Leapfrogging energy system flexibility for integrating high share of renewable electricity

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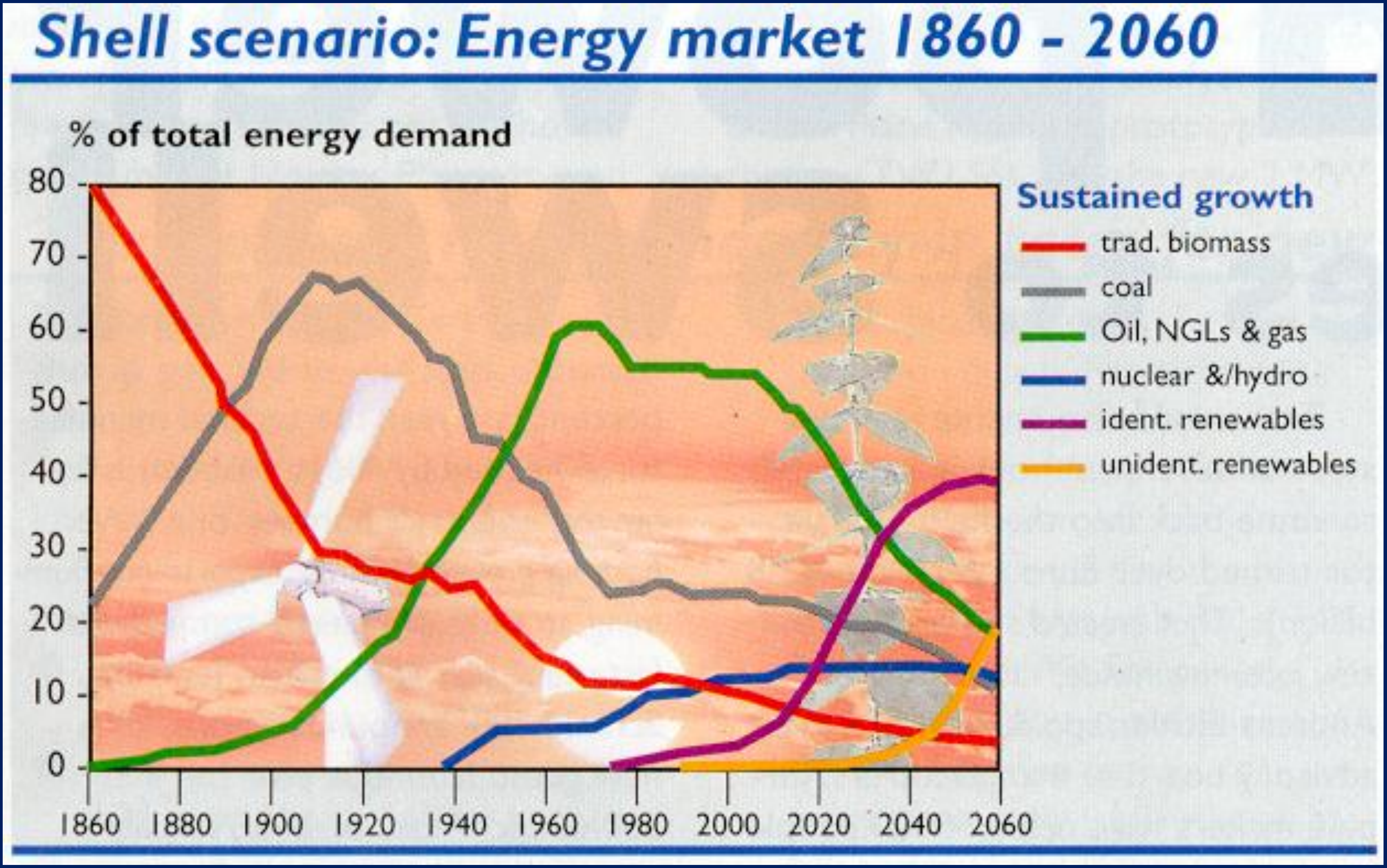
Outline

- Global energy & climate nexus
- Sustainable energy transition
- Energy systems innovations
- Cases on high RE share

Dynamics of the global energy system



The Energy-Climate challenge ahead in simple terms

I. Fossil fuels >80% of energy, oil>98% of traffic

II. Coal (power) and oil (traffic) 80% of CO_2

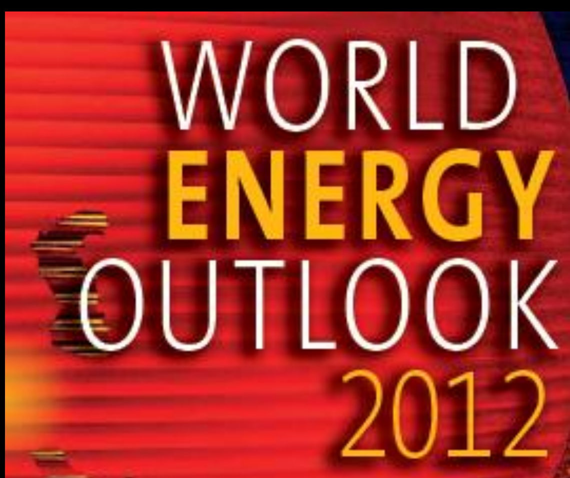
III. Goal: CO_2 down by 60% 2050, >80% in industrialized countries

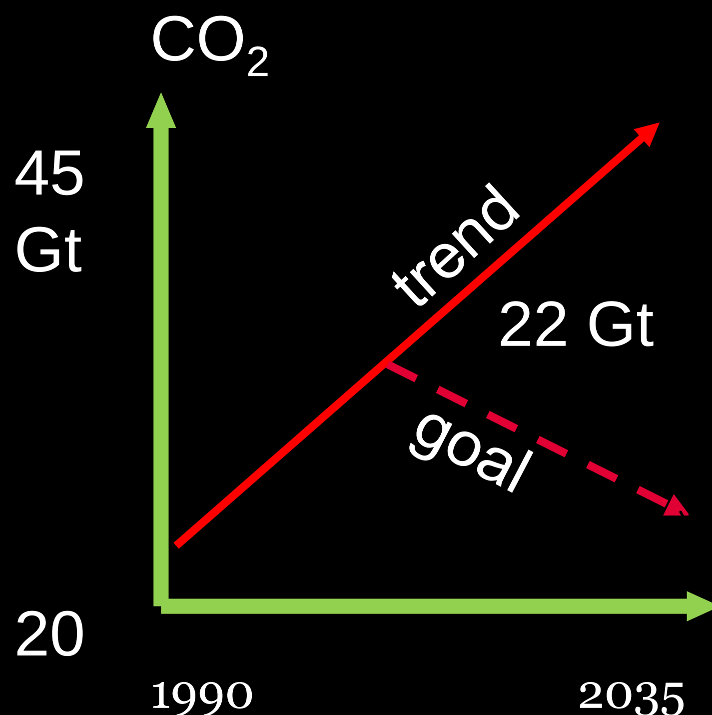
IV. 65% of energy used in cities(80% in2040)

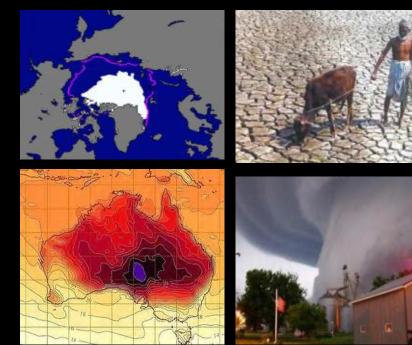
V. Energy issues shifting from industrialized countries to emerging economies, e.g. in Asia

Current trend: New record in human carbon emissions 2012

- **20% of population use 80% of all [energy] resources**
- **1/2 of all people earn less than 2$ a day**







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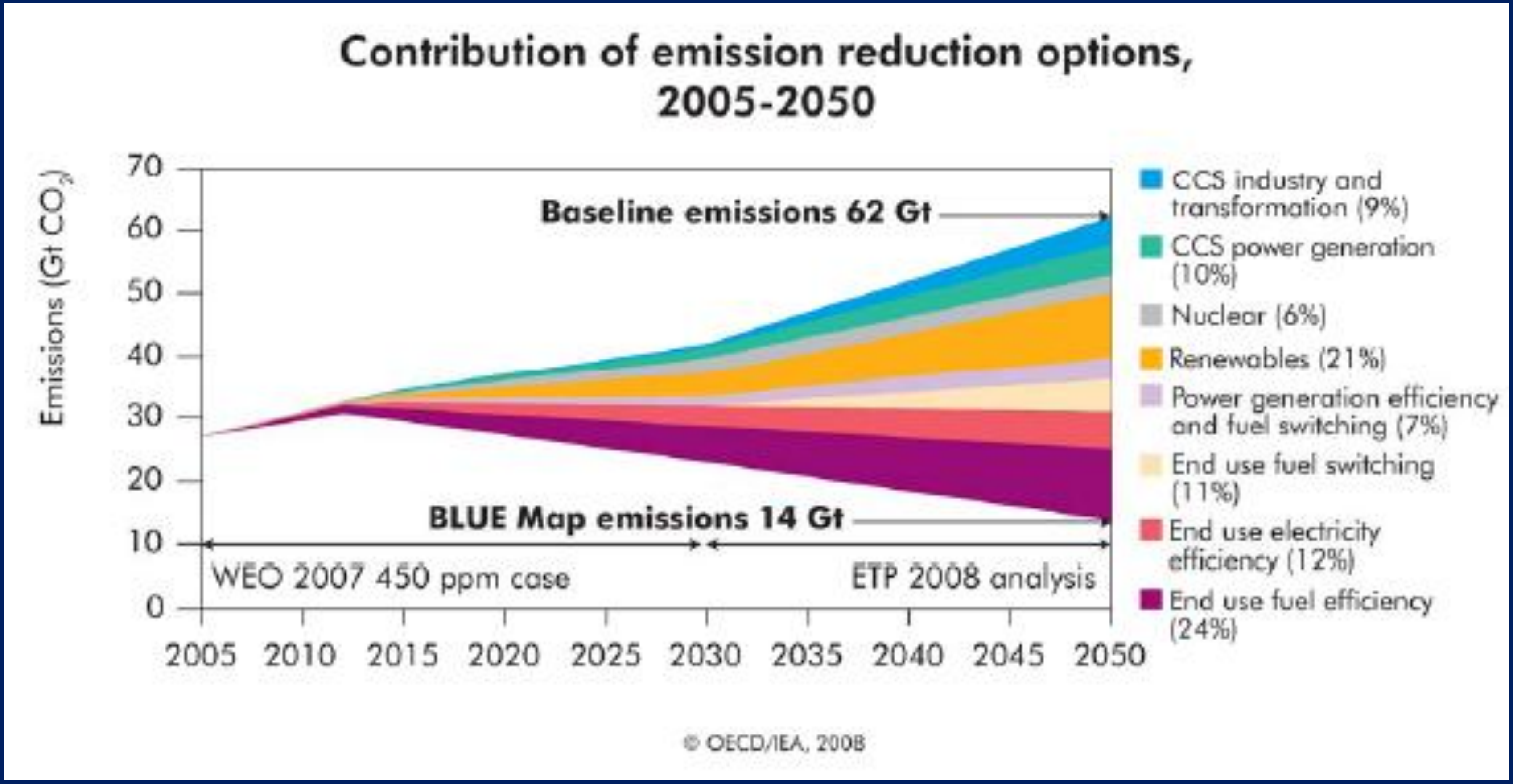
Energy technology options by 2050 (IEA 2008)



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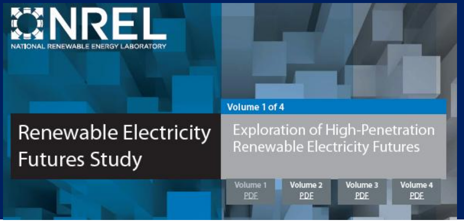
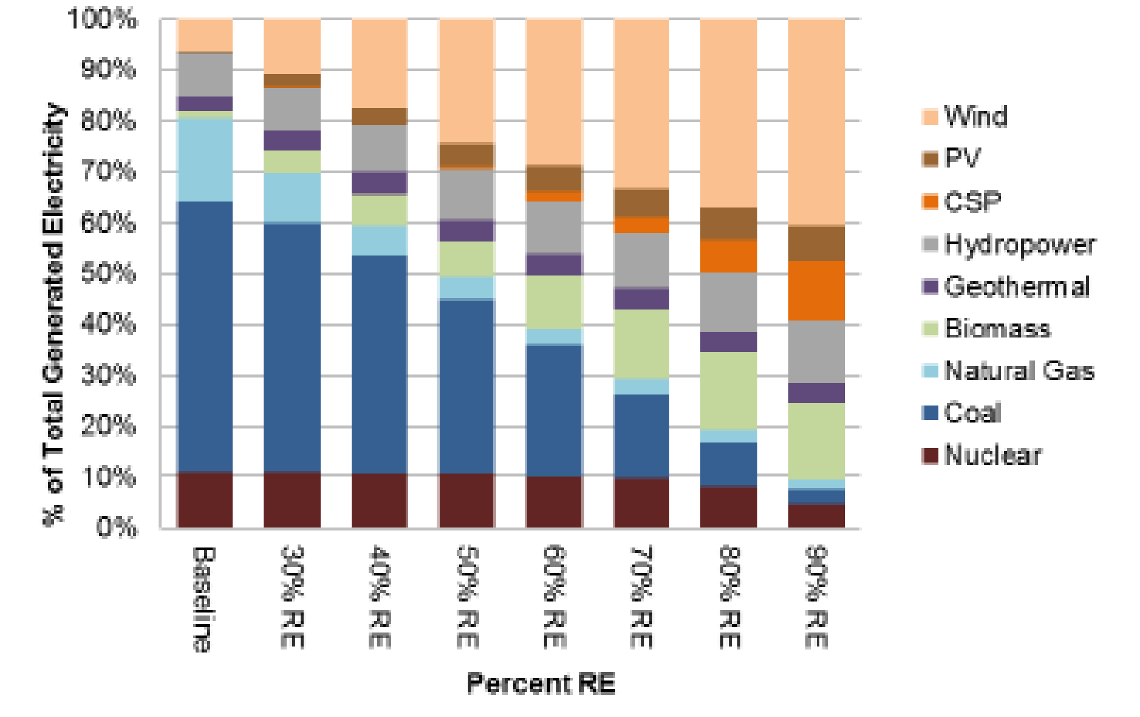
Ref: IEA, Energy Technology Perspectives, 2008

U.S. Renewable Electricity Futures Study (RE Futures)



- **Renewable electricity is more than adequate to supply 80% of U.S. electricity in 2050**;
- Increased electric system flexibility is needed (supply- and demand-side options);
- Multiple combinations of renewable technologies possible.

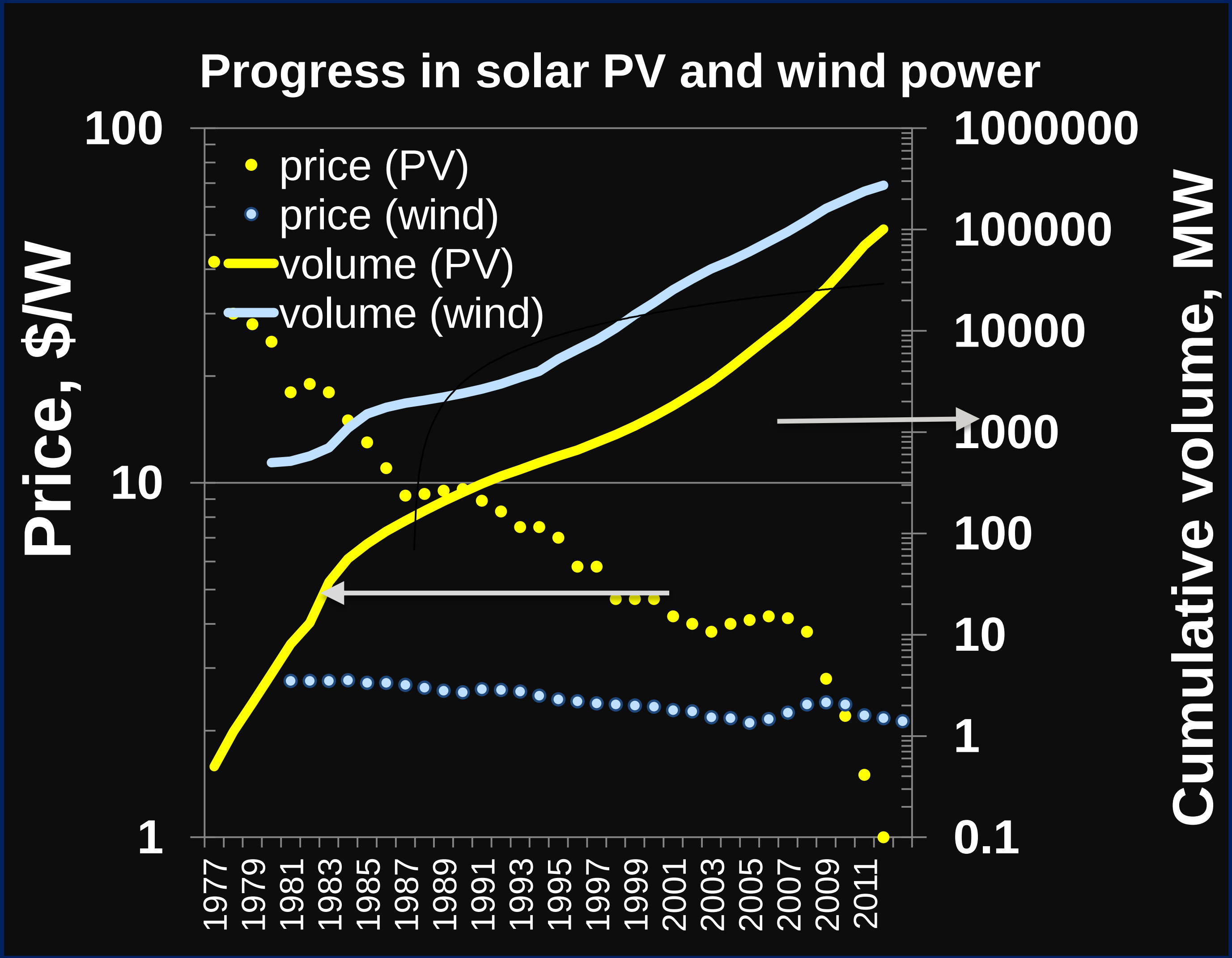


(b) Generation mix in 2050 for the exploratory scenarios

Source: NREL: Exploration of High-Penetration Renewable Electricity Futures, 2012

Trends in new energy

- growing markets and falling prices



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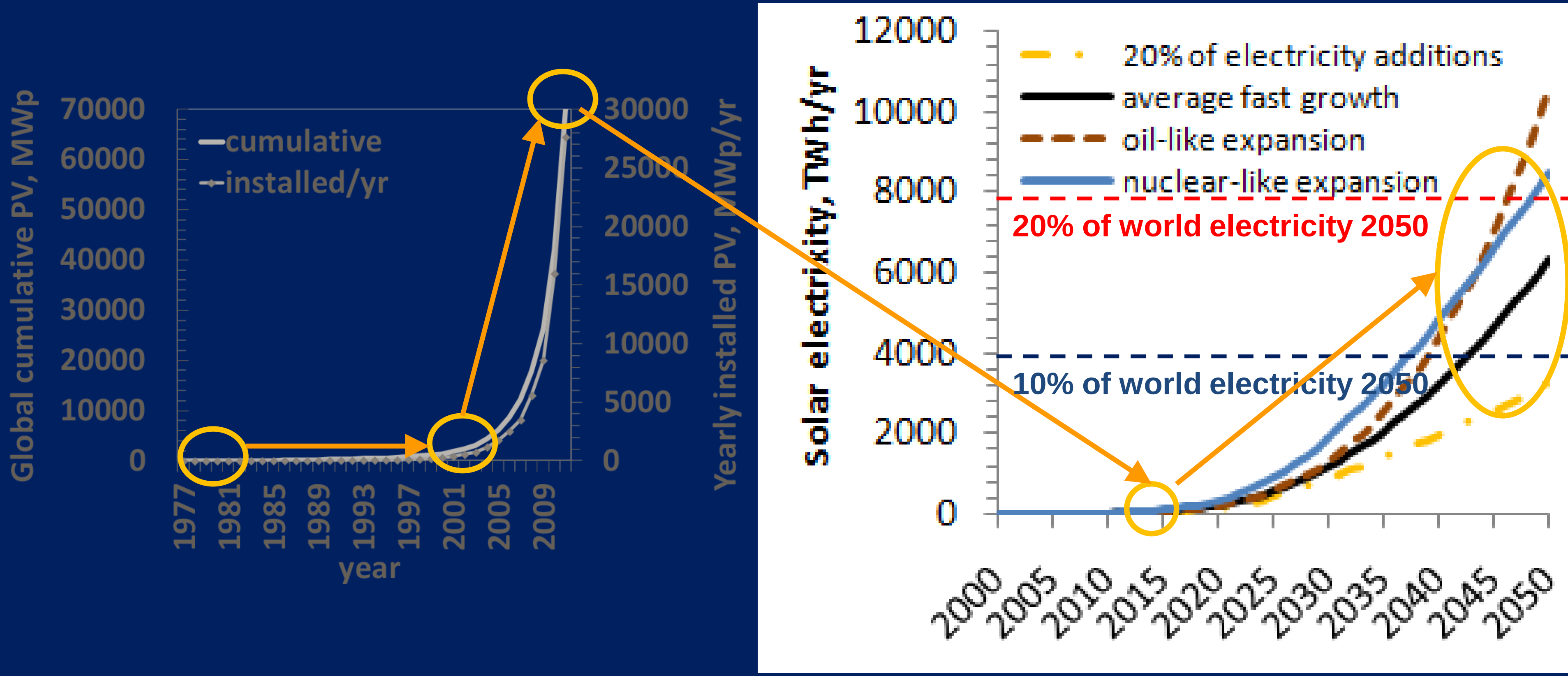
Take-off of Solar PV?

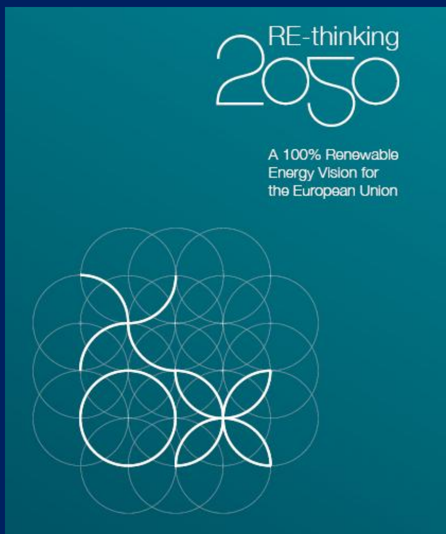
- **PV share of world electricity 2013 < 1%; By 2050: 5% (slowing progress)… 25% (fast-track)**

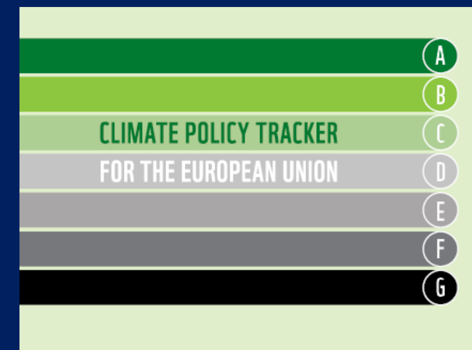


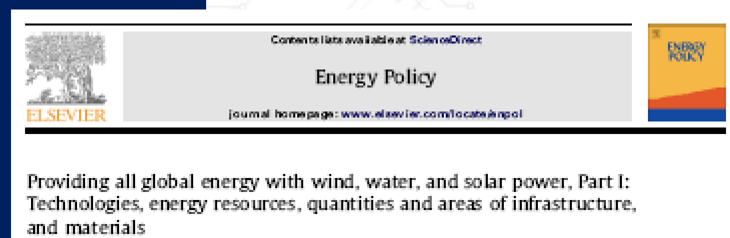
Ref Lund PD. Fast market penetration of energy technologies in retrospect with application to clean energy futures. Applied Energy (2010), doi:10.1016/j.apenergy.2010.05.024; P.D. Lund:Exploring past energy changes and their implications for the pace of penetration of new energy technologies. Energy 35 (2010) 647–656

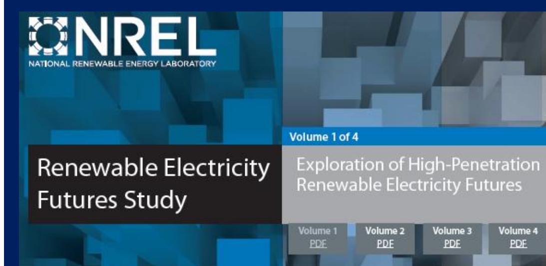
Shifting to sustainable energy

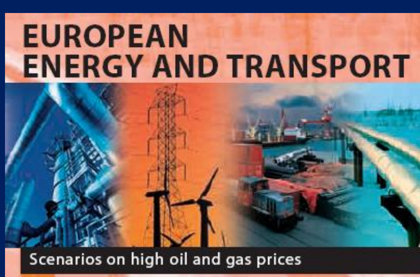
- **Several studies and scenarios indicate high future market shares of renewable energy and electricity**

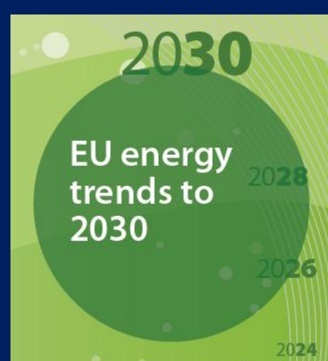






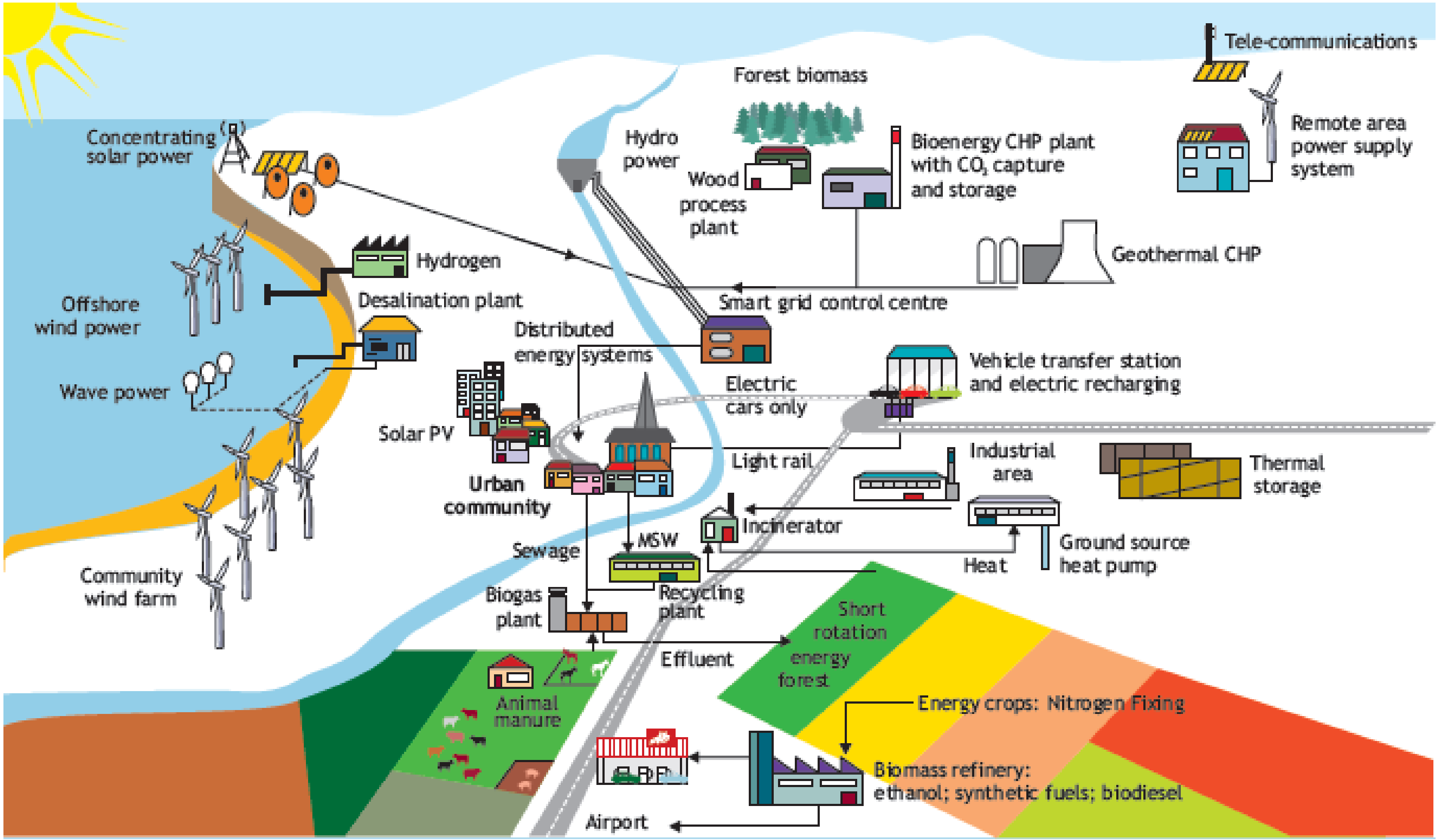




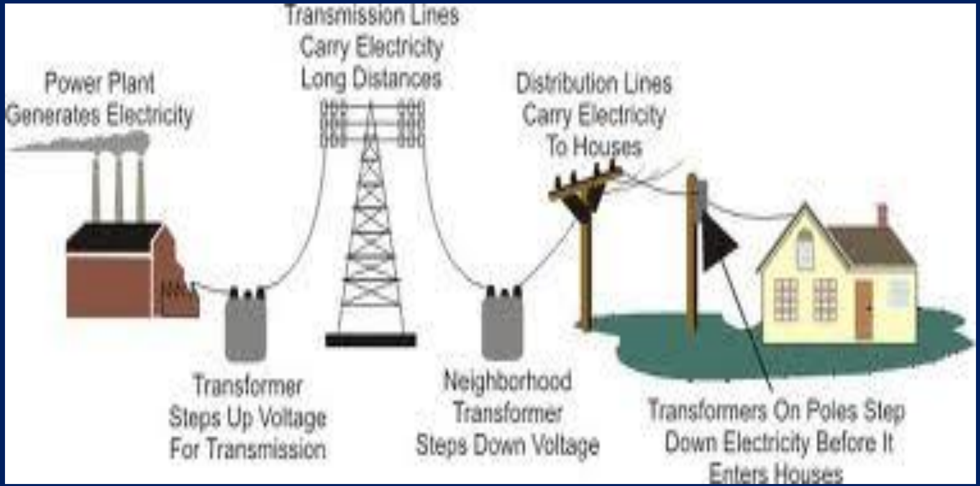


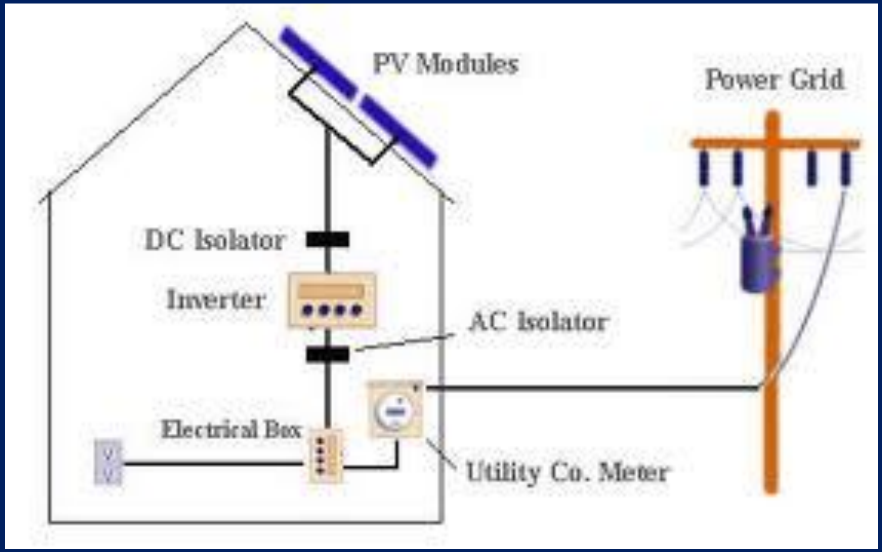
Distributed and renewable energy generation technologies

Figure 3 • *Producing significant shares of heat, power and biofuels from locally available resources including solar, wind, ocean, geothermal, energy crops and biomass from wastes, could be a future option for a municipality*

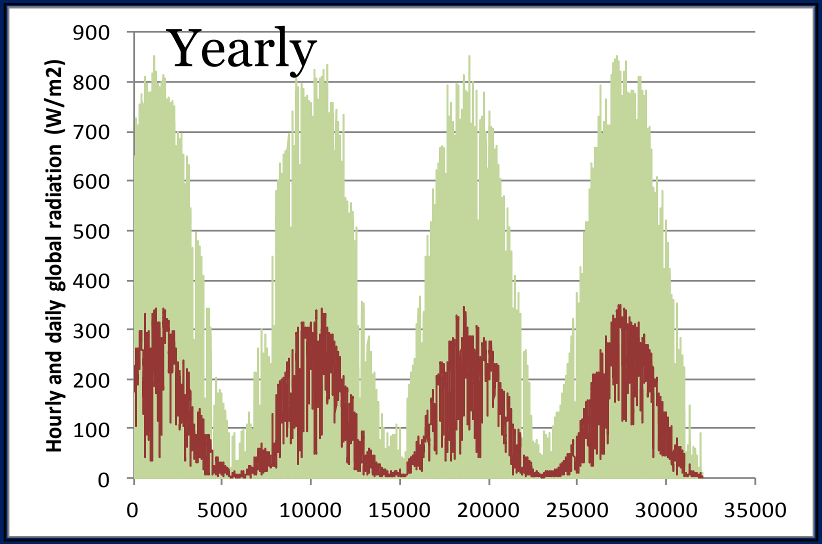


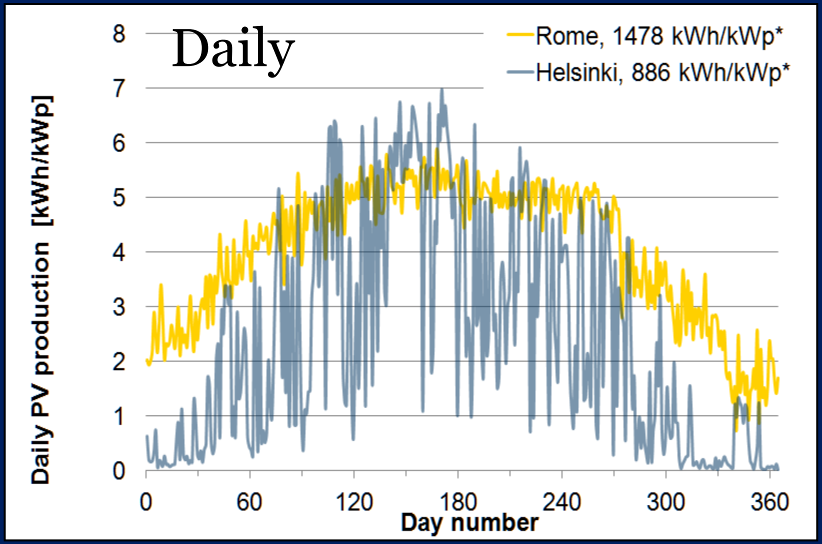
Distributed power topology

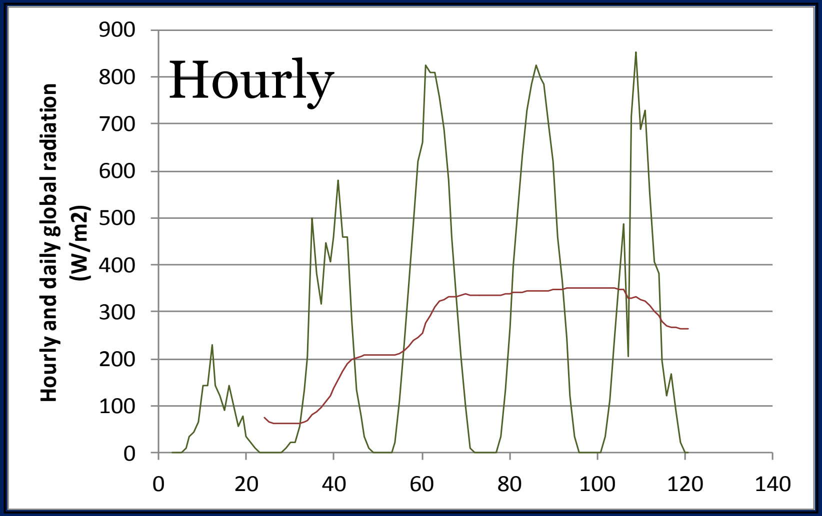


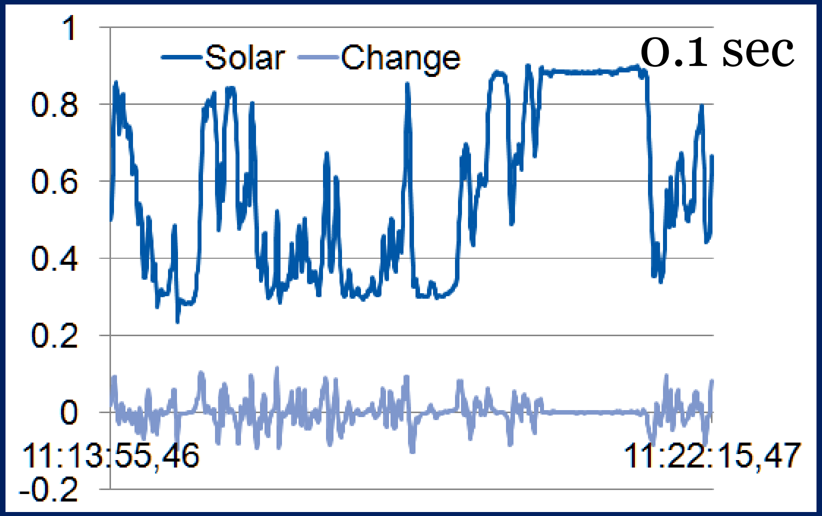


RE (PV) resource variability on different time scales



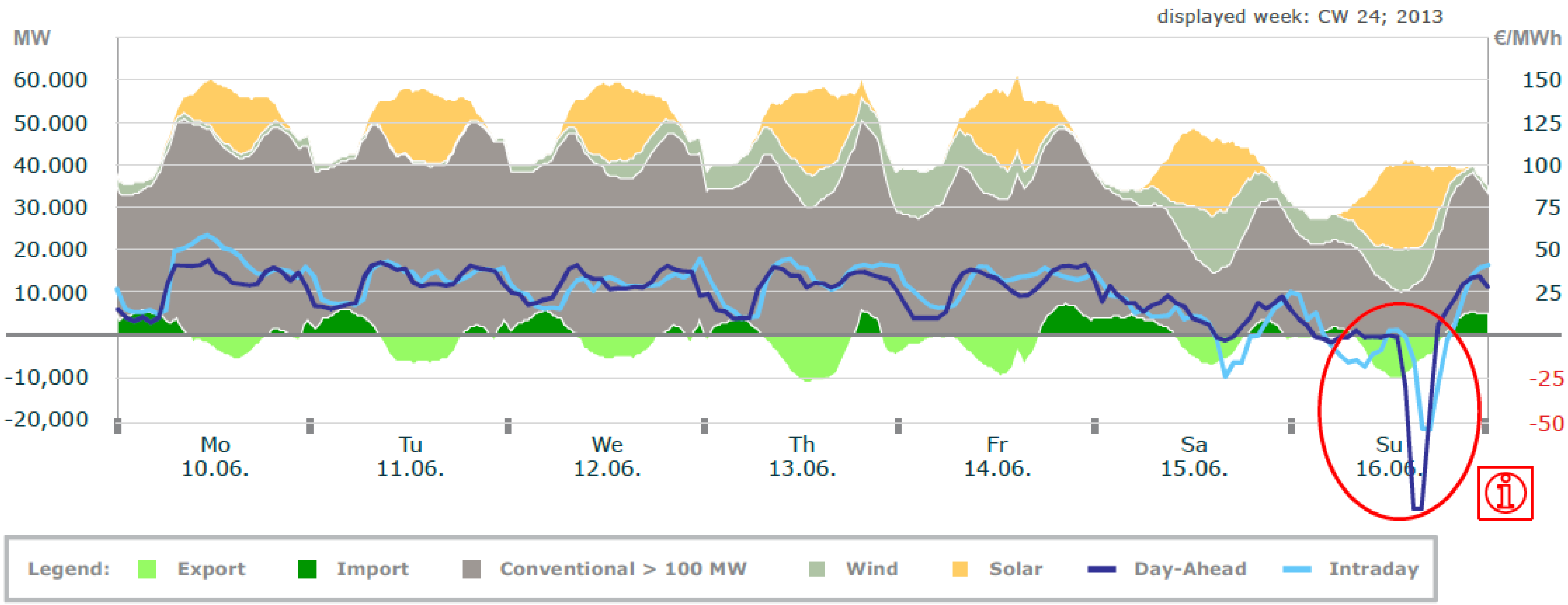






Temporal market effects from large-scale RE (Germany)

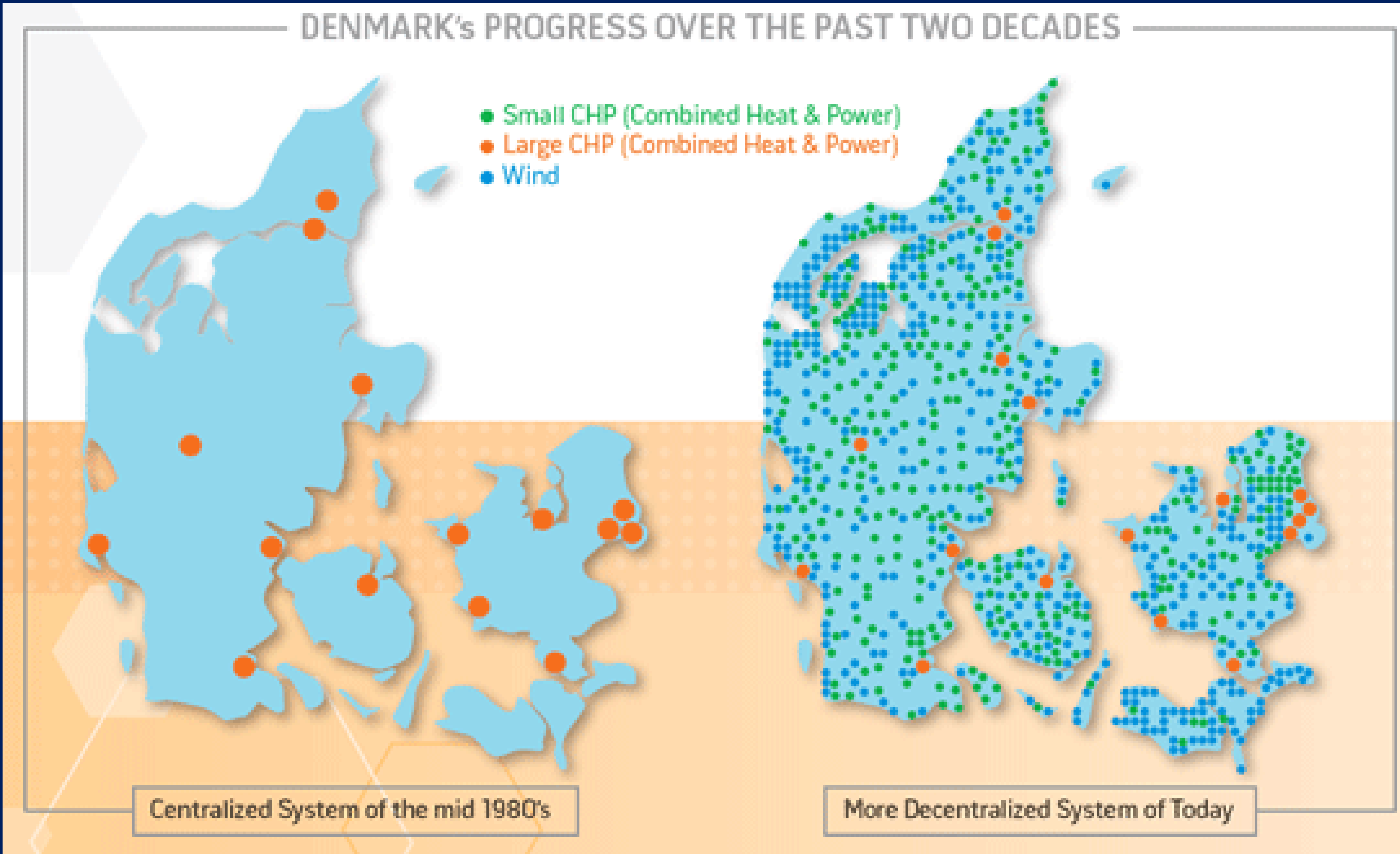
Electricity Production and Spot-Prices: CW 24 2013



€ / MWh	Period Mean	Period Min	Period Max	Std Deviation
Day-Ahead	**23.28**	**- 100.00**	**45.00**	**19.72**
Intraday	**26.95**	**- 53.50**	**59.50**	**18.99**

Source: Johannes Mayer, Bruno Burger, Fraunhofer Institute for Solar Energy Systems; Data: EEX, Entso-e

Spatial effects from RE schemes



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Large-scale RE schemes require systemic bridging innovations

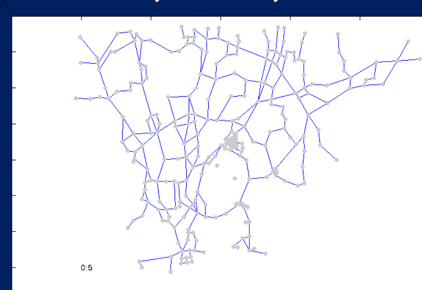
Old 100%

New 0%

•Multi-energy networks
• Flexible demand
• EV,ICT

How does the energy system work with much renewable energy?

• Storage
• E2T,V2G,E2Gas



New 100%

Old 0%

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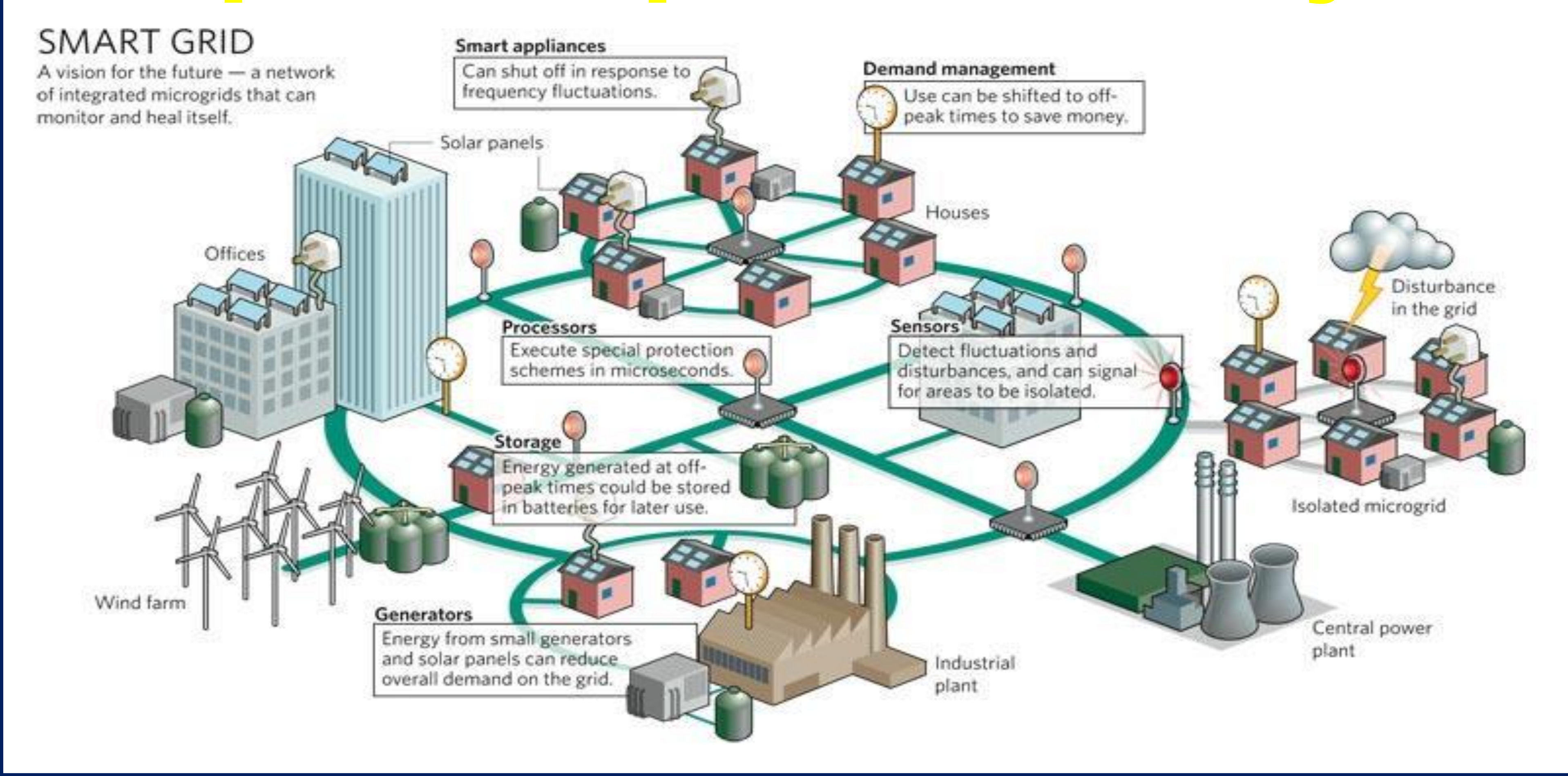
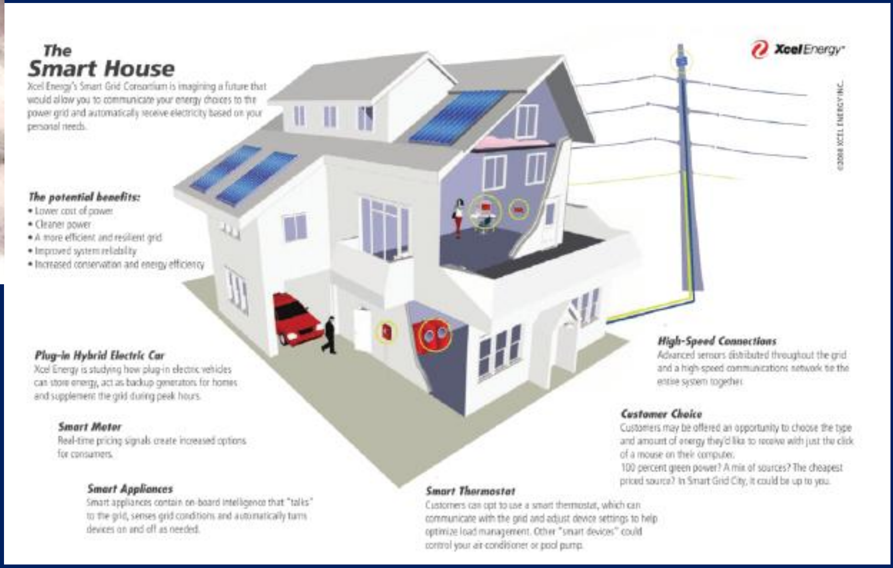
Smart infrastructures provide spatiotemporal flexibility



Smart built environment provide spatiotemporal flexibility



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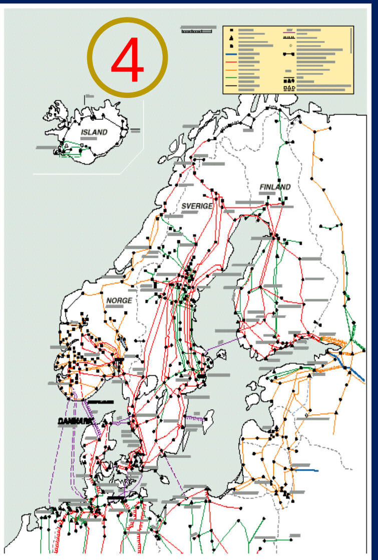
Energy systems perspective to high-shares of RE power

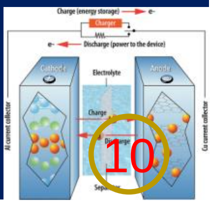
Q1: matching supply and demand of electricity with RE sources

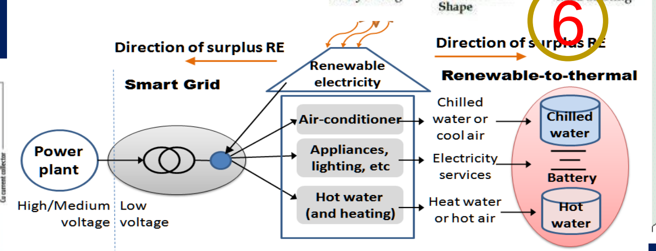
Q2: integrating distributed RE power into the energy system

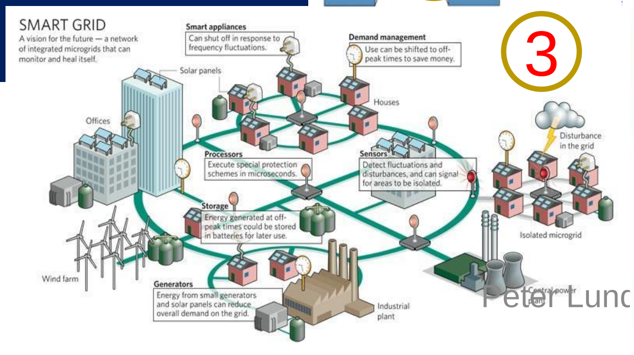
Examples of solutions:

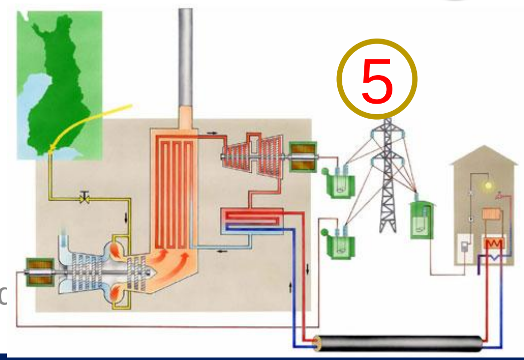
1. RE in urban context
2. Grid infrastructures
3. Smart Grids
4. Electricity markets
5. Co-generation (CHP)
6. RE coupled with end-use
7. Electricity-to-Gas
8. RE+Gas integration
9. Demand flexibility
10. Storage

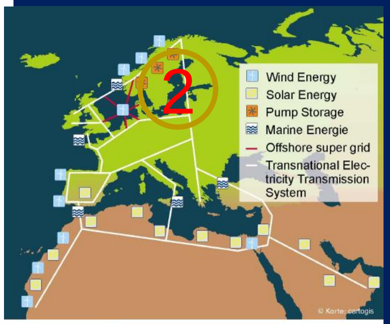












Potential of green generation for Europe determining the future transmission needs.
Source: Fraunhofer-Institut für Windenergie und Energiesystemtechnik (IWES).

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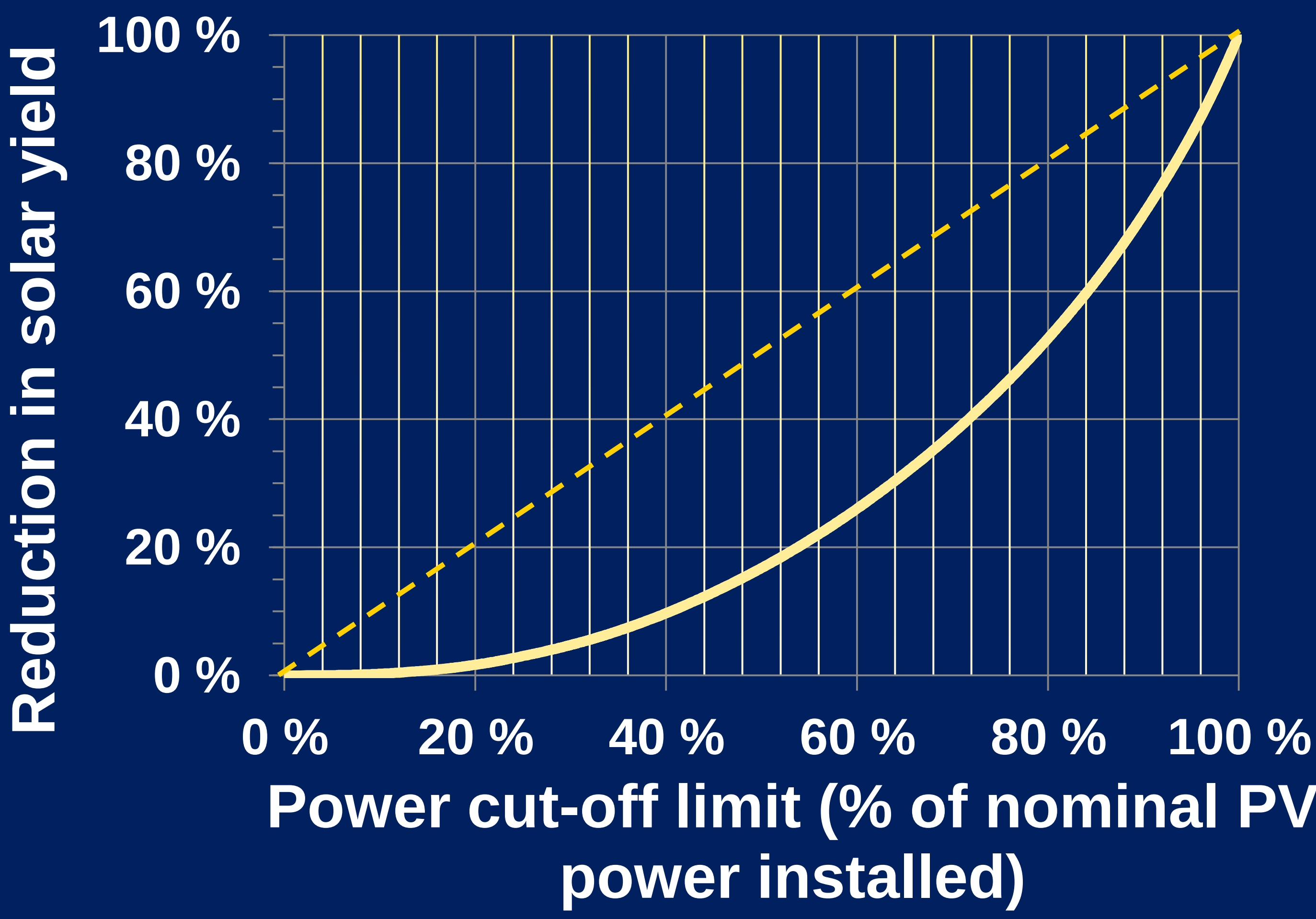
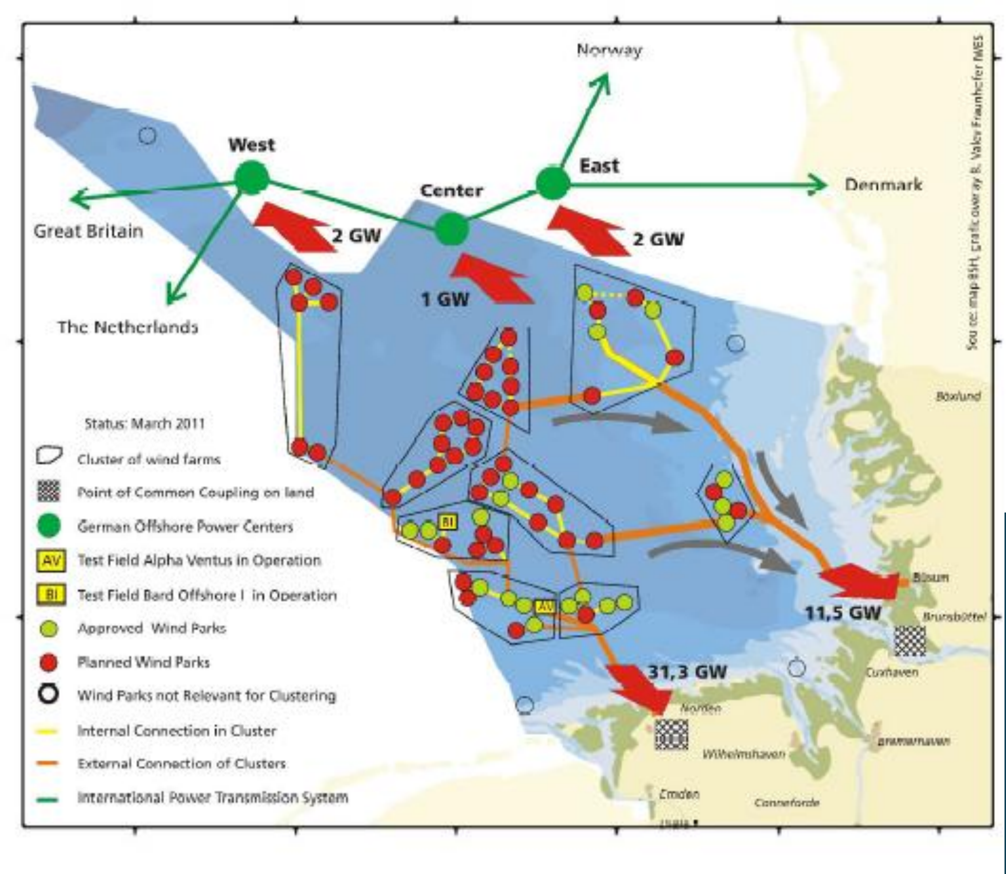
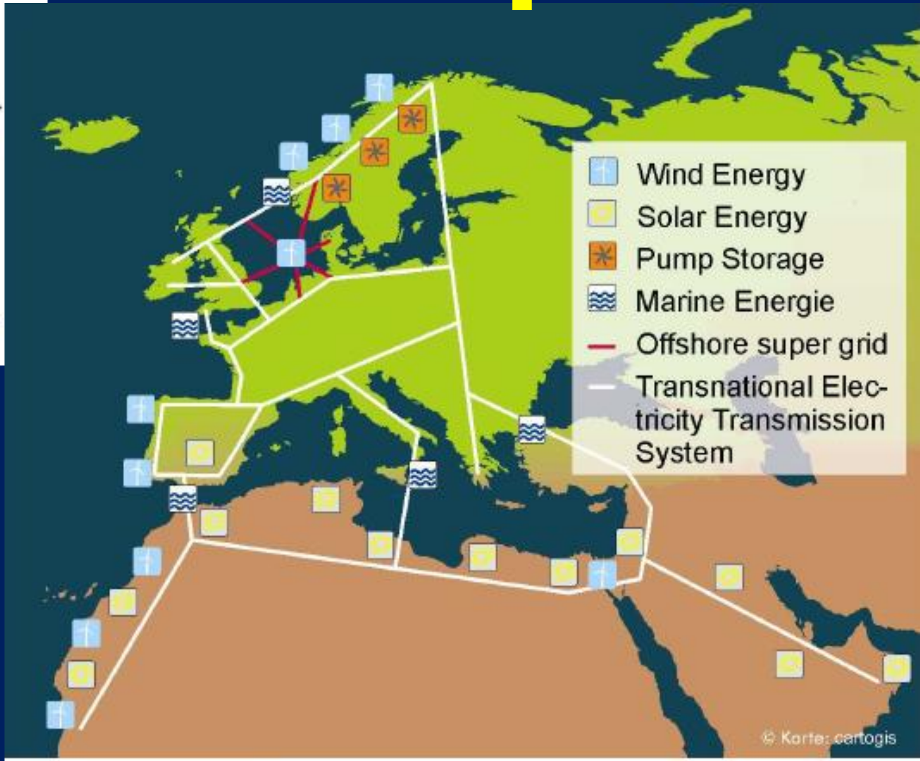
Simple control of large-amounts of RE:

Ex. Curtailing PV power



Examples of grid extension plans in Europe

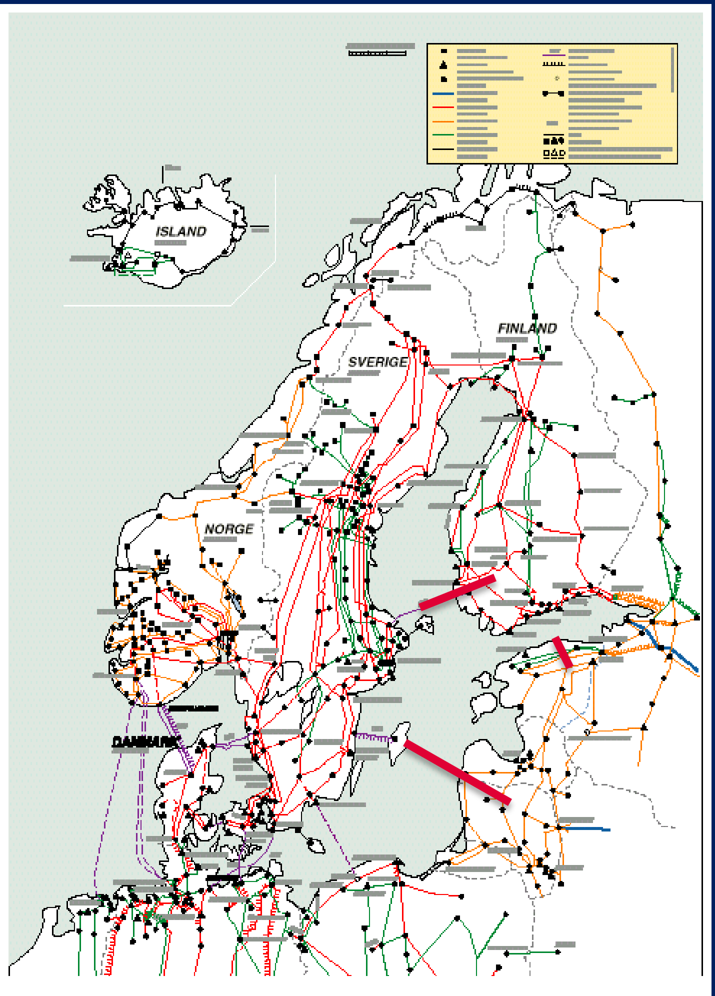




Potential of green generation for Europe determining the future transmission needs. Source: Fraunhofer-Institut für Windenergie und Energiesystemtechnik (IWES).

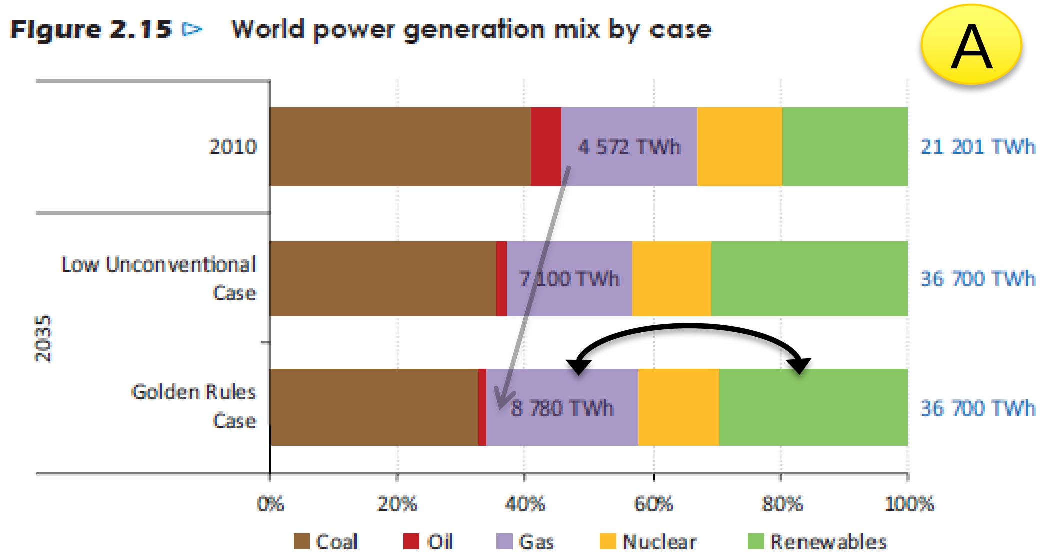
Integrated electricity market

– a Nordic system innovation for large-scale use variable renewables



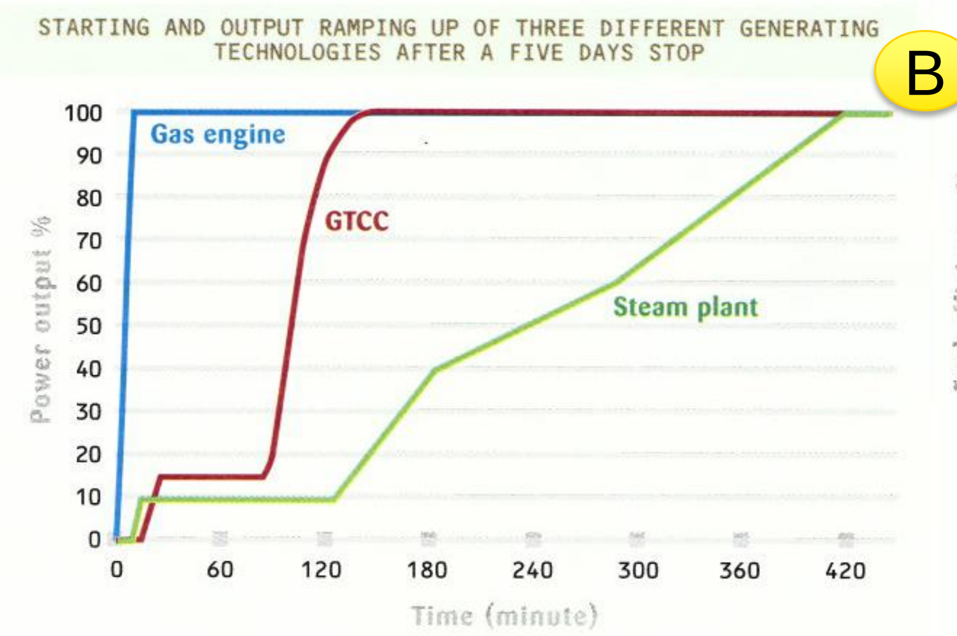
- Nordic electricity market has a common power reserve which can be accessed through the power exchange
- How much wind power is possible without major reserve power increase?
  - **If wind 10% of all electricity → extra cost for reserve power is 1 €/MWh**
  - **If 20%→ 1-7 €/MWh** (source: H.Holttinen, VTT)
- Vision: 20-25 % of all Nordic electricity wind power by 2030; Norwegian hydropower buffers

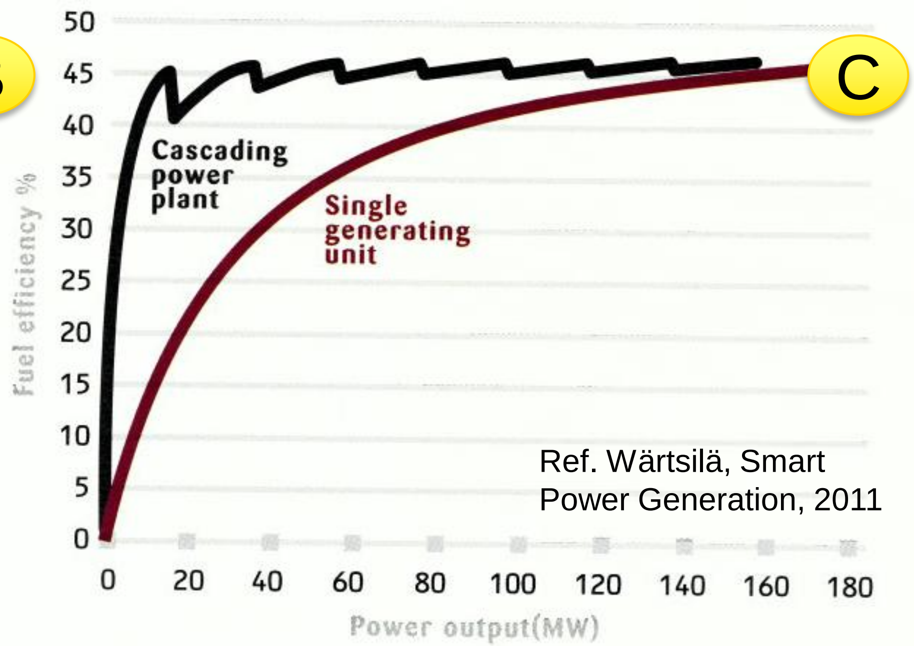
RE&Gas: better power plant flexibility



Note: TWh = terawatt-hours.

Ref. IEA, Golden Rules for a Golden Age of Gas

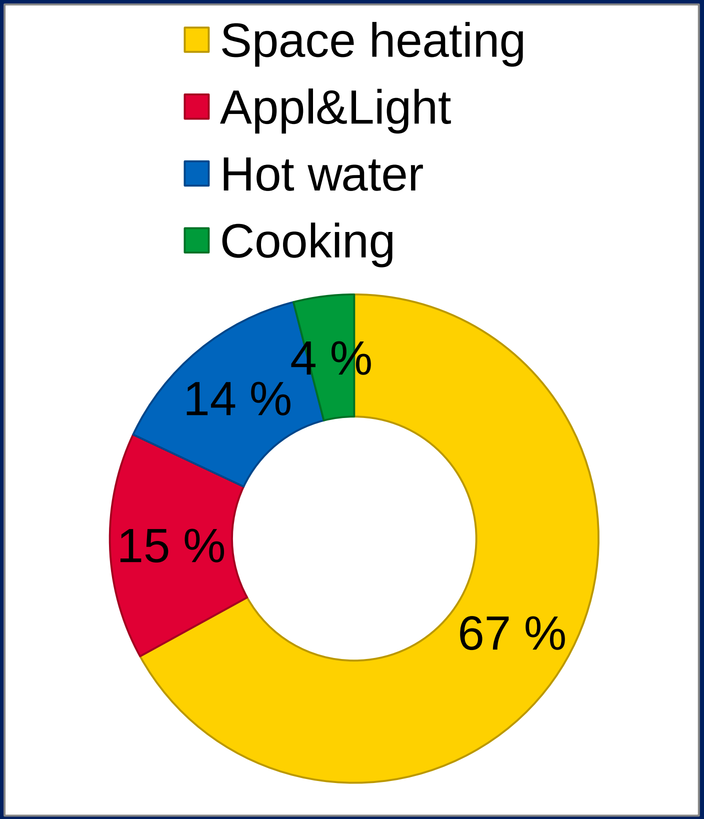


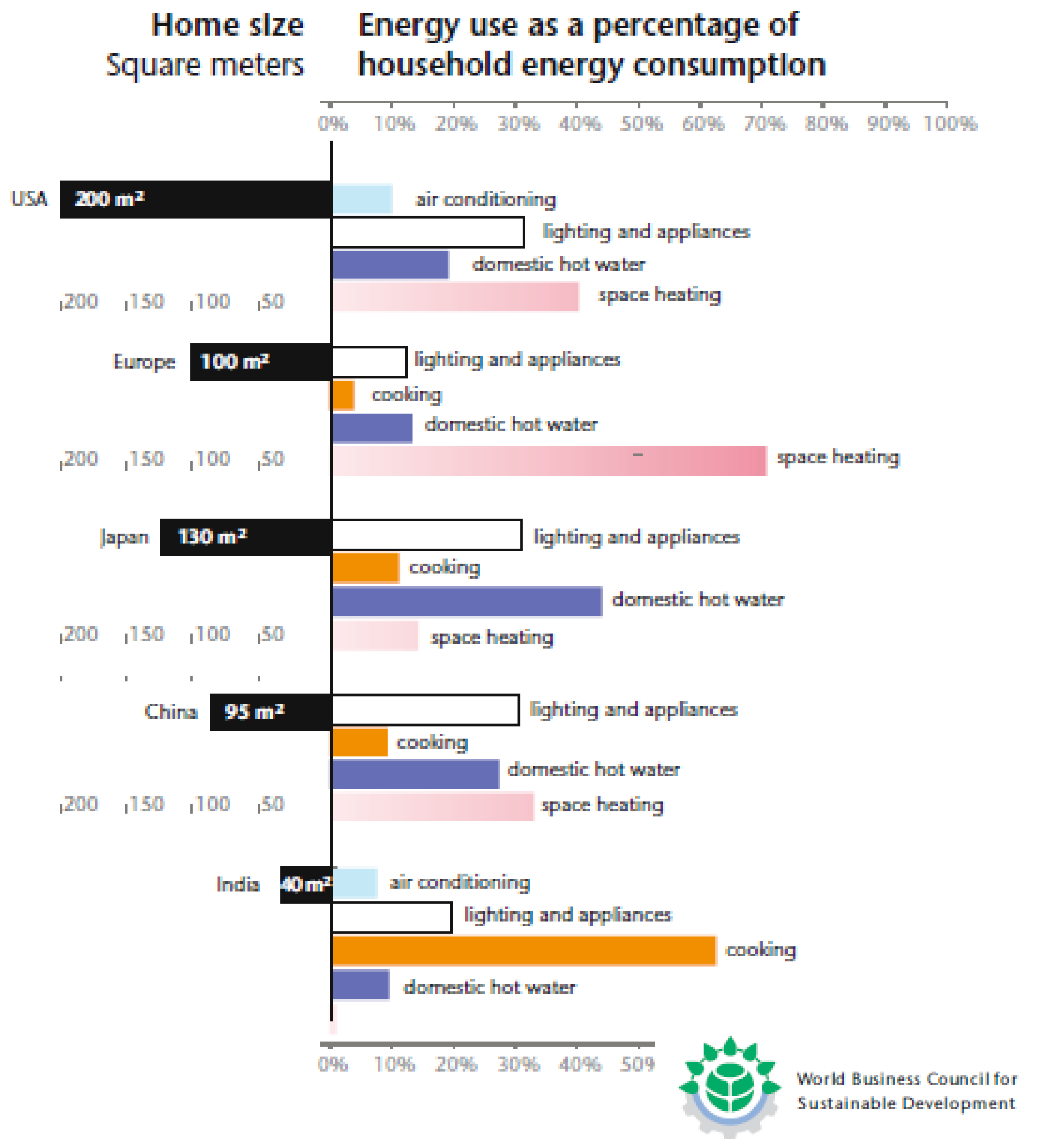


Ref. Wärtsilä, Smart Power Generation, 2011

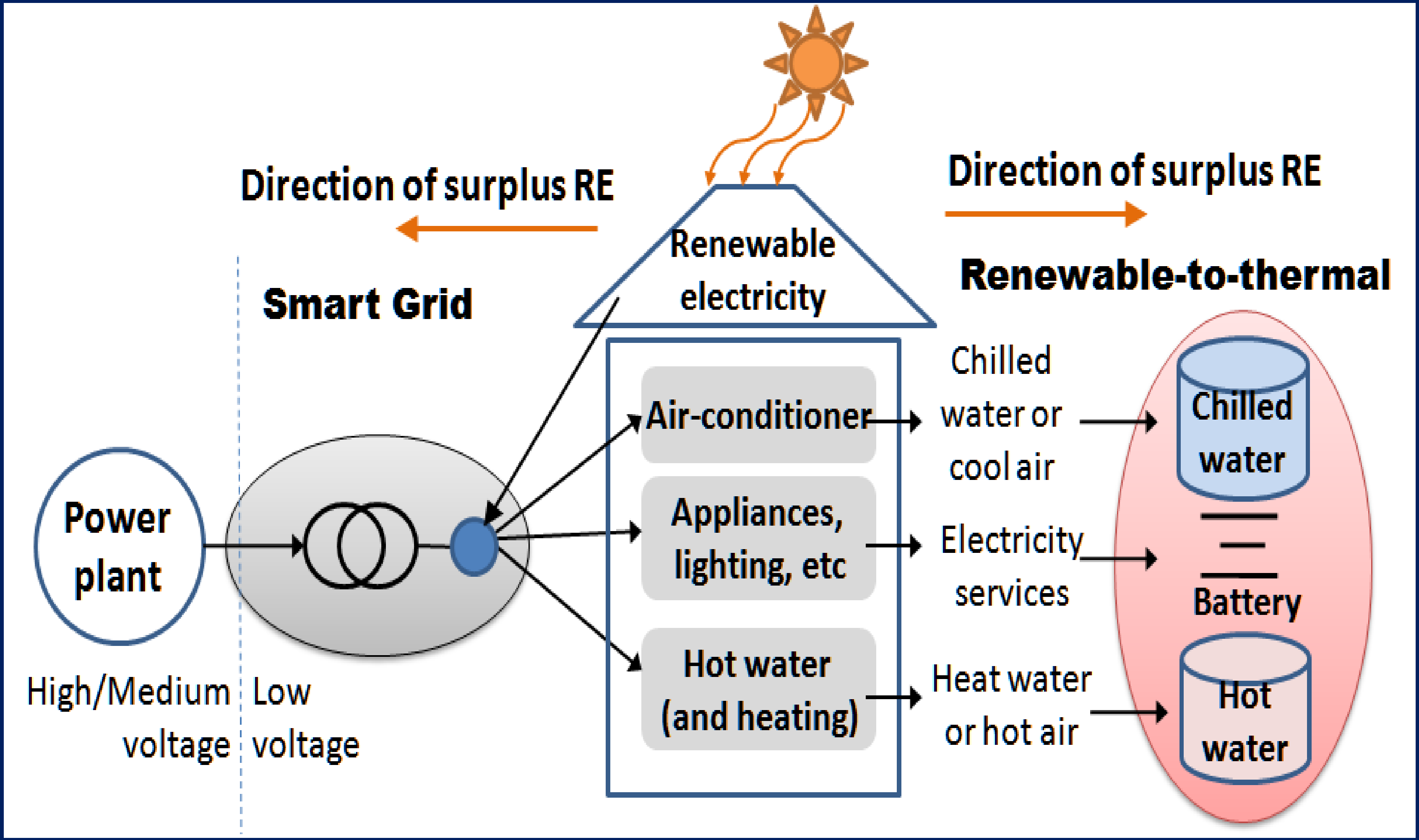
Final energy in urban environment
– thermal energy forms dominate end-use side

- Final energy use forms in buildings: heating, cooling, electricity
- EU-27household energy:





Electricity-to-thermal conversion of surplus renewable electricity



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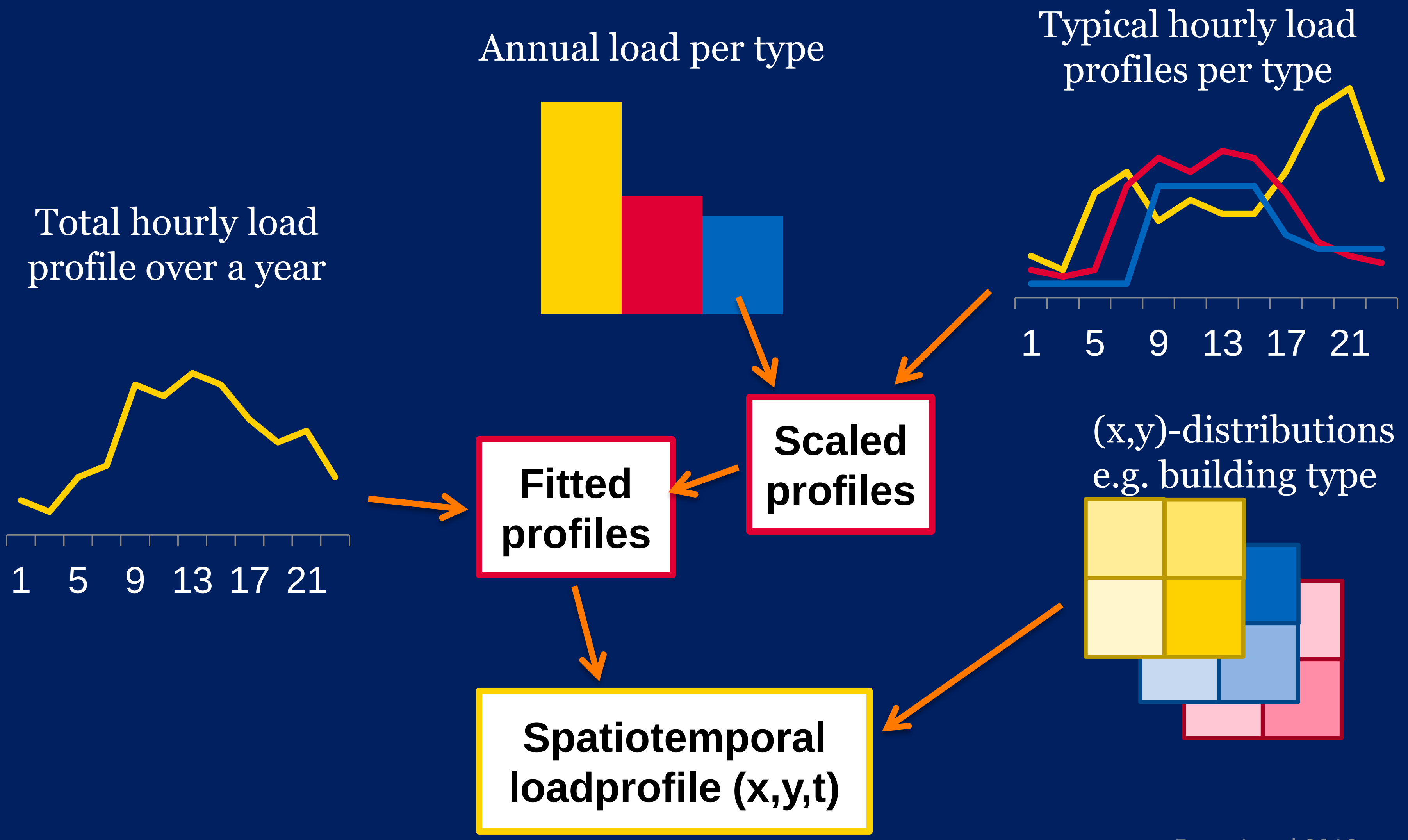
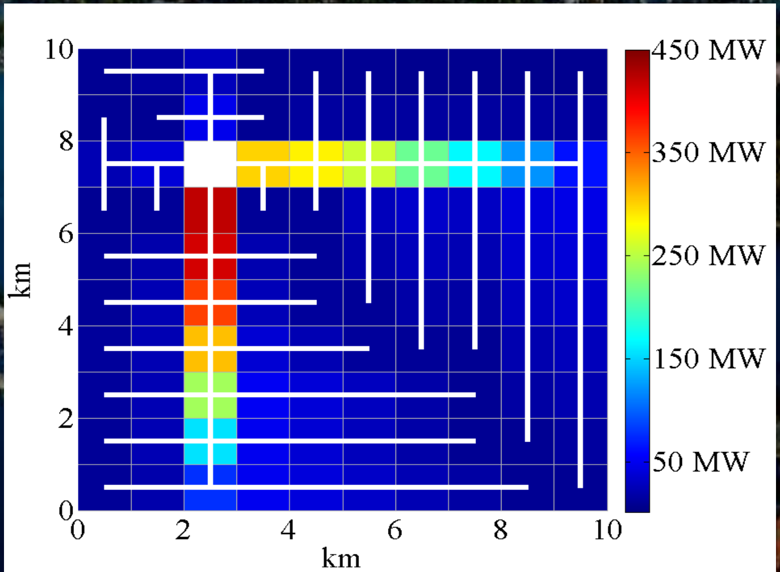
How much wind power could be utilized in Helsinki?

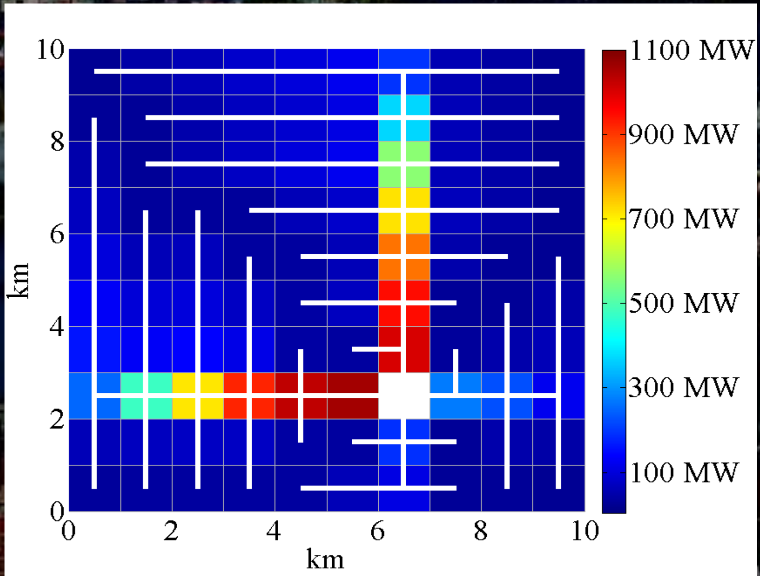
Picture: Helsinki Energy Annual Report 2010

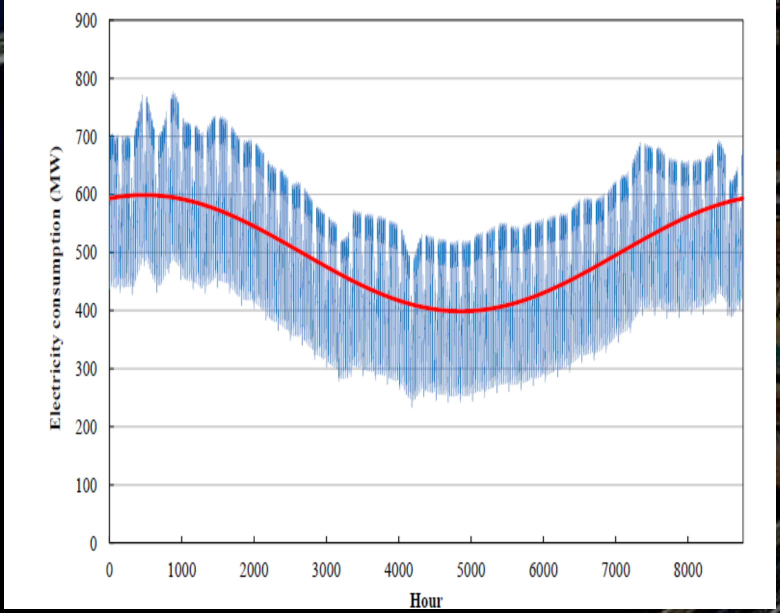
Generating spatiotemporal (load) profiles (x,y,t)

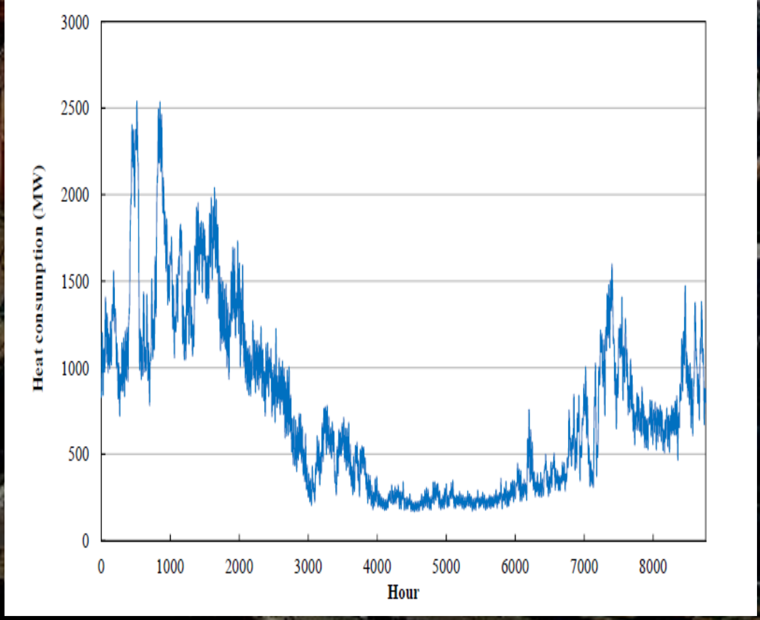


Electric (left) and District Heating Networks and Loads (right) in Helsinki



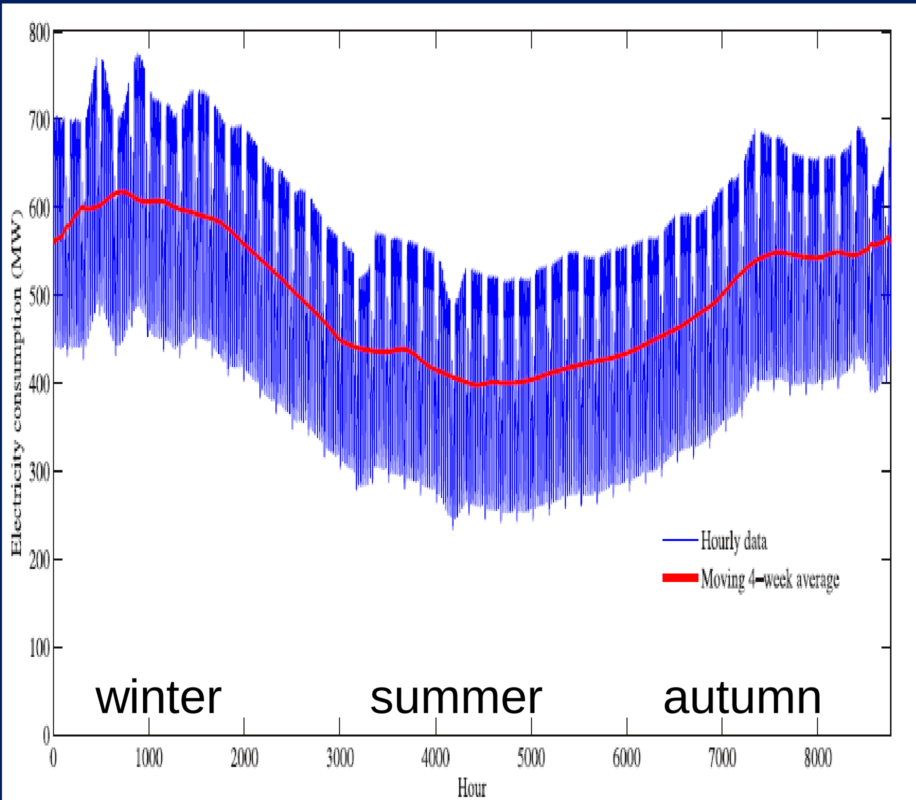




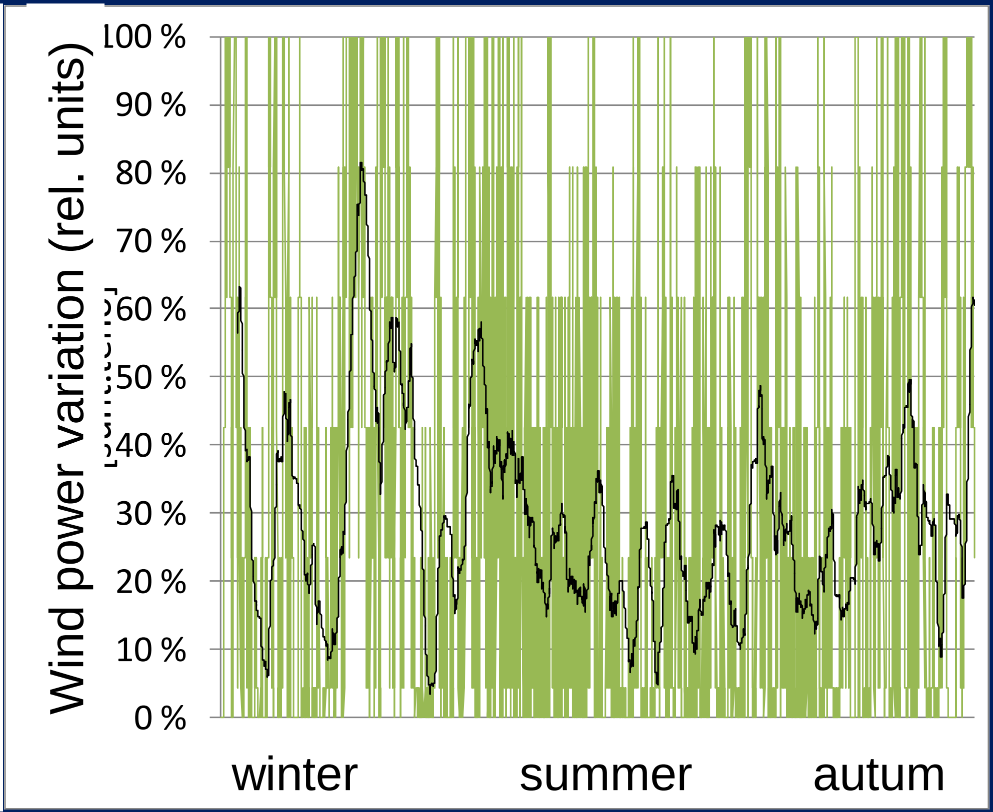


Matching power demand and supply – each hour of the year!

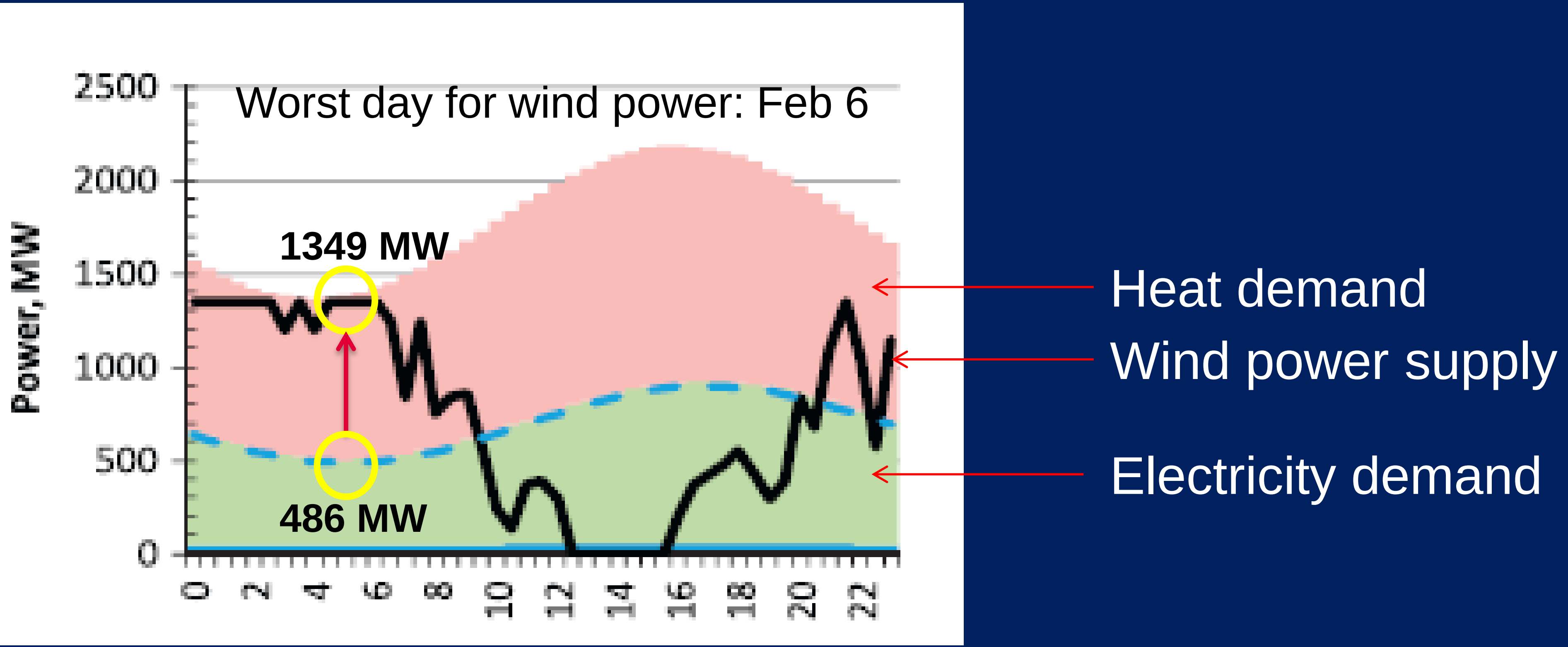
Helsinki power demand



Wind power production



How does wind power match demand?

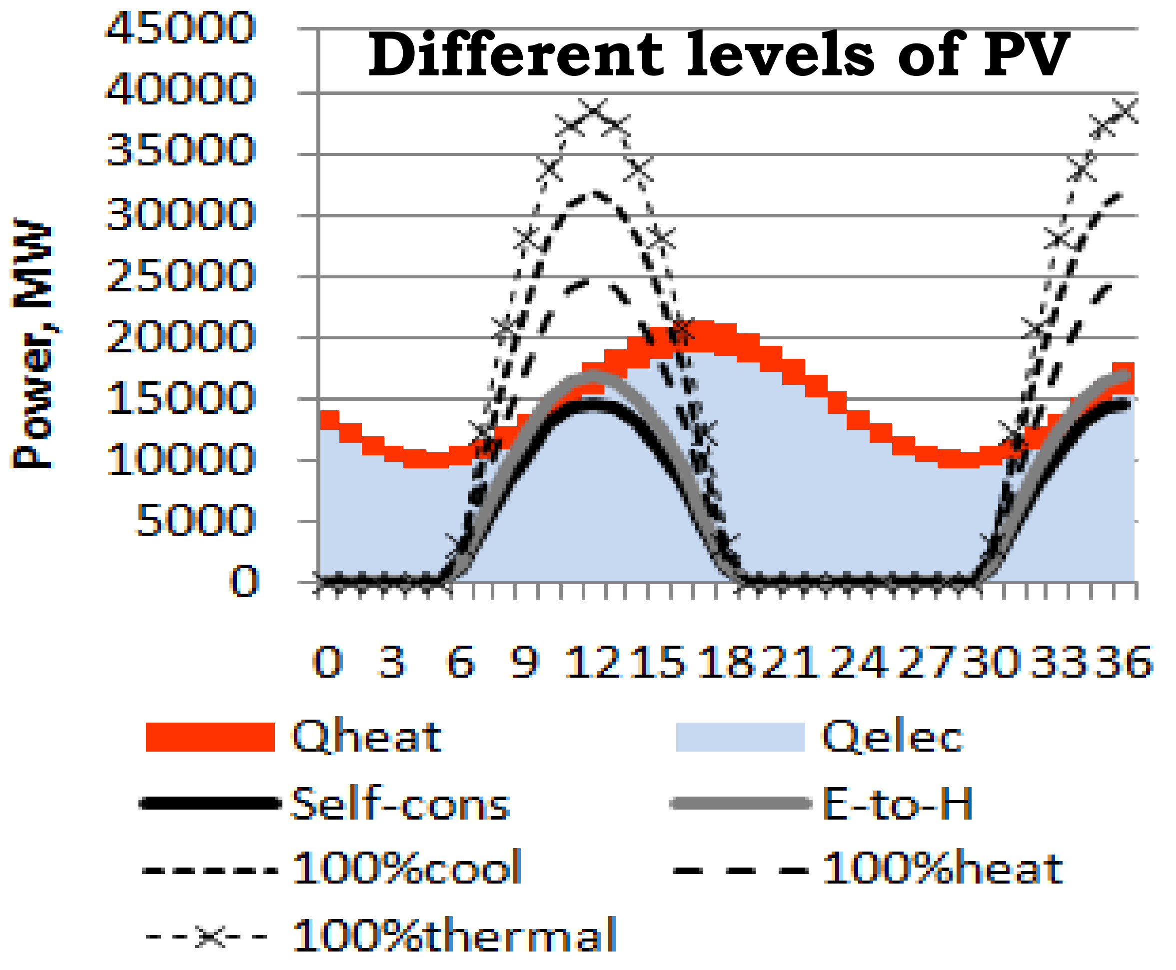


Wind = power demand → **486 MW** wind power
= **25%** of yearly electricity in Helsinki

Wind = power and heat demand →**1349 MW** wind power
= **71%** of electricity per year (2% of heat)

Ref: Lund, P. : Large-scale urban renewable electricity schemes - integration and interfacing aspects. Energy Conversion and Management, 2012
Ref: R. Niemi, J. Mikkola, P.D. Lund: Urban energy systems with smart multi-carrier energy networks and renewable energy generation. Renewable Energy, 2012.

Mismatch between PV and electricity demand – case Shanghai



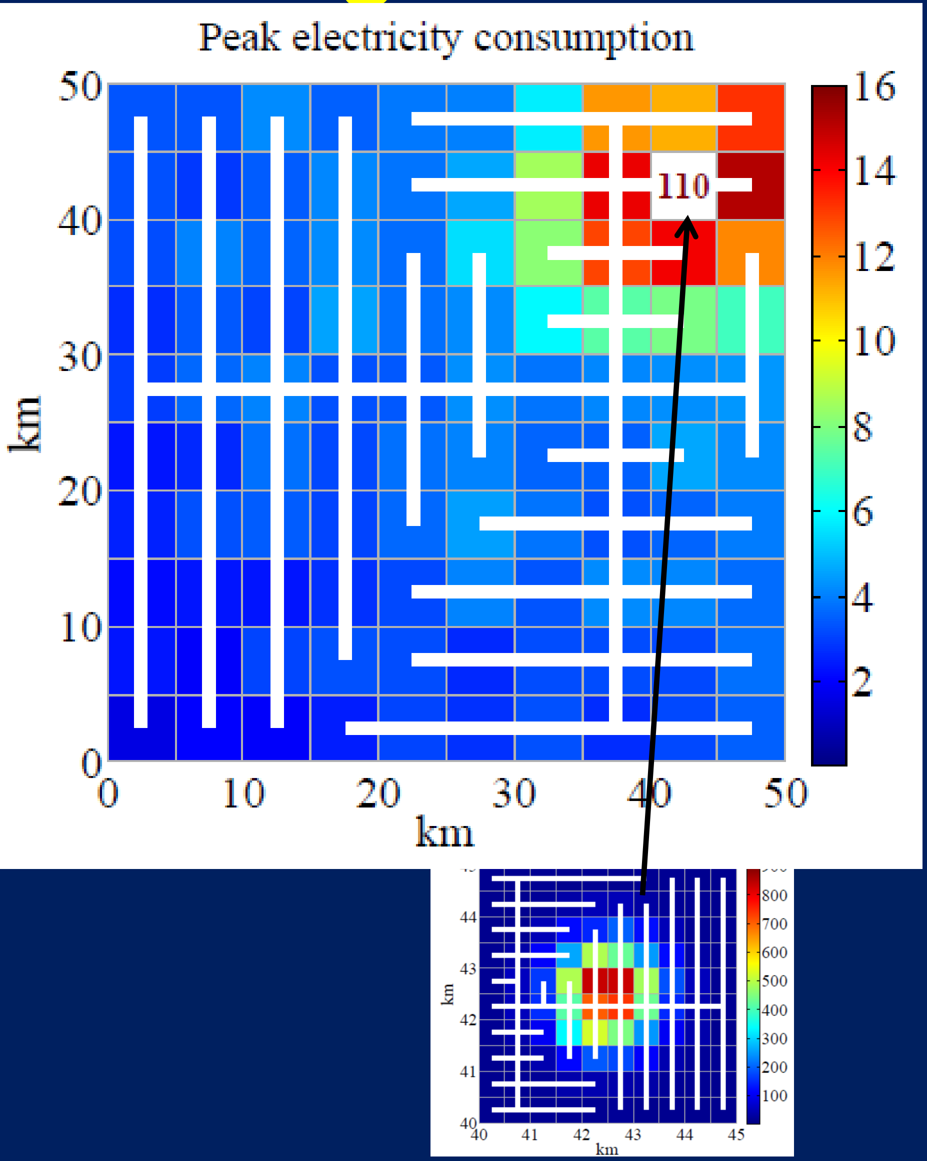
Smart energy may 2-3 x feasible PV capacity in Shanghai

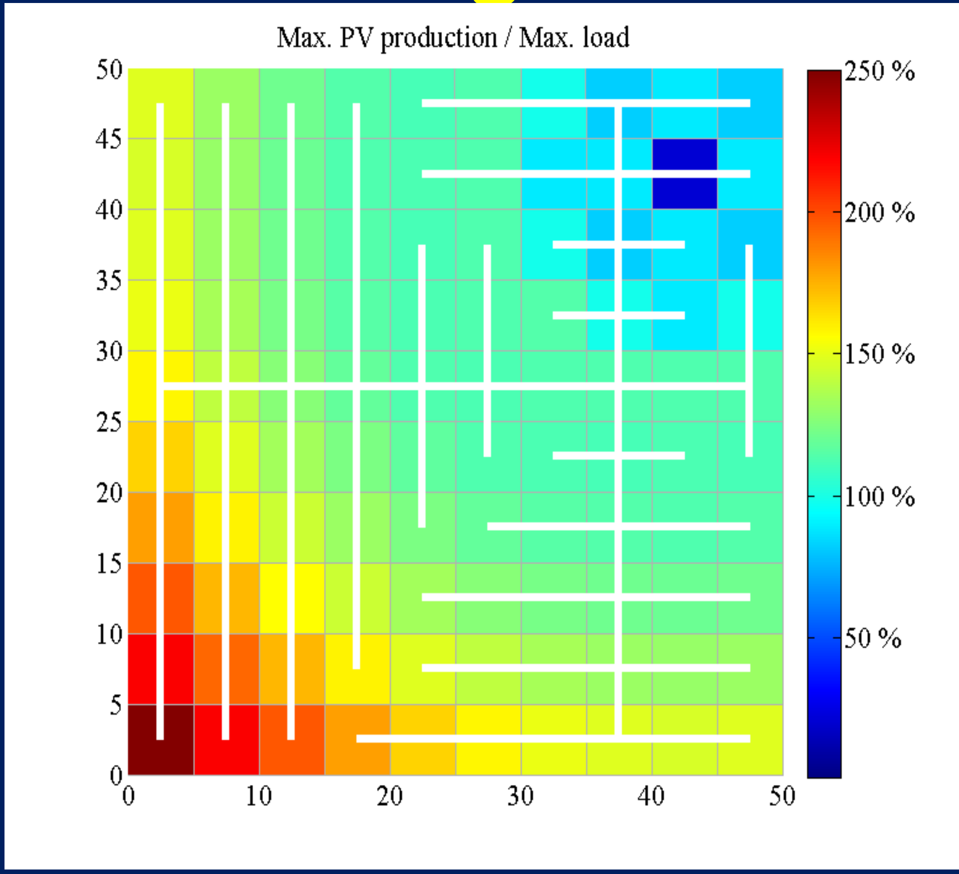
Base case (PV peak equals to electric load): 31% daily energy share, 25% of yearly electricity share

Advanced case (PV peak equals to total load: 50-70% of daily energy demand (40-55% of yearly electricity)

Ref: Lund, P. : Large-scale urban renewable electricity schemes - integration and interfacing aspects. Energy Conversion and Management, 2012

Example of power distributions with large PV schemes in Shanghai





Niemi, R., Mikkola, J., Lund P., Urban energy systems with smart multi-carrier energy networks and renewable energy generation, *Renewable Energy* 48 (2012) 524-536.

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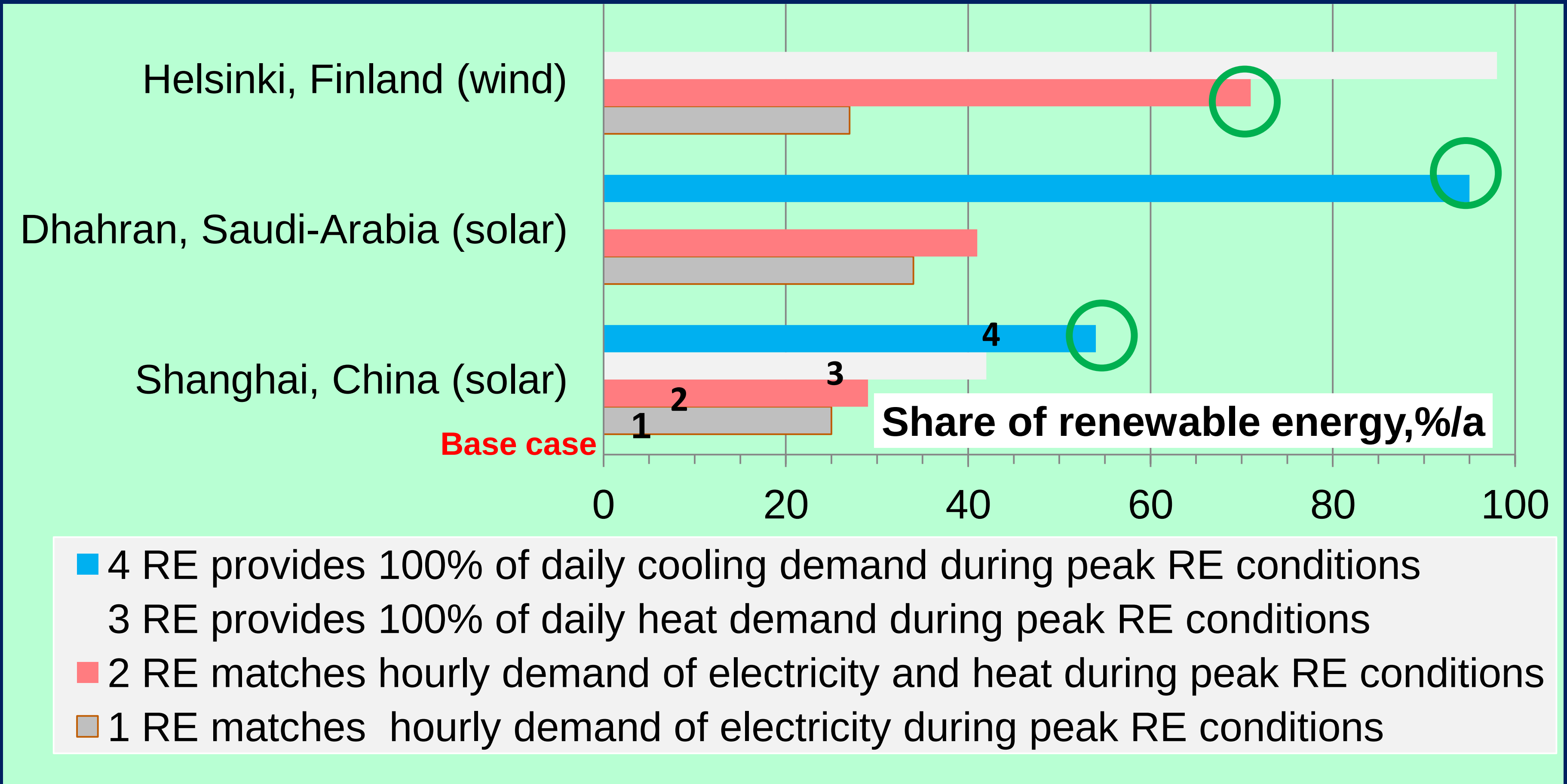
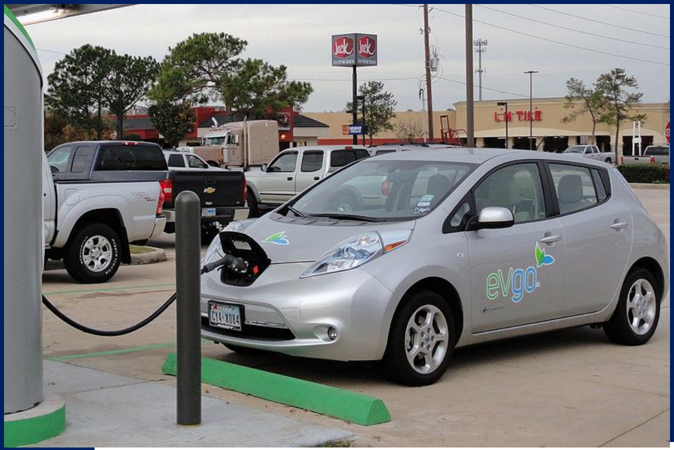
Pushing the share of RE power 2-3-fold beyond the traditional limit

- **Electricity-to-Thermal strategy: RE system is oversized, surplus turned into and stored as thermal energy (heat or cold) ; or curteiled**



Ref: Lund,P.: Large-scale urban renewable electricity schemes - integration and interfacing aspects. *Energy Conversion and Management*, 2012

Electrified vehicles providing electricity servives (E2V, V2G)




Tesla Motors - Model S lithium-ion battery pack

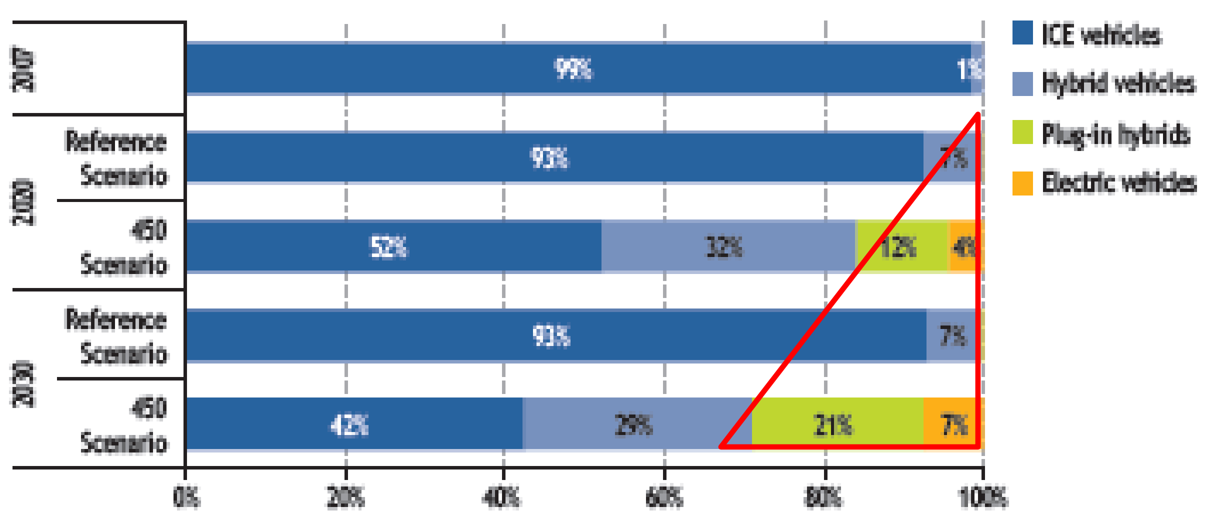


Figure 6.10 • Share of global passenger vehicle sales by engine technology and scenario

Source IEA

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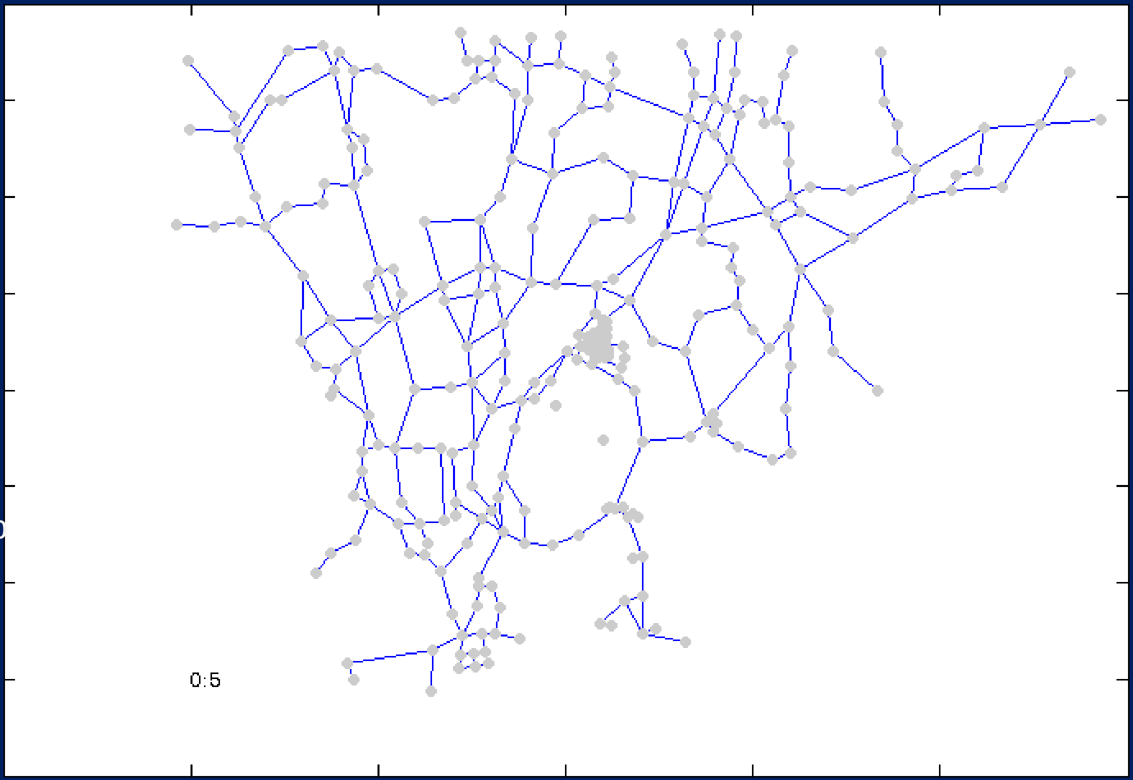
EV & PV & Grid

- **Case Helsinki Metropolitan region Area (1 million people)**

Key parameters for the simulation:

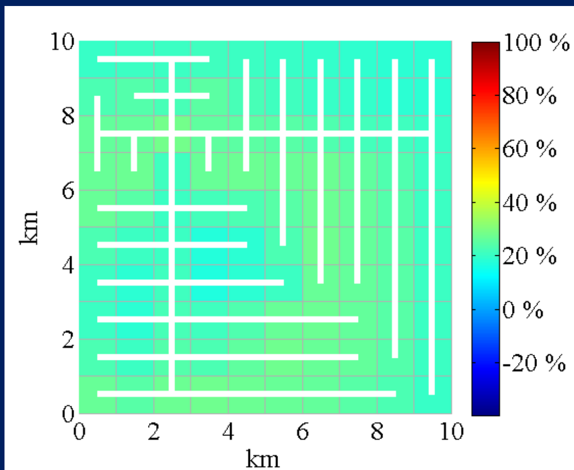
•battery capacity10 kWh
•electricity consumption 0.2 kWh/km
•charging efficiency 0.9
•power coefficient @ home: ∞ kW
•power coefficient @ work: ∞ kW
•sockets: *plenty* (no queuing)
•socket power limit 7.4 kW
•battery recharge limit: 1-hour 0→100%



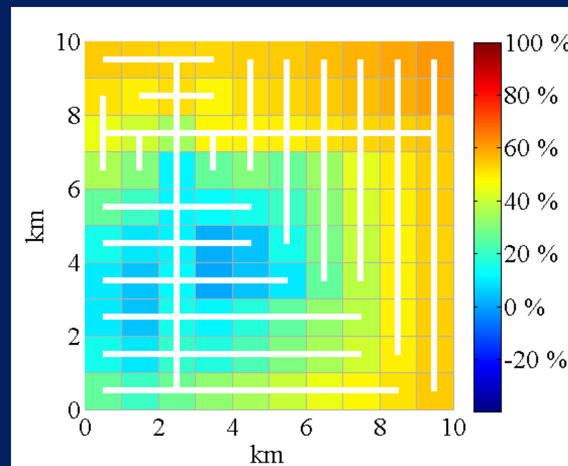
Large-scale PV+EV case for Helsinki:

2 GWp PV (1/3 of yearly demand, 6x min. summer demand)

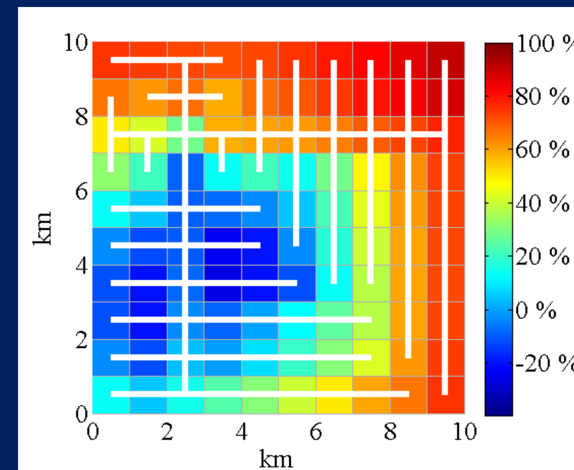
Maximum PV power overflow at peak conditions:



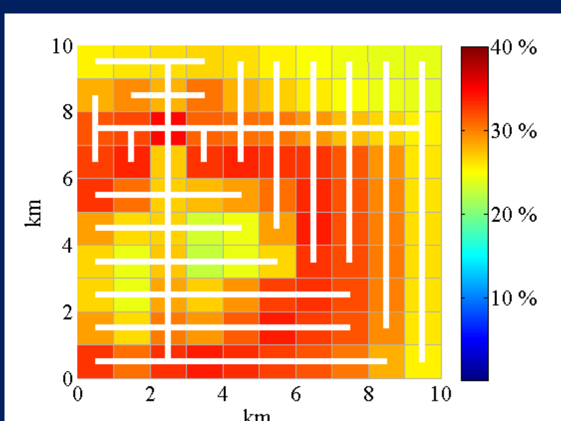
100% of PV placed based on load



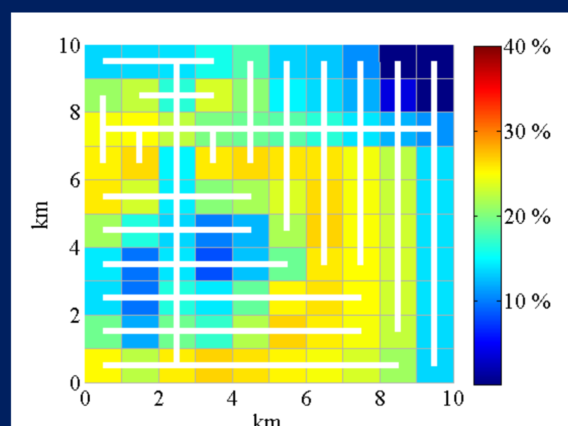
½ on consumption and ½ evenly



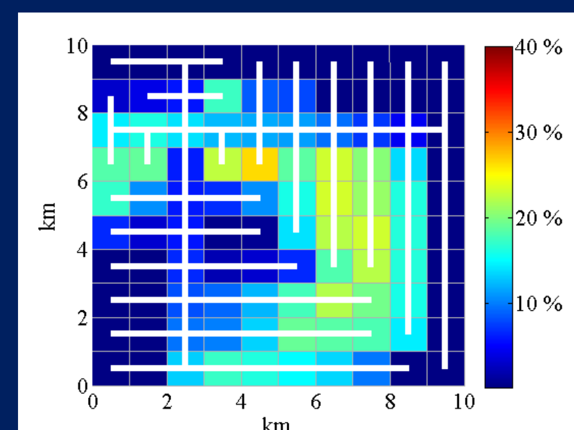
100% of PV evenly placed



0 EVs



50,000 EVs (a' 10kWh)

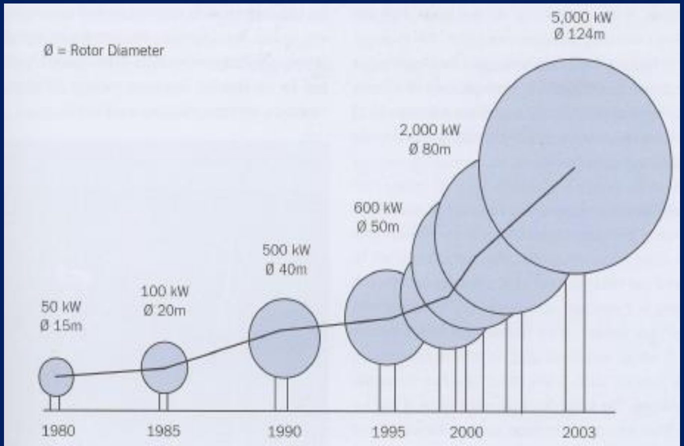


100,000 EVs

EXTRA

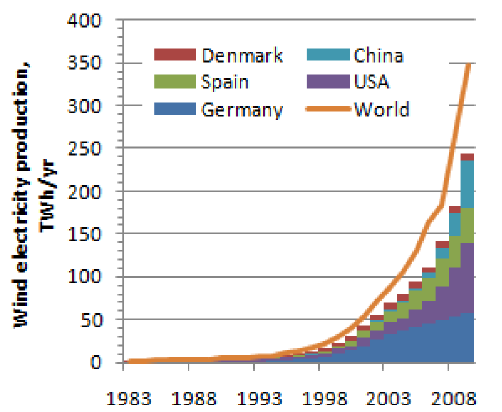
How to build your own power plant in ”1 minute” ?

1 wind turbine = 3-10 GWh electricity (ca1000-3000 households)



Peter Lund 2013

New energy technologies moving into large scale



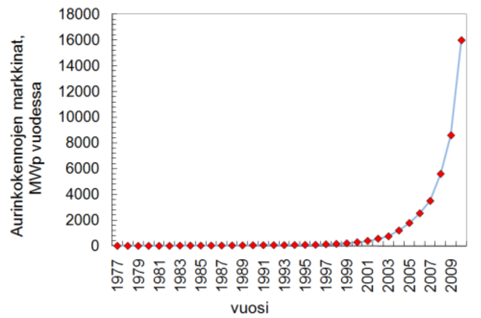
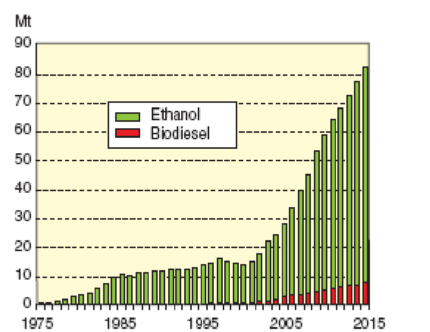
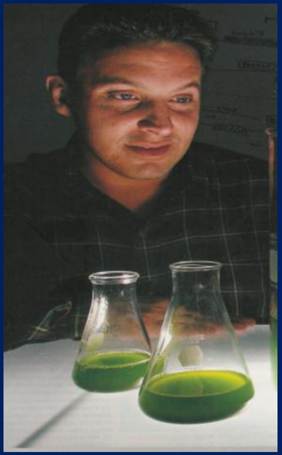


Fig. 1 Trend in world biofuel production



Source: F.O. Licht, Christoph Berg, presentation made at World Biofuels 2006, Sevilla, May 2006

- ❑ <u>Wind power</u>: now 3 % of world electricity, 25% in 2050 ? Costs may drop by ½
- ❑ <u>Solar electricity</u> (PV) : ½% of world electricity ($100 B business), 5-25% in 2050; Price<$1/Wp, a massproduced commodity?
- ❑ <u>Bioenergy</u>: 4% of EU's energy; energy may set the price but environment limits of use; large potential is 3rd and 4th generation biofuels

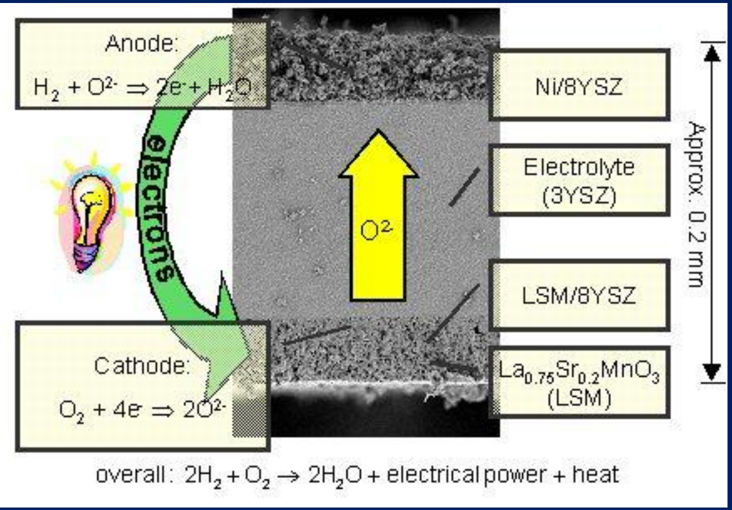


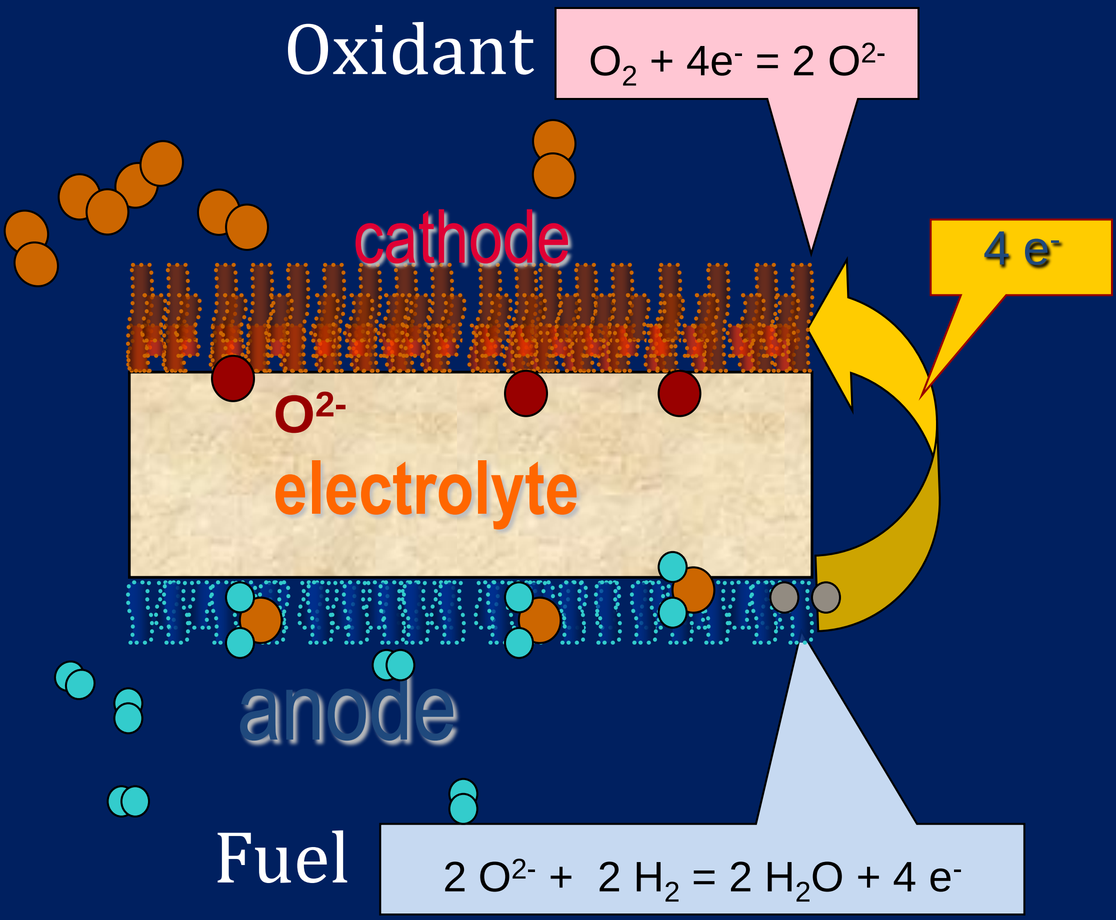
Mass-production (roll-to-roll) of solar cells

Source: Janne Halme

Electrochemical conversion of fuel to electricity

– Fuel Cell (solid oxide fuel cell)





Courtesy Bin Zhu