The cost of reliability of supply in future power systems

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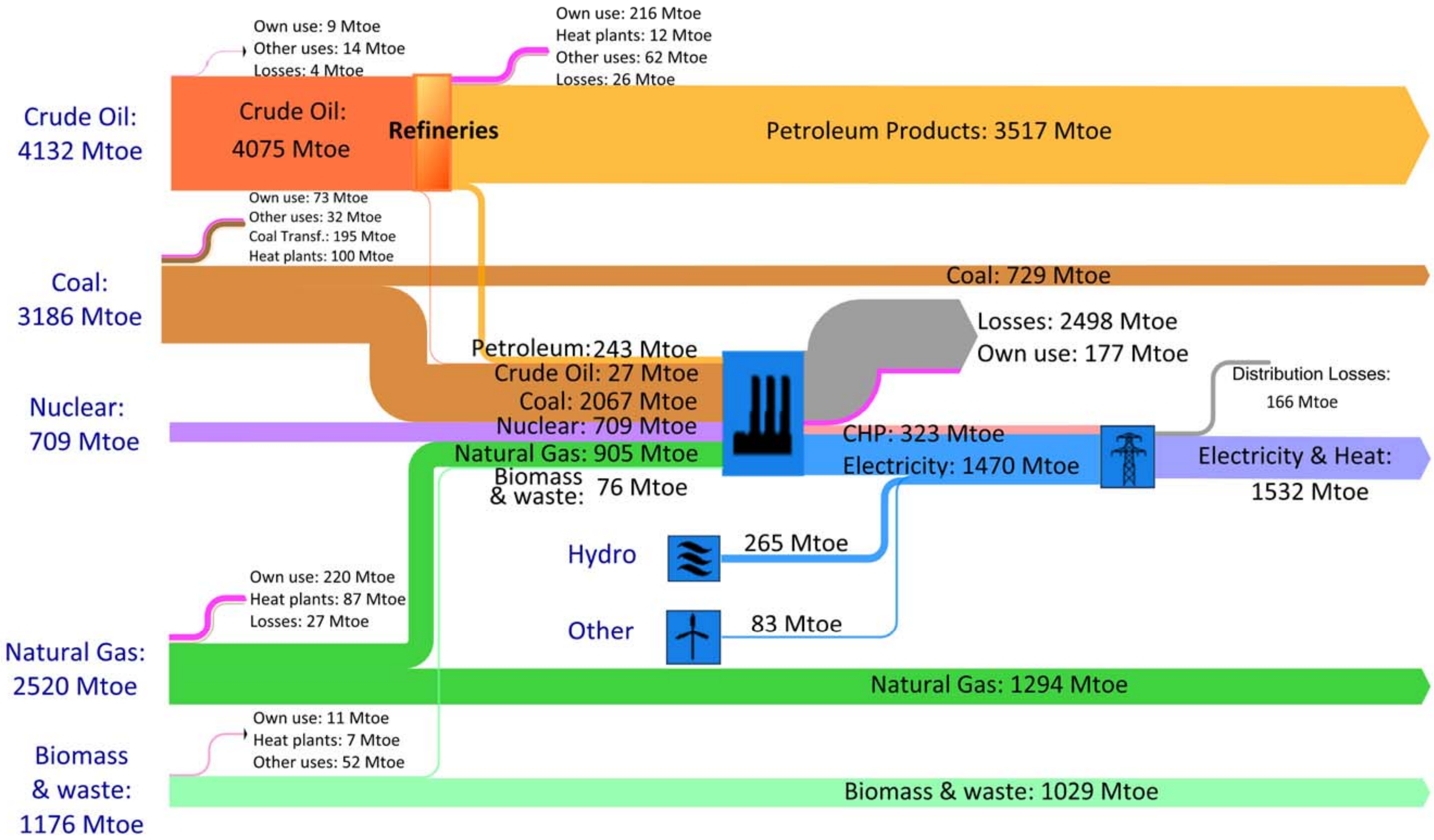
Energy supply Chain (from IEA 2007)



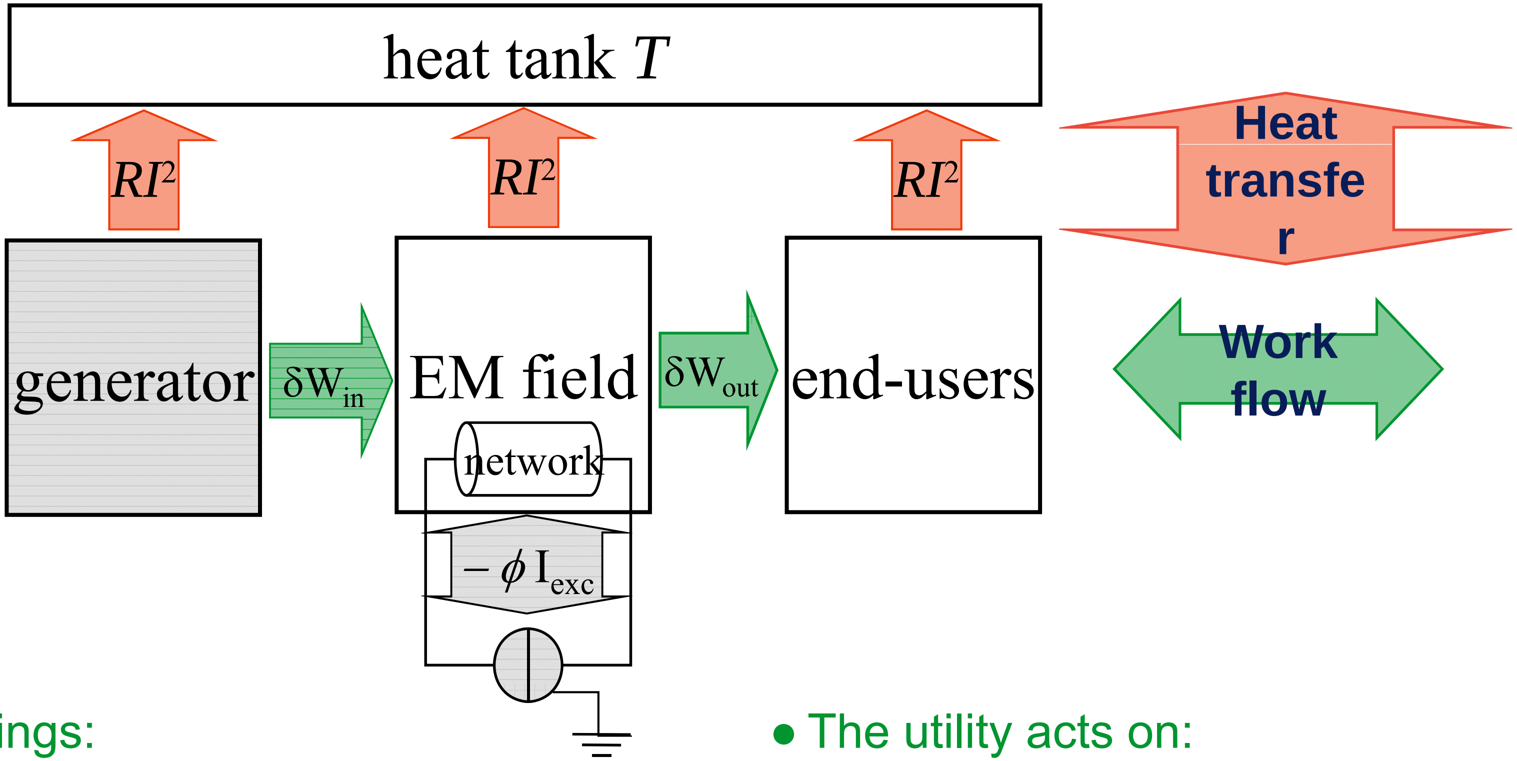
A tight equation toward sustainability

- Demography:
  - Rise of energy systems in emerging countries
  - Refurbishment of existing capabilities in developed countries
  - Urban population, from 50% today to 80% in 2100, claims for high density power networks
- Earth: An isolated chemical system
  - Fossil (and fissil) fuels depletion:
    - Peak oil around 2020
    - Peak gas around 2030
    - Around two centuries for coal or Uranium
  - Climate change:
    - Whole electrical generation provides 45% of CO_2 emissions
    - Global efficiency of the whole electrical system is just 27% (37% for all fuels)
    - Despite a thermodynamic trend toward reversibility
- Earth: A fully open energy system
  - Domestic energy is 10.000 times smaller than natural energy flows:

    Solar direct, wind, geothermy, waves and swell
  - But very diluted and intermittent

Thermodynamic framework

Electromagnetic description



- Couplings:
  - magnetic — free currents — I
  - heat tank — Joule losses — "RI^2"
- The utility acts on:
  - the mechanical power P_m
  - the excitation of the rotor I_{exc}

➔ Energy conservation (1st principle):

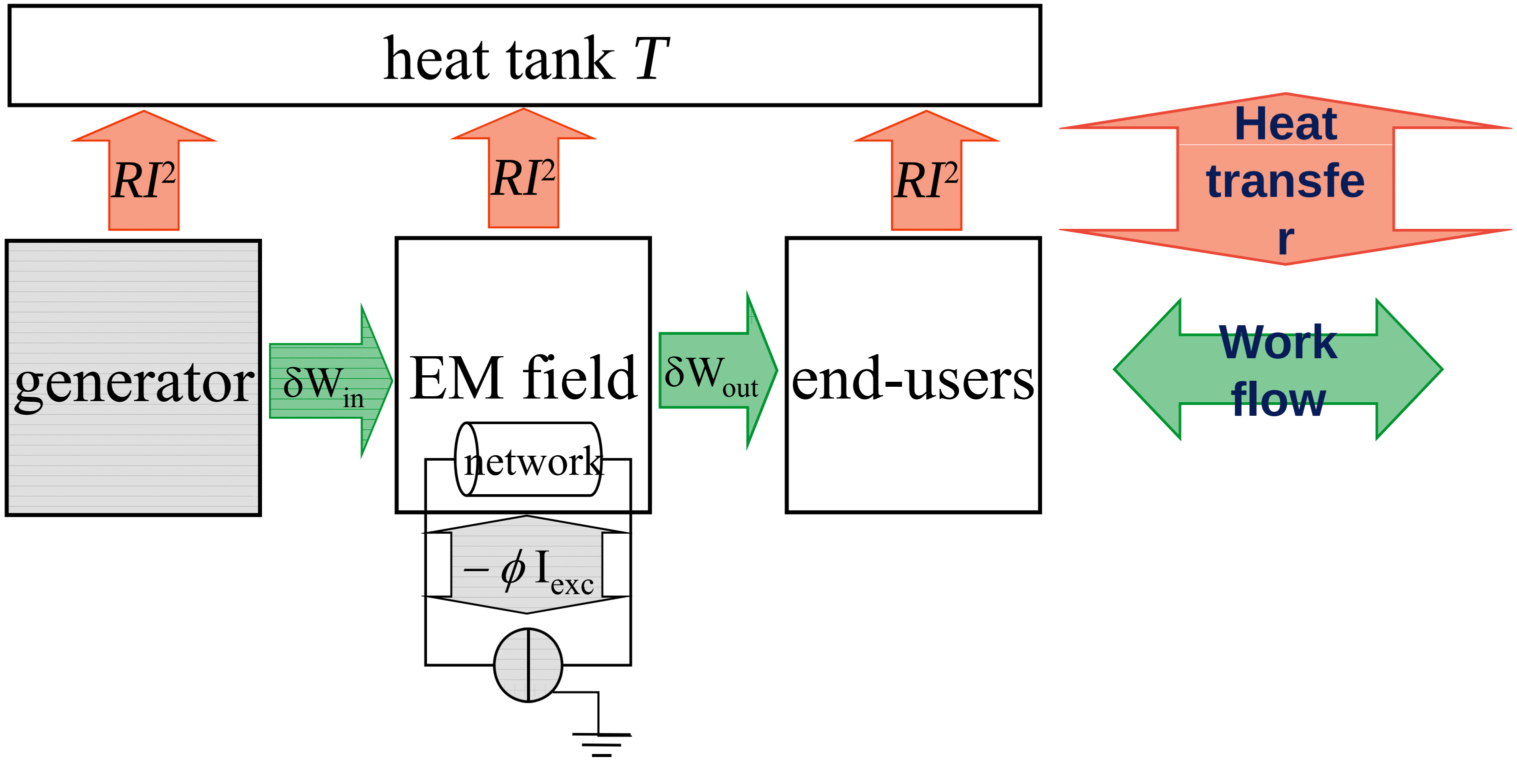
$$\frac{dU}{dt} = P_m - T\frac{dS_{th}}{dt}$$

➔ State functions:

$$G = U - TS - \phi I_{exc}$$

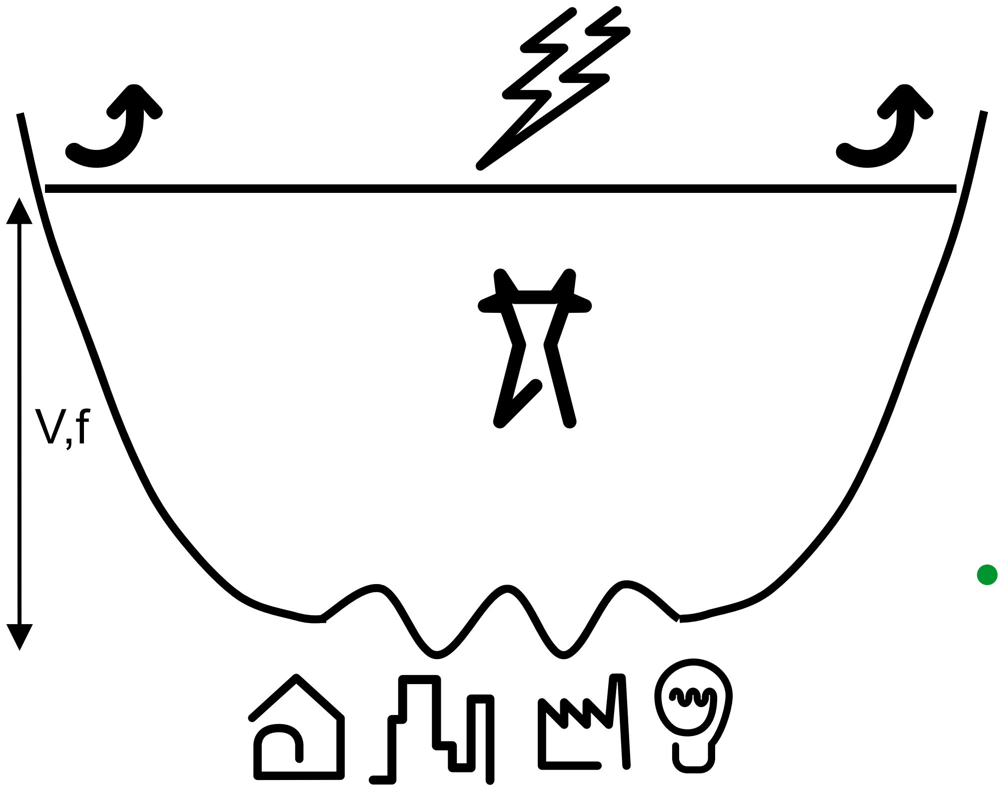
$$P_m - \frac{dG}{dt} = \underbrace{T\left(\frac{dS}{dt} + \frac{dS_{th}}{dt}\right)}_{RI^2>0} + \frac{d(\phi I_{exc})}{dt}$$

An evolution toward reversibility



- Faraday's law is restored by assuming a reversible evolution:
  - ➔All the energy losses (conversion, distribution, usage) are **attainable**
  - ➔**Multi-scale** framework with successful issues (material law, CAD tools)
  - ➔Focus on the higher aggregated scale to inspect reliability conditions dedicated to power transmission

Centralized power grid



- The supply side controls the power system and fixes its physical behavior (voltage and frequency)
  - Stability under load fluctuation
  - Elastic generation
  - Huge investment in generation
  - Transmission and distribution losses
  - Reliability losses
  - Convergence between regulator and supplier
- The physical correlation between actors at the demand side is insignificant

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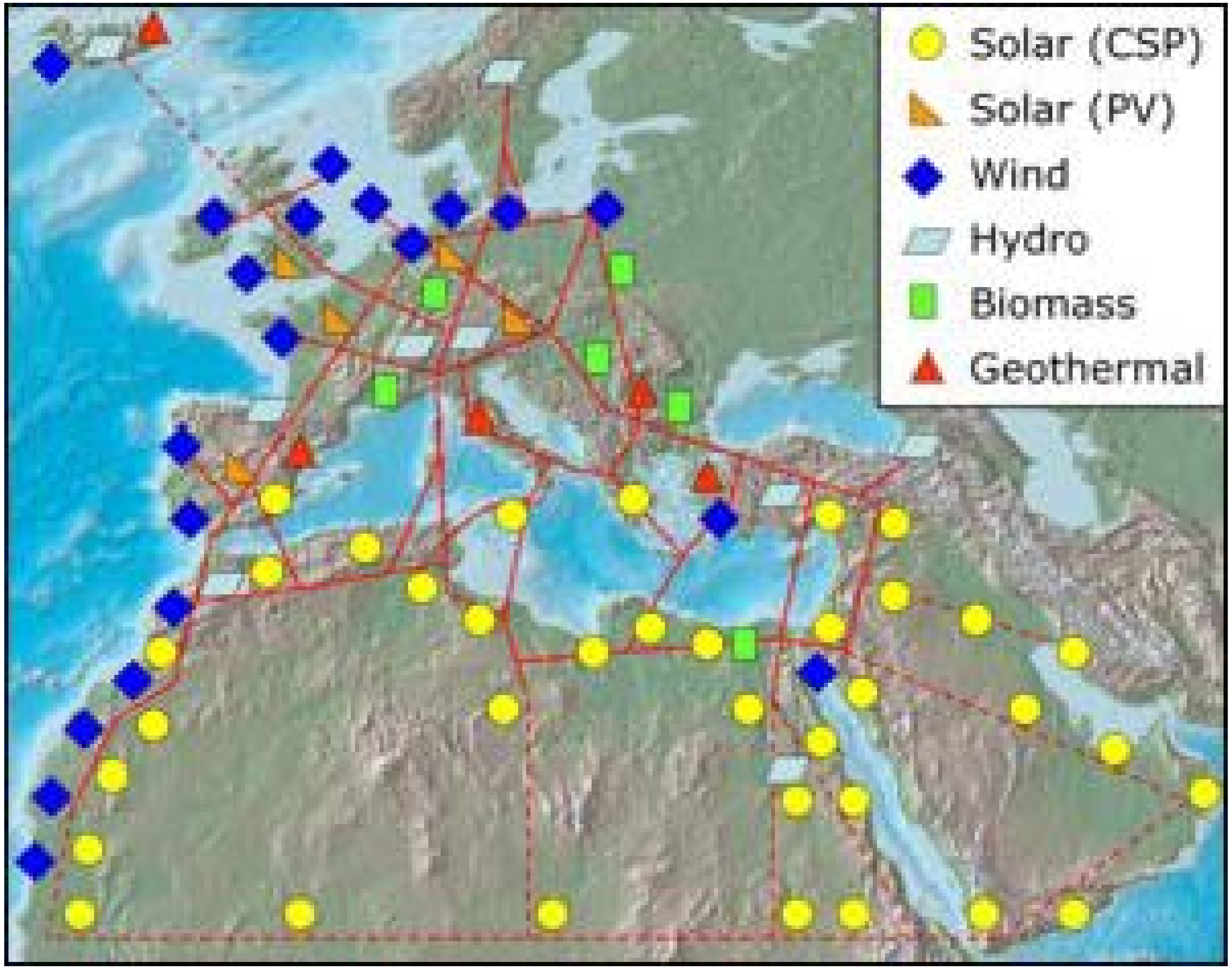
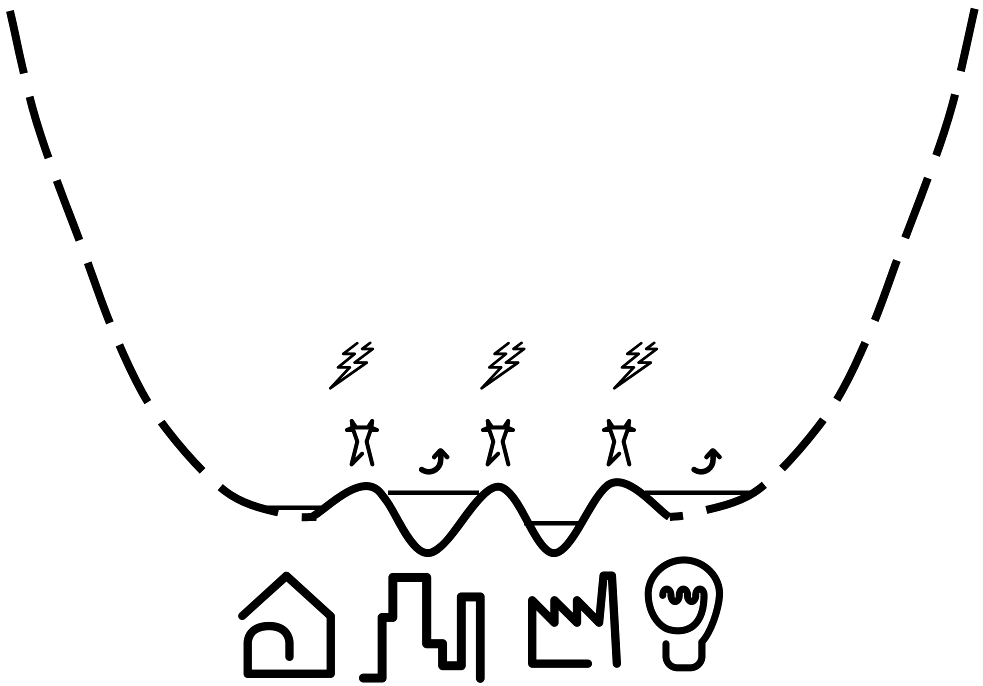
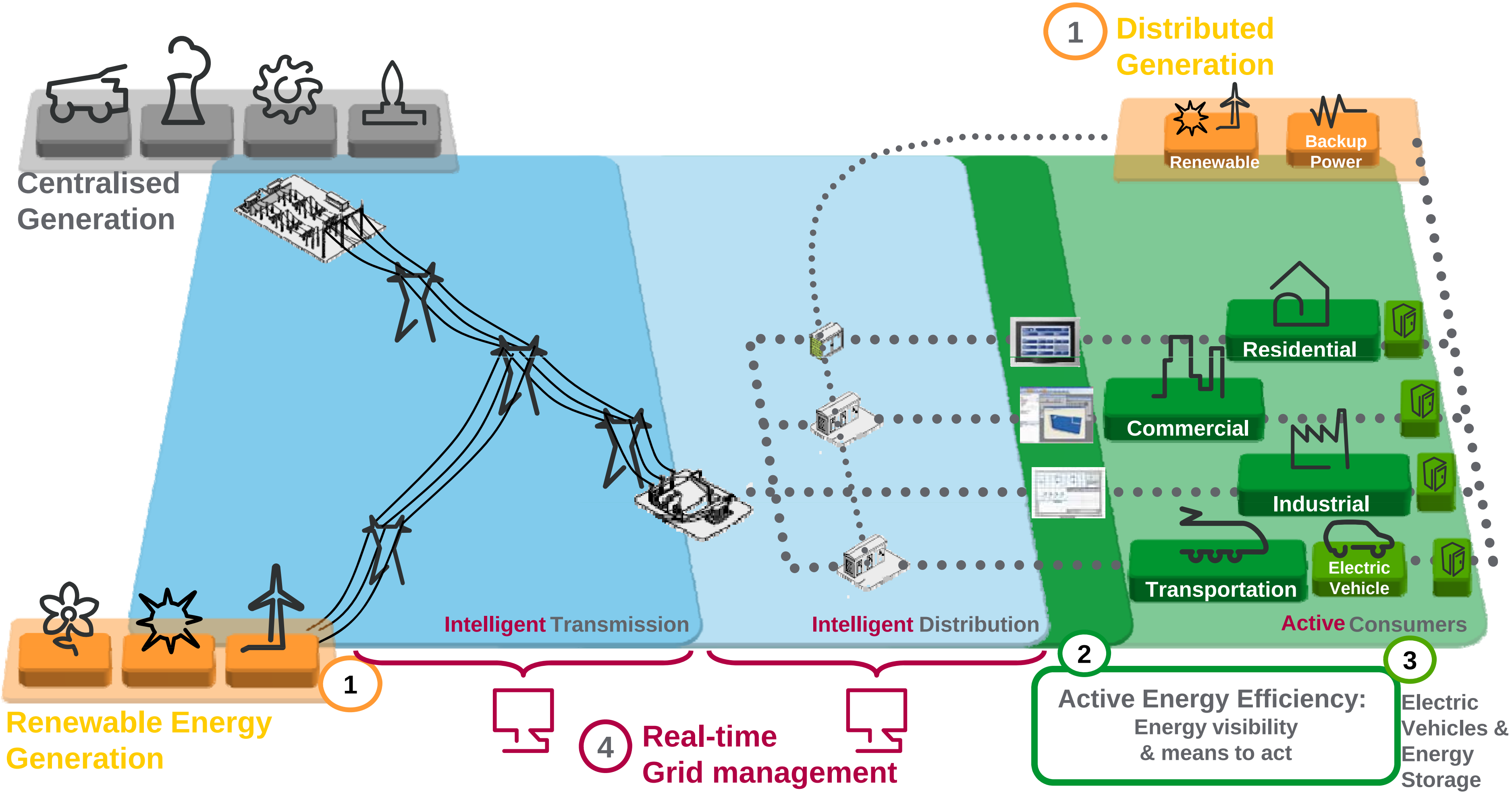


Decentralized power grid



- The demand side controls the power grid and fixes its topology at the distribution level through "player" games
  - Splitting between regulator and suppliers/players
  - Sequential generation with intermittency
  - Huge investment in control
  - distribution losses only
  - Weak stability under load fluctuation

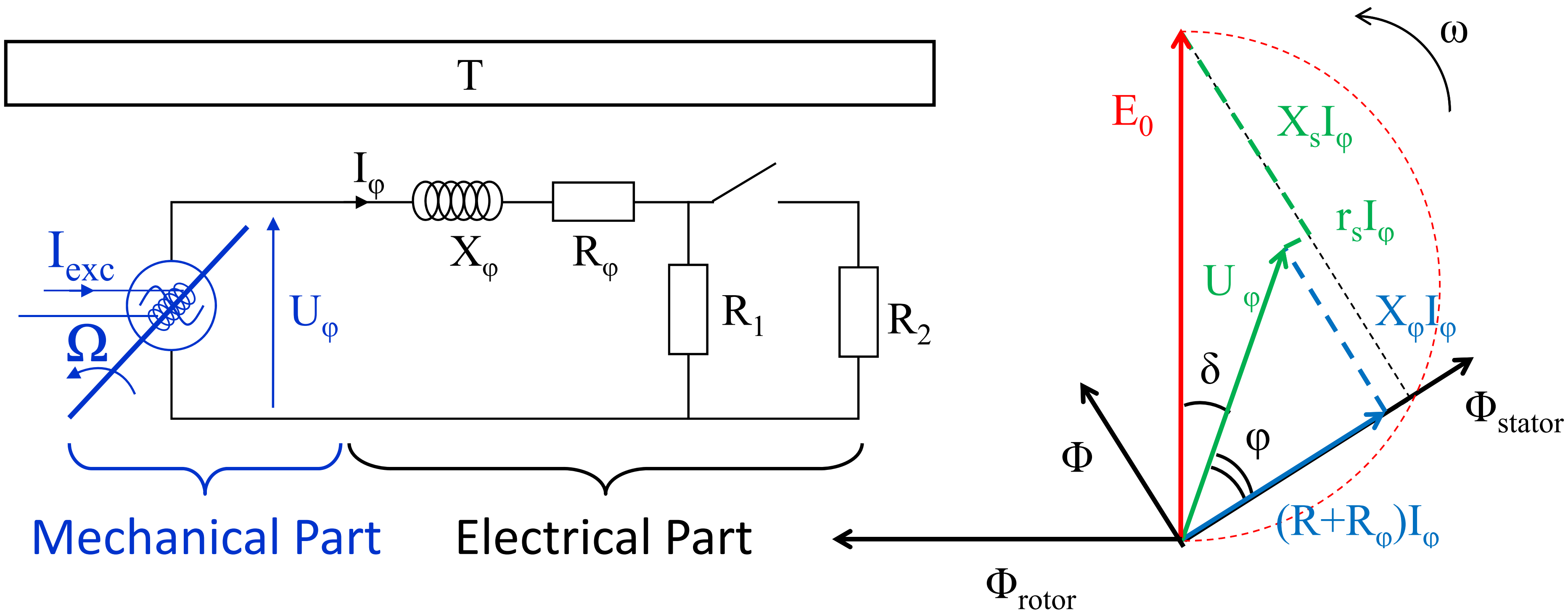
A possible evolution of the power network



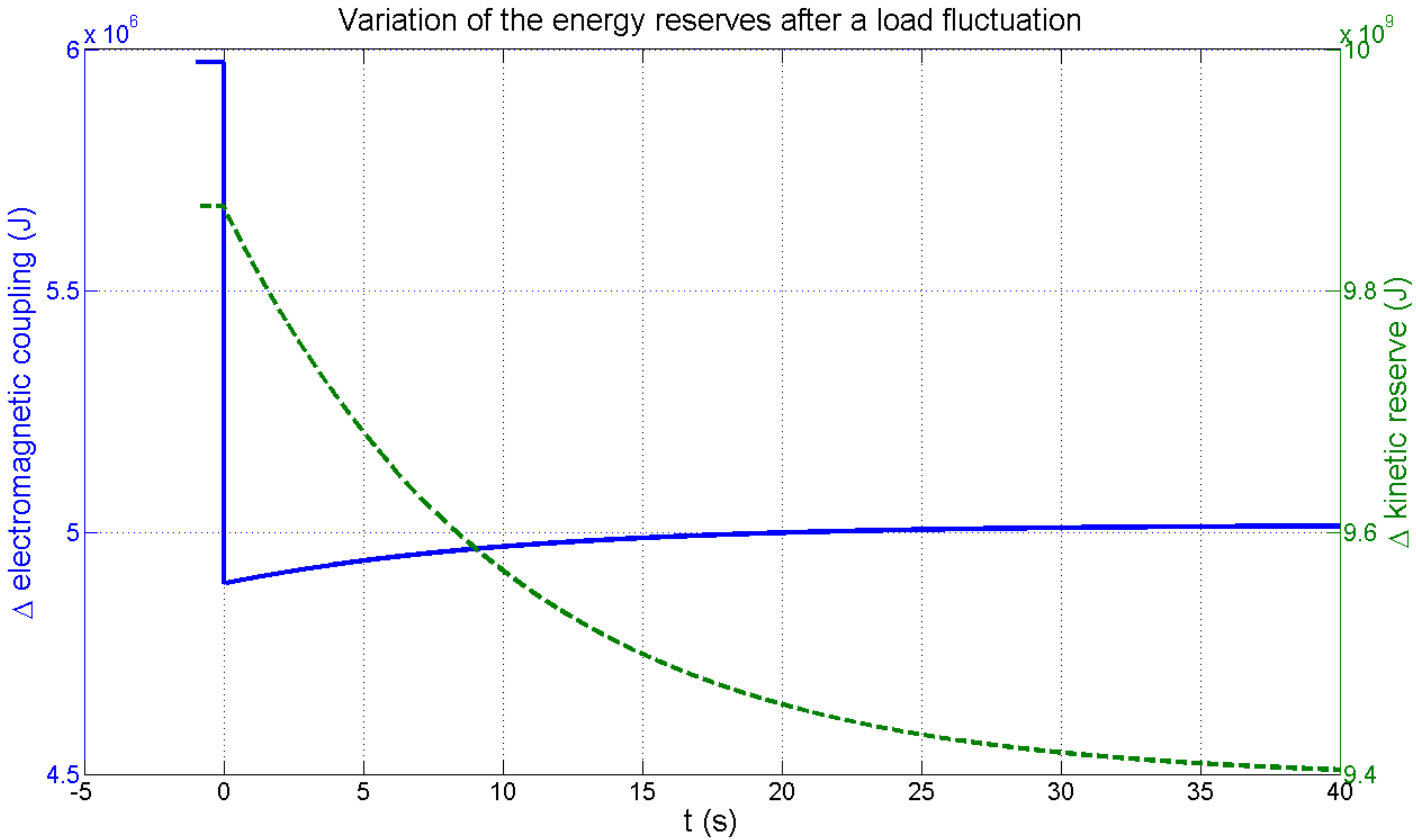
Transmission conditions…

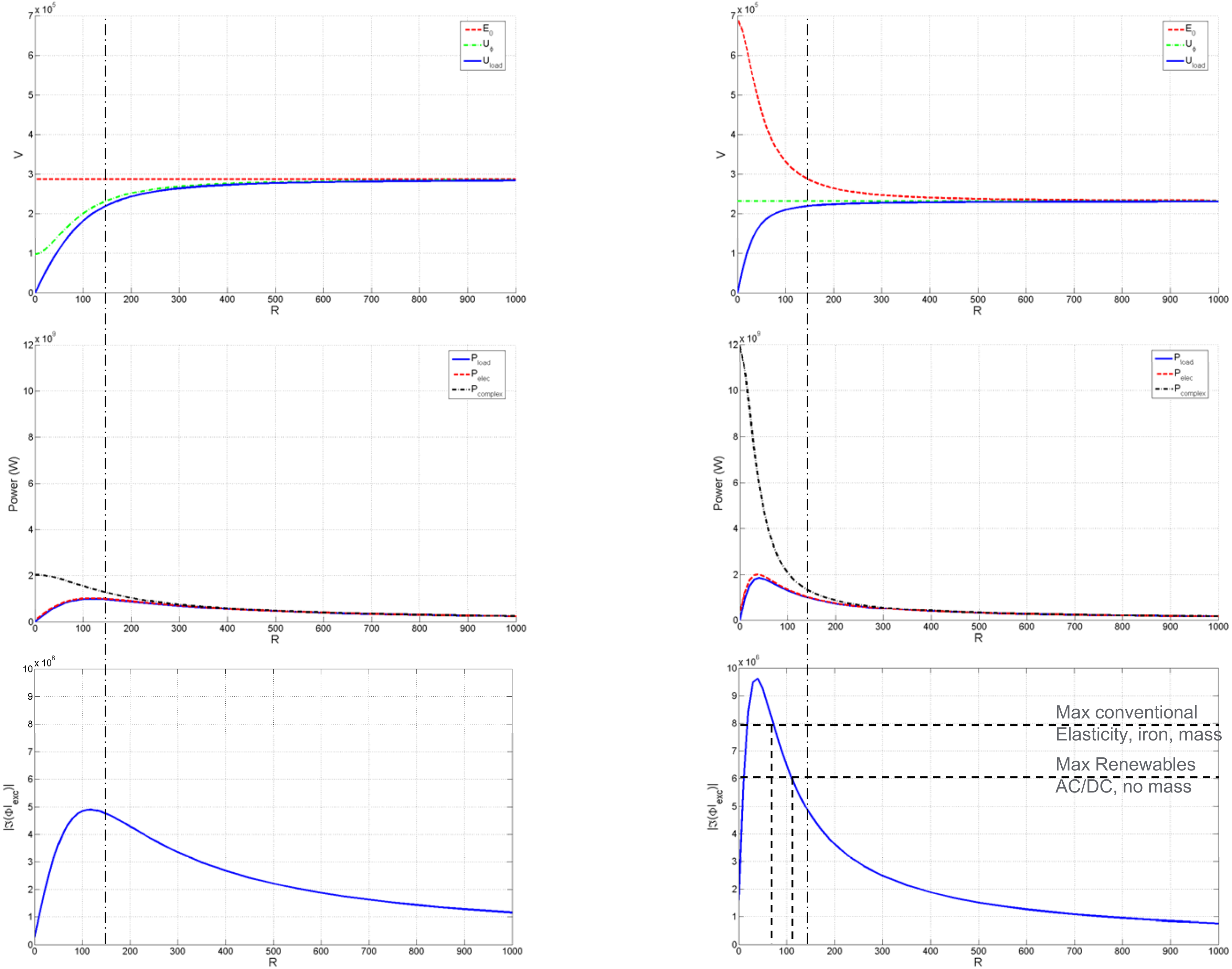
for any electrical systems

Aggregated one-loop grid



Magnetic linkage under load fluctuation





V
R
Power (W)
$|\Im(\Phi I_{exc})|$
E_0
U_ϕ
U_{load}
P_{load}
P_{elec}
$P_{complex}$
Max conventional
Elasticity, iron, mass
Max Renewables
AC/DC, no mass

Summary

		centralized	decentralized
Relaxation time			
under	spinning reserve	few mn	lower
load or generation	kinetic reserve	few s	lower
fluctuation	magnetic linkage (transmission)	10 ms	lower
	elasticity of generation	few mn	no (AC/DC static converters)
Losses			
	self-consumption		
	auto-control		monitoring and data processing
	T&D losses		
	reliability losses		???
Investment			
	sizing of capacity	global peak	Σ (local deficits)
	backup/storage	discard peak	balance intermittency
	demand response	discard peak	minimize local deficit
	generation & transmission	10.000 BillionUS$ (WEO, IEA 2003)	???
Systemic risk		weak but global	important but isolated
Emissions/Depletion			
	hydro	large	
	renewables	farms	
	fossils		back-up
	nuclear		no