offshore applications proven
  - Technical challenges remain…
    - DC breaker
    - Fast fault detection and localisation
    - Losses
    - Ratings
    - DC voltage control

    …but can be solved
  - Need to further look into economical and political challenges

Virtual Power Plant

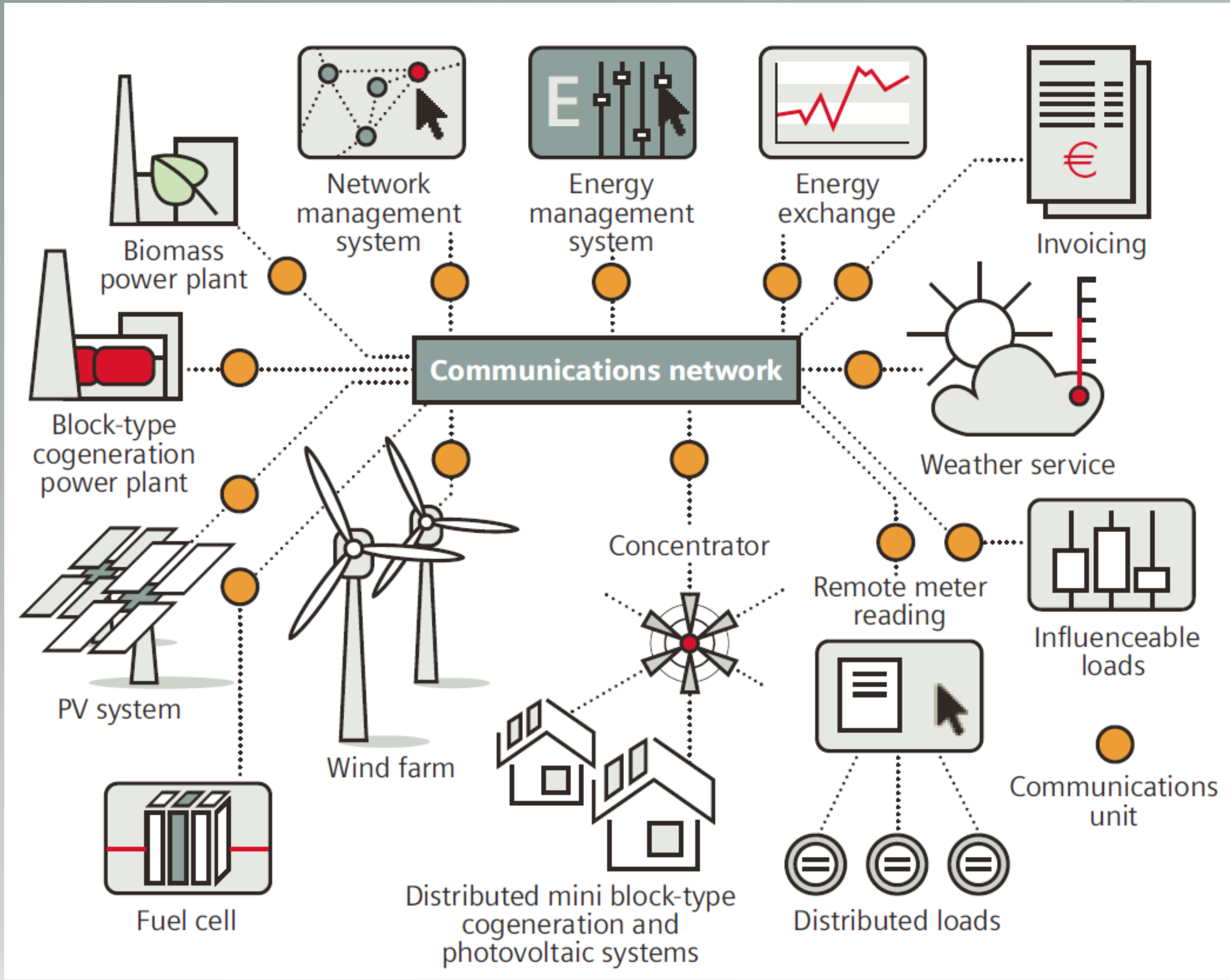
- Virtual Power Plant:
  - Dispersed generation
  - Dispersed Storage
  - Controllable loads

  Aggregated to work as a conventional power plant
- Not necessarily by physically connecting plants but by interlinking them via soft technologies (ICT)
- VPP as key delivery mechanism to provide access of DER
  - to energy market (commercial aggregation)
  - to ancillary and network management services markets (grid aggregation)

➢ The goal is to manage DER to provide as much services as a conventional generators

Virtual Power Plant

- **Advanced IT** is the core element of a virtual power plant!



Virtual Power Plant

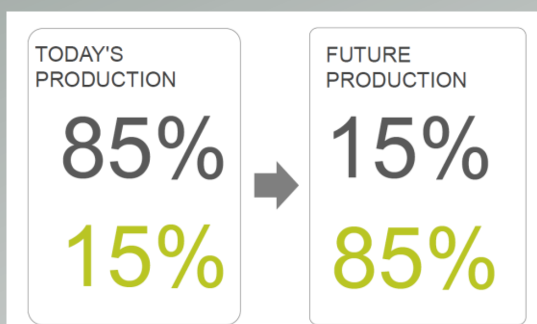
- Why do we need a VPP?
  - **Dispatchability:** Aggregation creates units dispatchable by TSO (several MW) and DSO
  - **Visibility:** Aggregators can give transparency to TSO/DSO of their aggregated resources, providing real-time information
  - **Deterministic behaviour:** Adequate aggregation can perform close to conventional power plants (e.g.: Wind+CHP+DSM)
  - **Entry of new agents:** Non-network owners can create value thanks to the existing flexibility of DER and DSM

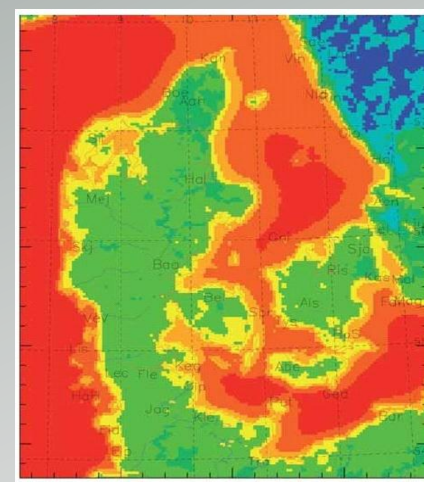
Virtual Power Plant

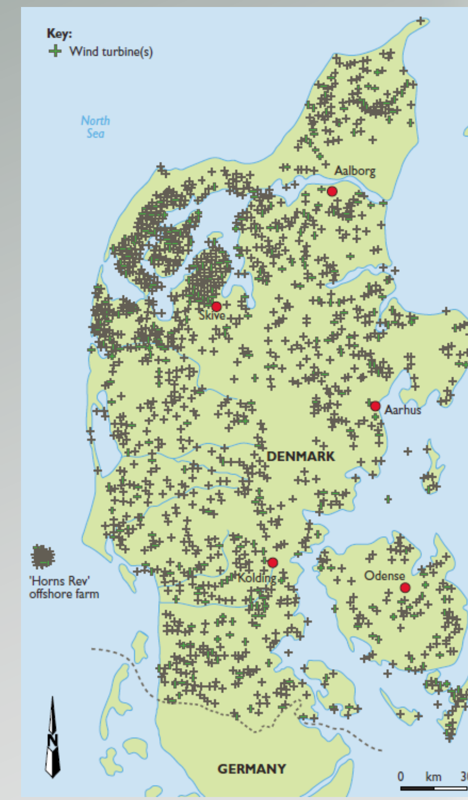
- Services of VPP
  - **Locally performed ancillary services**
    - Voltage control and reactive power supply
    - Optimize grid losses, local power quality
    - Local (distribution network) congestion management
    - Islanded operation capacity
  - **System wide ancillary services**
    - Frequency control
    - Active power reserve
    - Network restoration

Virtual Power Plant

- Denmark
  - Large share of Wind production
    - Installed capacity: 3,482 GW (2009)
    - Electricity generated: 6,72 TWh in 2009
      - Load factor: 20%
      - 16% of national demand
- Dong Energy´s vision







➢ Integration of large amount of wind power causes both energy and power balancing issues

Virtual Power Plant

- Wind carpet or Virtual Power Plant
  - Many wind farms joined together to form what is effectively a large, virtual power station

- Wind farms, in different parts of the country, will be observed giving very different outputs at the same time
  - However, from time to time, a cyclone covers the whole of west Denmark.

Load management: Smart metering and communication

losses management & rewards

"an RTU at every service head"

intelligent demand control in emergencies

the portal to demand & micro-gen services

moving consumption

operational visibility of local networks

load-limiting & remote disconnection

new services to delight customers….

Grid require smart metering to increase flexibility

- More electrical consumption
  - +1à2% per annum
- Unpredictable generation
  - photovoltaics (PV), wind,…
- Storage is not possible *yet*
  - battery storage, electric car batteries,…?
- Communication required

Increased flexibility

- **Load** control
  - ***active*** demand management
    - *Easily* controllable loads: heating, ventilation, airco
      future: also electric vehicles
    - *Moderately* controllable loads: washing machines, dryer, dish washer, freezer,… (residential constraints!)
  - besides ***passive*** demand response
    - awareness, different tariff schemes (e.g. real-time pricing)
- **Storage** control
  - e.g. electric vehicles (plug-in and/or full EV)
- Distributed **generation** control
  - *limiting peak PV power can allow more PV energy*

What is Smart metering?

- AMR – automated meter reading
- AMM – automatic meter management
  - AMR + dimming, shutdown, reconnection, etc.
    - AMI – automated meter infrastructure
  - includes bidirectional communication technology
- Smart meters
  - AMM + *real-time* control
    - streaming, demand response, ….

AMR 1: Actaris ACE 4000 RF AMR 3 – Telvent/Echelon AMR 2 - Iskraemeco MT 351

Monitoring and control applications

- **End-user** management
  - demand response applications
    - peak shaving, load shifting, usage flattening
  - energy management systems
    - incorporate prices & external circumstances
    - (de)activate appliances (heat pumps, fridge, battery chargers, ...)
  - *remote meter reading*
- **Grid** management
  - aggregating data (profiles, peaks, services, …)
  - controlling grids and elements (topology, power quality, …)
- *Smart meters enable smart grids*

Communication

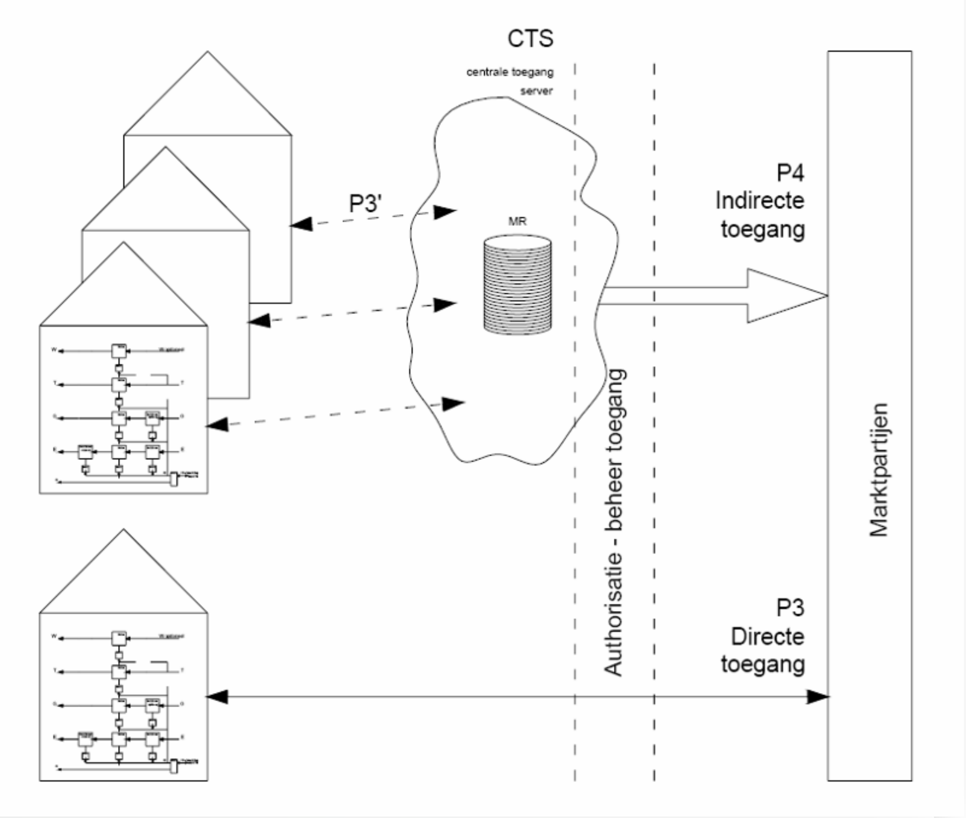
- Possible communication means:
  - PLC: Power Line Carrier
    - + no extra cabling required
    - - not available during certain power problems, less reliable than other comm. means, smallband
  - wired over telephone / cable infrastructure
    - + very reliable
    - broadband when DSL or TV cable
    - - requires phone connection or access to cable, short distances
  - wireless mobile telephony and data (2G/3G)
    - - smallband (2G) ⇔ + broadband (3G)
    - - no good coverage in cellar, availability 3G < 100%
  - wireless: radio frequency (RF)
    - - smallband, requires antenna infrastructure
    - + very reliable, good coverage

Requirements / Architecture

- Small bandwidth sufficient for basic information
  - additional services require broadband

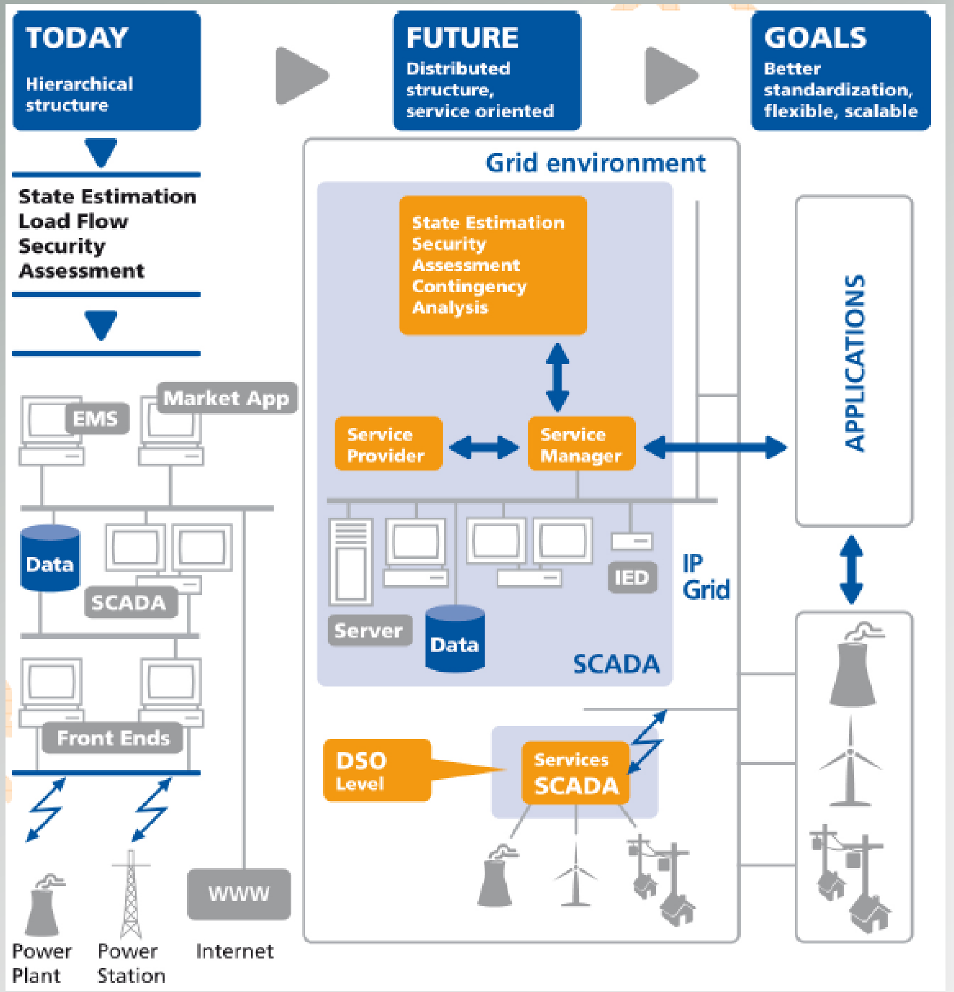
transaction type	time critical	response (min/typ/max)	#times/yr	#data (min/typ/max)
command store measurement registers	yes	immediate 5 min 1 h	1	0.5 KiB 1 KiB 16 KiB
send **measurement registers** (periodically + on demand)	no	immediate 10 min 2 h	13 (12+1)	1 KiB 32 KiB 16 MiB
command reduce load	yes	immediate 5 min 1 h	1	0.5 KiB 1 KiB 16 KiB
adjust **parameters**	no	immediate 10 min 2 h	2	0.5 KiB 1 KiB 16 KiB
upgrade **firmware**	no	-	0,2	0.5 KiB 1 KiB 512 KiB
send **alarms**	no	immediate 10 min 2 h	0,2	0.5 KiB 1 KiB 16 KiB

- Single (centralised) vs. multiple (distributed) access



Power, telecom and software: reliability and dependability (1)

- Copper based energy infrastructure (electricity)
  - Optimized topology
  - Power electronic devices
- Communications layer
  - Requirements of speed, quality, reliability, dependability with costs
  - Different communication technologies at the same time
- Software layer
  - Multiple software functions for normal operation: doing locally and independently the maximum number of functions, reporting/requesting from upper level minimum possible information necessary
  - Network reconfiguration
  - Self-healing procedures
  - Fault management
  - Forecasting, modeling & planning



Power, telecom and software: reliability and dependability (2)

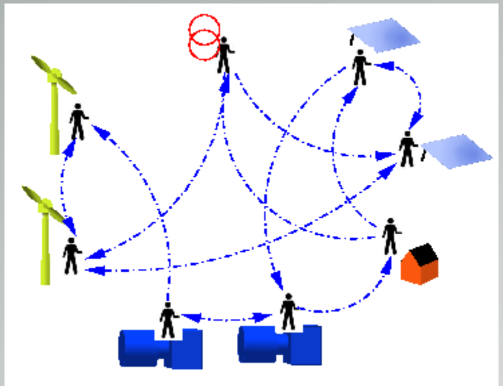
- Availability: fraction of time that the system is operational
- Reliability: probability to function correctly for specific time period
  - *redundancy* increases *A* and *R*
  - *encoding & protocols* enhance *A* and *R*
- Integrity: no undeserved changes
  - important for specific messages (data packets)
  - *encoding* can enhance integrity
- Confidentiality: no unauthorised disclosure
  - important for specific messages (data packets)
  - *encryption* can enhance confidentiality

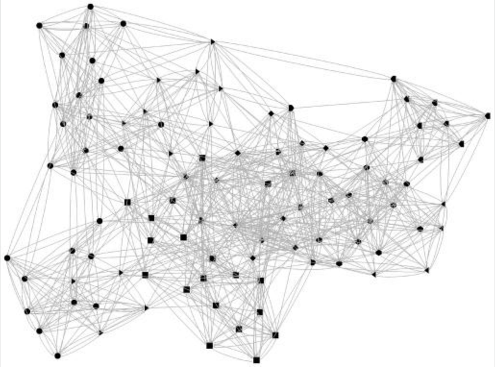
Power, telecom and software: reliability and dependability (3)

- electricity grid is robust
  - fully at transmission level
    - “N-1 security”: functional with single failure
      - generator, transformer, line, controller, communication, …
    - but also sometimes N-2, N-3, N-x, …
  - often at distribution level
    - minimal, localized impact of failures
- only 2, 3, or + failures result in unavailability
  - also ICT architecture at least N-1, or N-x !!
    - including common cause failures
- interdependence ICT ←/→ power infrastructure

Fault tolerant energy system

- to deal with
  - internal problems
    - physical faults in controllers or communication
  - external dynamic environment
    - changing interconnection topology
    - bandwidth reduction
- to exploit redundancy & diversity
  - in interconnections and resources
- in dynamic environment
  - resource discovery
  - overlay networks
- for quantitative & qualitative assessment
  - explicit fault and failure model
  - dependability, time & cost constraints





System threat assessment

- Accidental fault scenarios
  - Network delays/packet loss

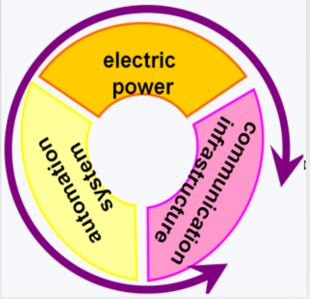
  → *Slower convergence of 2nd-ary / 3rd-ary control loops*
  - Communication failure; soft-/hardware crash

  → *Overlay network can manage dynamism*, *if available*
- Malicious fault scenarios
  - Denial-of-service attacks → *similar, not critical*
  - Intrusions on control PCs
    - Attacks on middleware level → *critical*
      - e.g. influence overlay topology
    - Attacks at application level→ *critical*
      - e.g. tampering with *3rd-ary* control (financial gain)
      - e.g. tampering with *2nd-ary* control (voltage profile disturbance)

Design methodology for dependable energy systems

- explicit fault and failure models of energy infrastructure

- dependability modeling
  - reliability, safety, …
  - fault prevention, ~tolerance, ~removal, ~prediction
- instantiation of modular middleware architecture
  - dependable communication & computation
  - in dynamic environments
- assessment of dependability, time & cost constraints
  - conceptual evaluation and fault injection
  - interdependencies on other critical infrastructures
    - energy, telecom, information & fault propagation



Impact of electric vehicles

- Hybrid electric vehicles (HEV)
  - Additional electrical motor
  - Downsizing of internal combustion engine
  - No loss of performance
  - Reduction of exhaust gases
- Plug-in hybrid electric vehicle (PHEV)
  - HEV
  - Battery charging
    - On-board
    - Plugging into a standard electric outlet
  - Limited range in electric only mode
- Battery electric vehicle (BEV)
  - Electrical motor only
  - Charging: only plugging into a standard outlet
  - Limited range

Impact of electric vehicles

- Advantages of EV for society as a whole:
  - Reduction of polluting and GHG emissions
  - Increase in energy usage efficiency
  - Maximization of number and variety of primary sources of energy, including RES
  - Reduction of Europe and member states foreign energy dependency
  - Reduction of noise pollution in urban areas
- But:
  - What is the impact on the electric power system?
  - Market models forthcoming infrastructure needs?

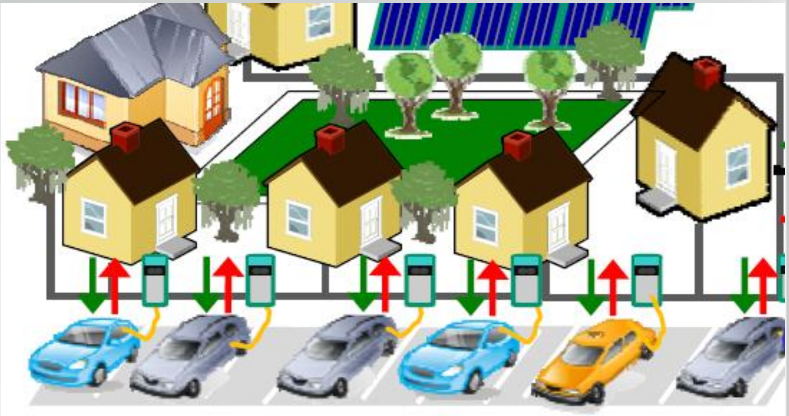
Impact of electric vehicles

- Impact on the electric power system
  - Load increase
    - +/- 3500 kWh per car annually
    - Doubling household energy consumption
    - Impact on distribution grid
      - Voltage levels/deviations
      - Line losses
      - Transformer investments
    - Impact on power generation
      - Additional generation capacity
      - Creation of new demand peaks

Importance of Smartness of EV integration

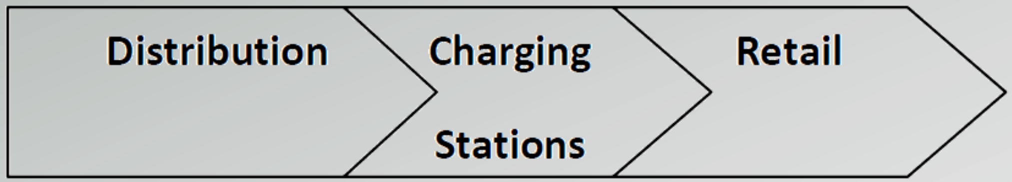
Impact of electric vehicles

- Impact on the electric power system
  - Smart integration
    - Flexible load
      - Coordinated charging
      - Integrating variable/unpredictable RES: central or distributed
      - Integrating inflexible generation facilities
    - New storage facility
      - Bidirectional power flows
      - Arbitrage between different hours
    - Grid support
      - Delivering ancillary services
        - » Frequency regulation
        - » Voltage regulation
        - » Load leveling
      - Large availability: 90 % not driving



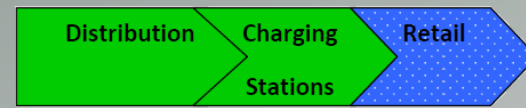
Impact of electric vehicles

- Market models forthcoming infrastructure needs
  - Market for charging infrastructure
  - Services provided by the infrastructure
- Depending on locations for EV infrastructure
  - Public/private areas – public/private property
  - Fast charging locations
- Different market structures

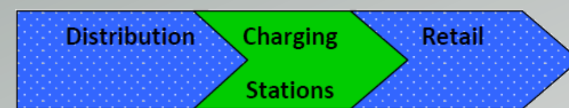


Impact of electric vehicles

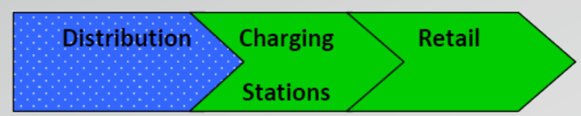
- Integrated infrastructure



  - Into DSO’s assets
  - Socialized cost recovery (tariffs)
- Separated infrastructure



  - Separate, independent, but regulated operator
  - New billing and authorization system
- Independent e-mobility / spot operator owned stations

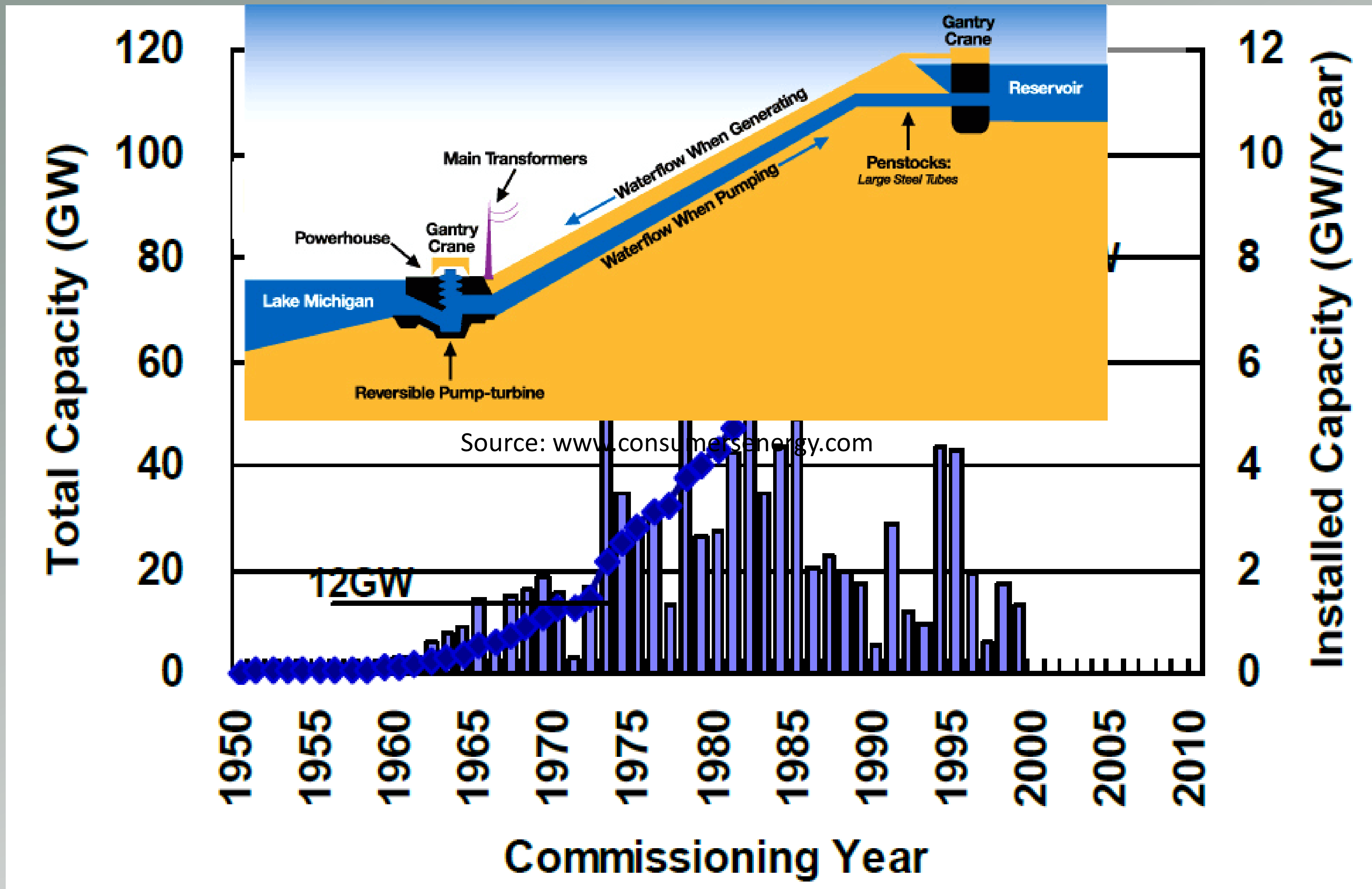


  - Private operator
    - Retailer
    - Parking spot owner
  - Roaming / reselling electricity

Impact of and need for storage
(electricity and heat)

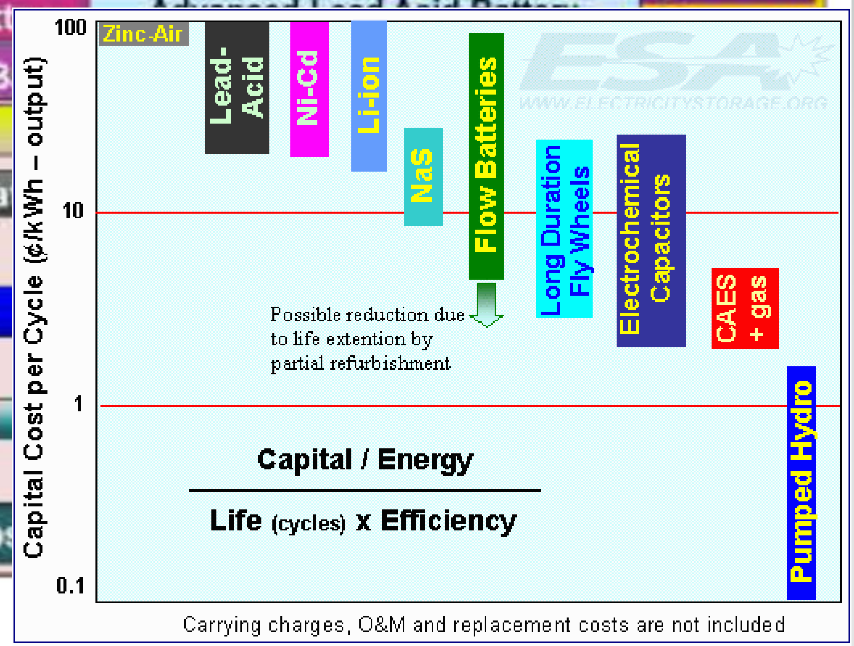
- Large scale integration Renewable Energy Resources
  - Curtailing?
  - Energy Storage
- Grid Services
  - Peak shaving
  - Voltage control
  - PF correction
  - Energy arbitrage

Pumped Storage



Source: IEA, based on data from Mc COY report 2008, (2008).

Electricity storage systems and applications

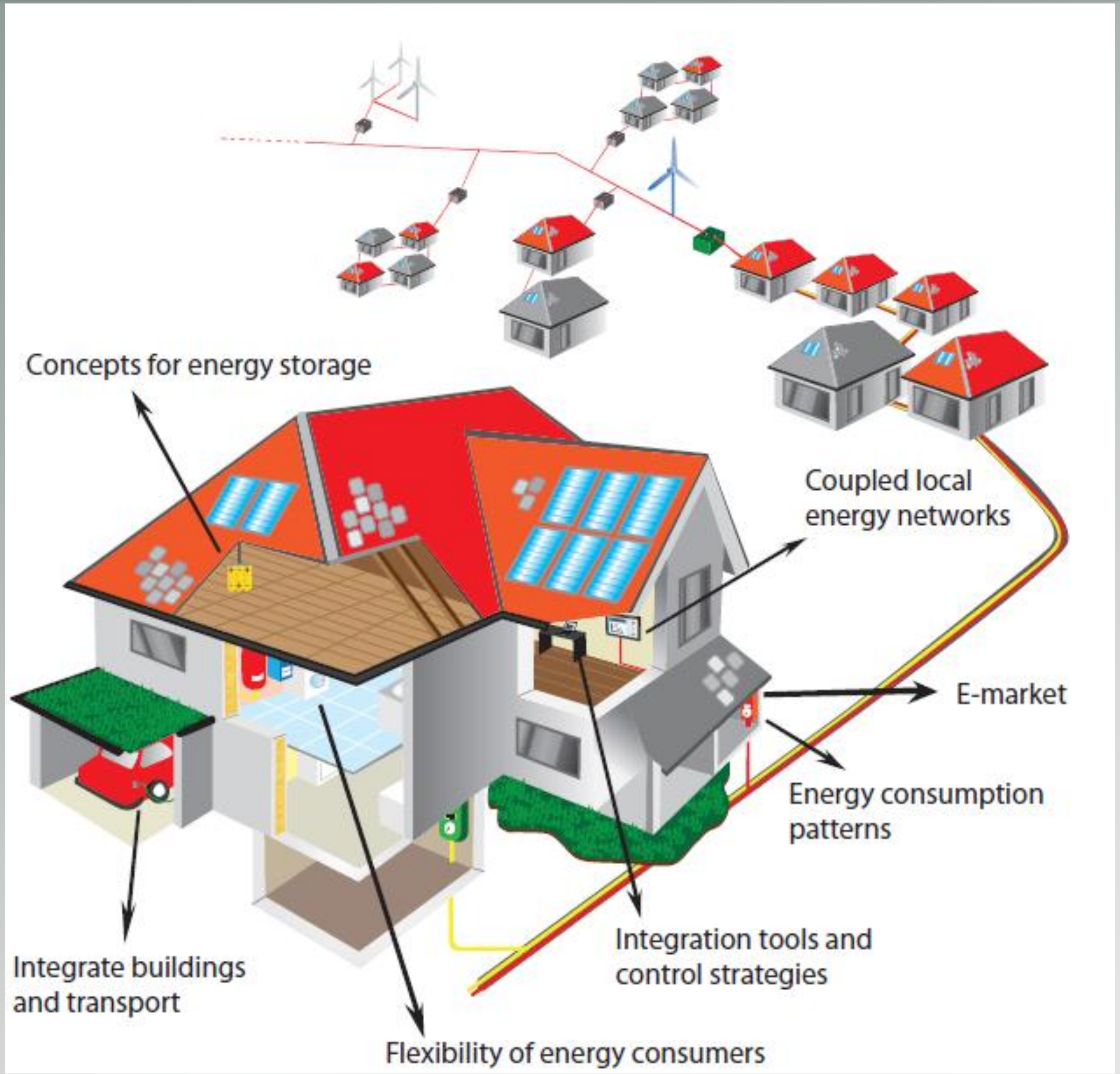


Source: Prospects for Large-Scale energy Storage In Decarbonised Power Grids; IEA; 2009

Source: Electrical Storage Association, www.electricitystorage.org

Source: EPRI, 2008.

DER, storage, networks



Source: KULeuven - ELECTA

Thermal storage

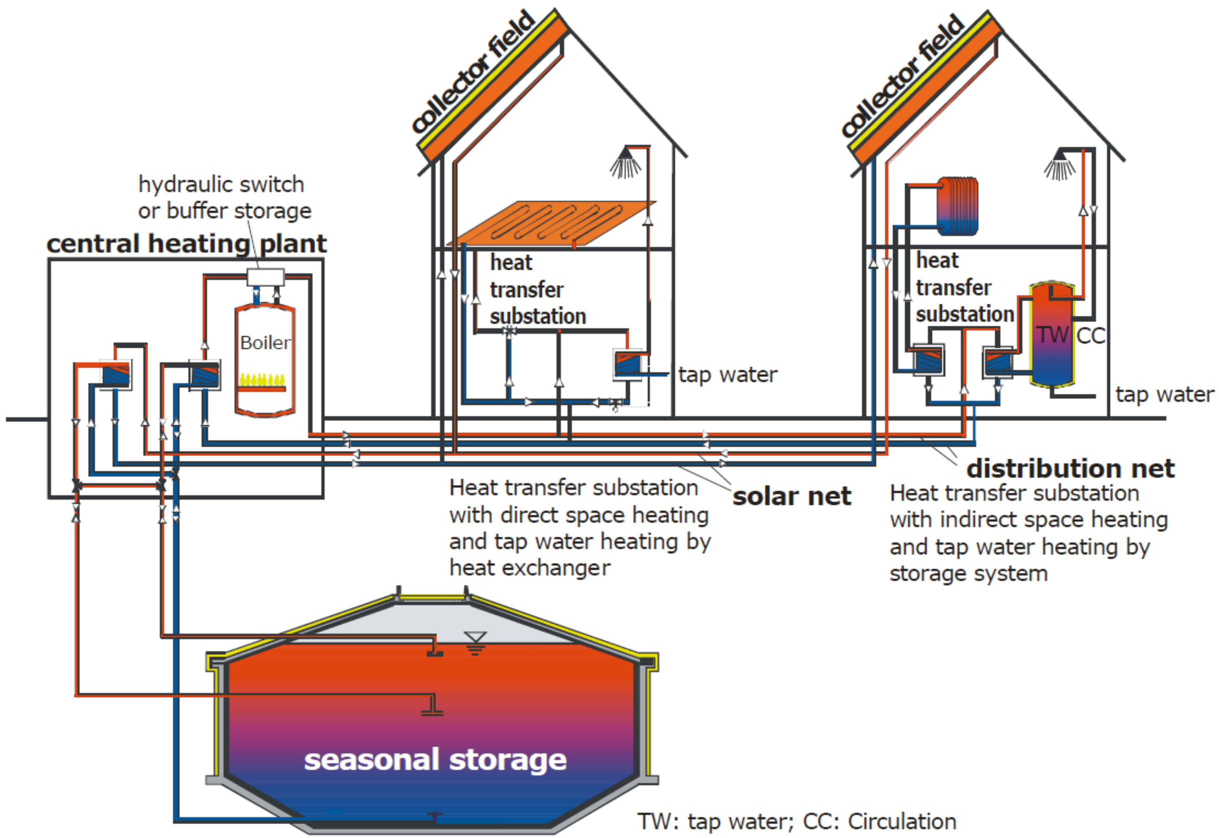


Figure 1: Central solar heating plant with seasonal storage (CSHPSS)

hot-water heat store **gravel-water heat store**

Source: ISES Solar World Congress 2003, Seasonal Thermal Energy Storage In Germany, T. Schmidt, D. Mangold, H. Müller-Steinhagen

Green cities

Source: Lava Architects

Thank you for your attention!

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