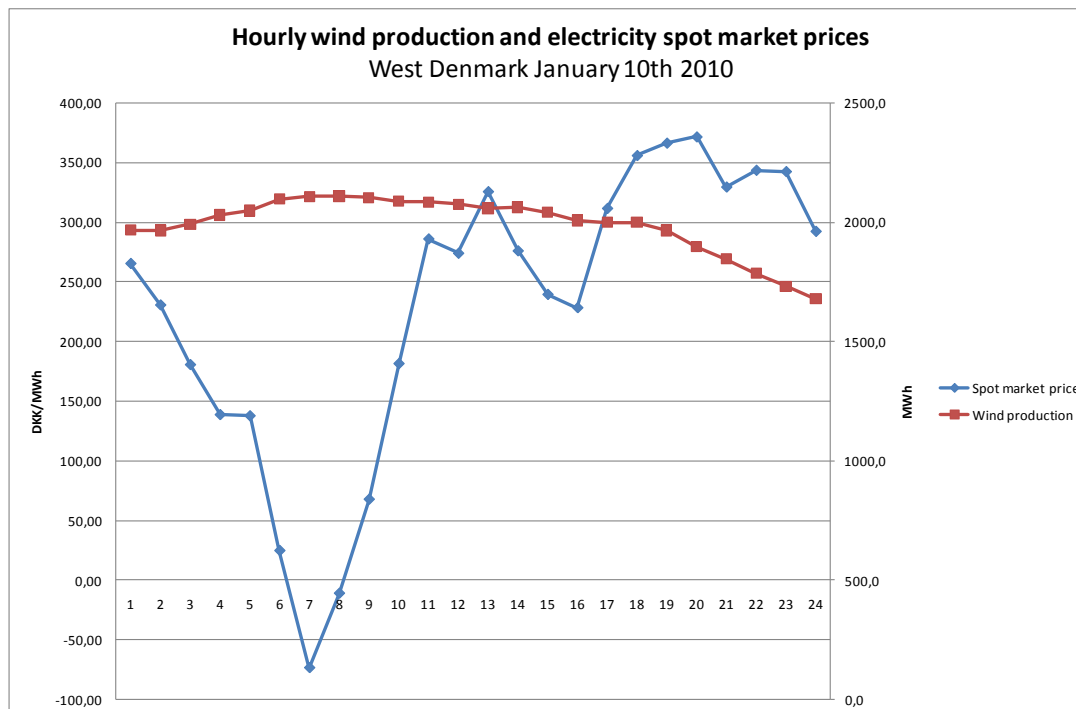


Towards an intermittency-friendly energy system

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“Wind-friendly” technologies ?

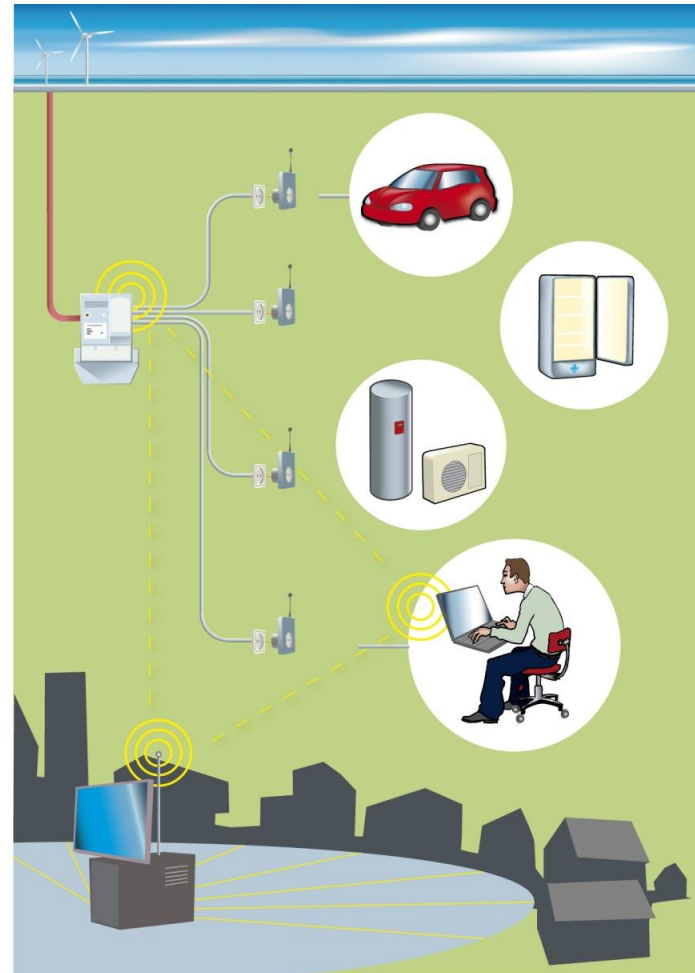


Hour/Price (DKK/MWh)

1	245.47
2	230.65
3	180.58
4	138.61
5	137.65
6	24.55
7	-73.73
8	-11.24
9	67.63
10	181.47
11	286.08
12	274.03
13	325.74
14	276.04
15	239.51
16	228.35
17	311.68
18	356.02
19	366.44
20	371.65
21	329.61
22	343.67
23	342.56
24	292.41

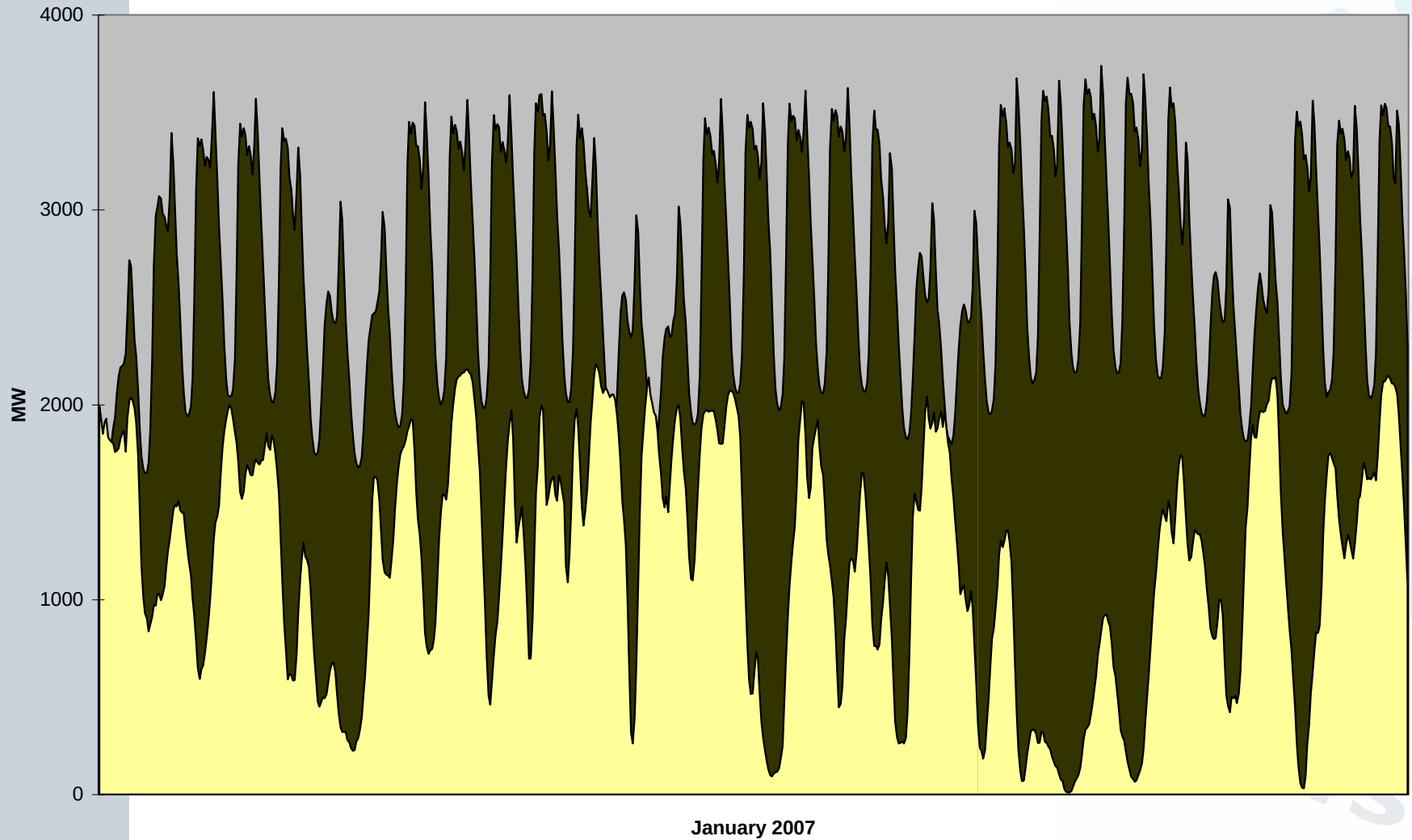
Options for increasing the energy system's "intermittency-friendliness":

- Electro-chemical storage (batteries)
- Electric vehicle with battery
- Heat pump with thermal storages
- Flexible demand behaviour
- Hydrogen conversion and storage
- Compressed air storage
- Refrigeration with ice storage
- Wind-friendly co-generation with heat pump and storage
- Transnational cable connection (export/import)



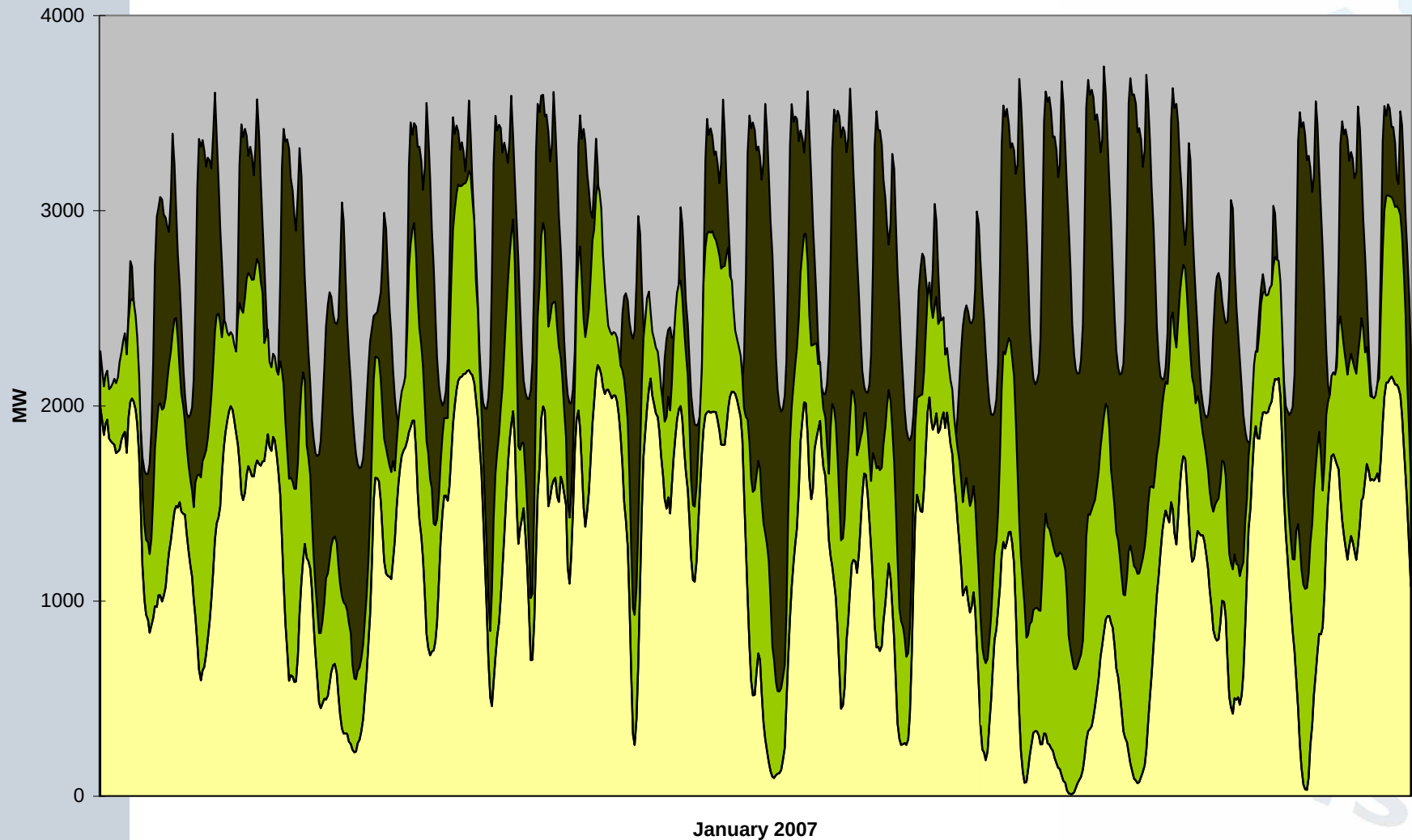
Wind, Demand

West Denmark, January 2007



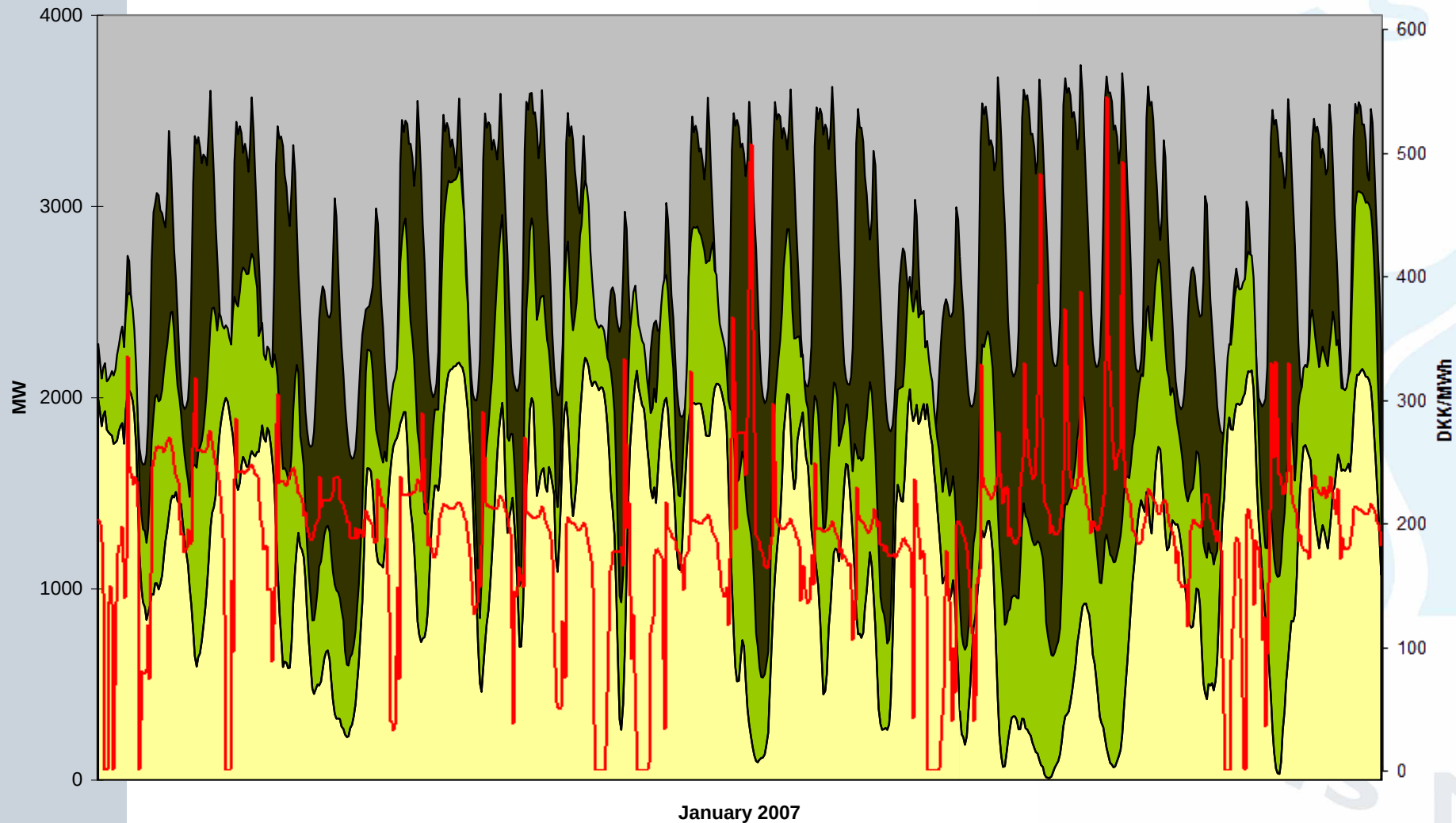
Wind, Distributed Generation, Demand

West Denmark, January 2007



Wind, Distributed Generation, Demand, Spot Market Price

West Denmark, January 2007



Important historical correlations in West-Denmark (2006-9)

- Wind power production – Electricity demand: 0,19
- Electricity demand – Spot market: 0,55
- Wind production – Spot market: -0,30
- Electricity demand **minus** wind production – Spot market: 0,67

The relocation coefficient (“intermittency-friendliness”)

1. The relocation coefficient: the statistical correlation between net electricity exchange between plant and grid (e), and the electricity demand minus intermittent renewable electricity production (d).

$$R_c = \frac{\sum (e - e_m)(d - d_m)}{\sqrt{\sum (e - e_m)^2 \sum (d - d_m)^2}}$$

2. The relocation coefficient is useful for...
 1. Policy analysis: Evaluating the overall intermittency friendliness of distributed generation with respect to a maximum relocation coefficient given by market conditions and operational strategies.
 2. Project planning: Evaluating the intermittency friendliness of individual power producers, storage options, and electricity consumers. The relocation coefficient may be used to identify alternative options for increasing the intermittency friendliness of supply or demand.

Gasoil boiler

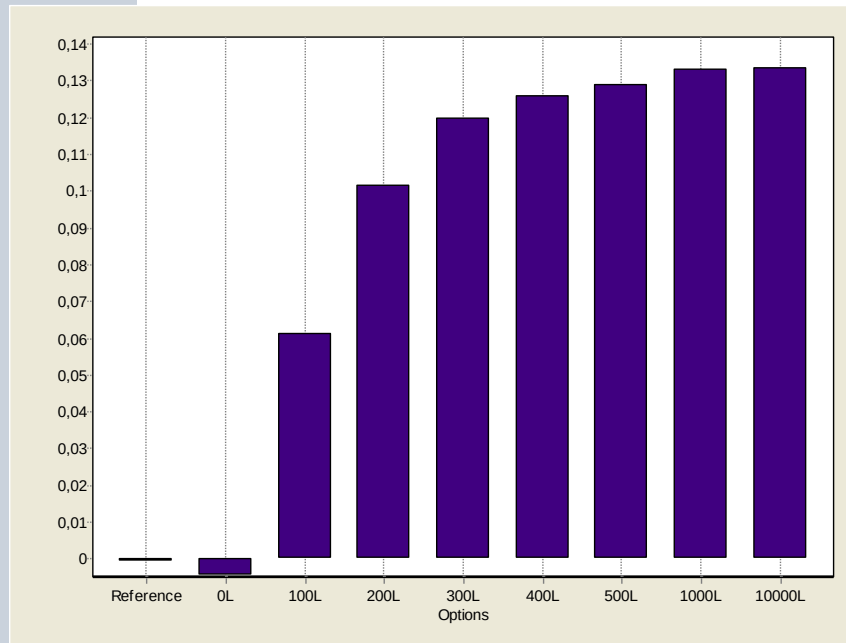


versus

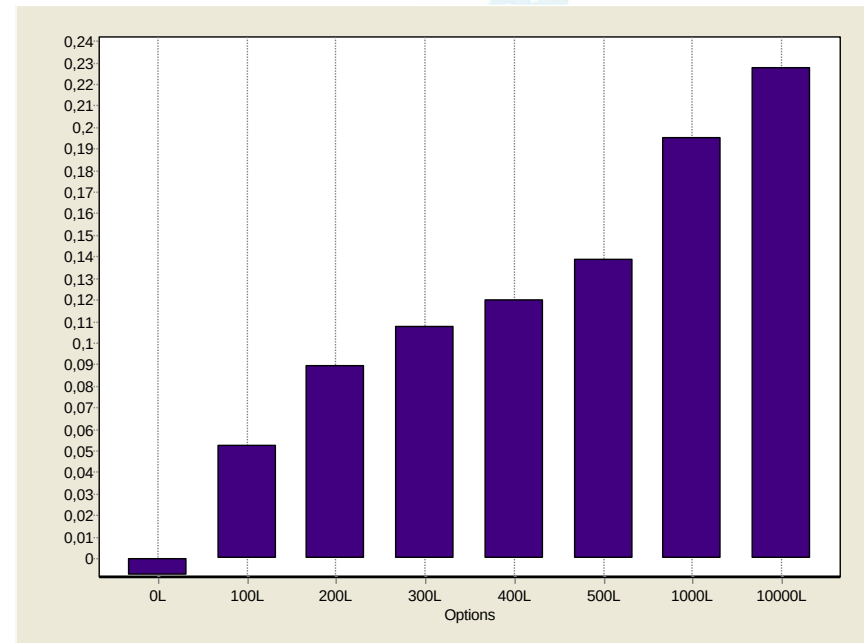


Air-Water CO2 heat pump

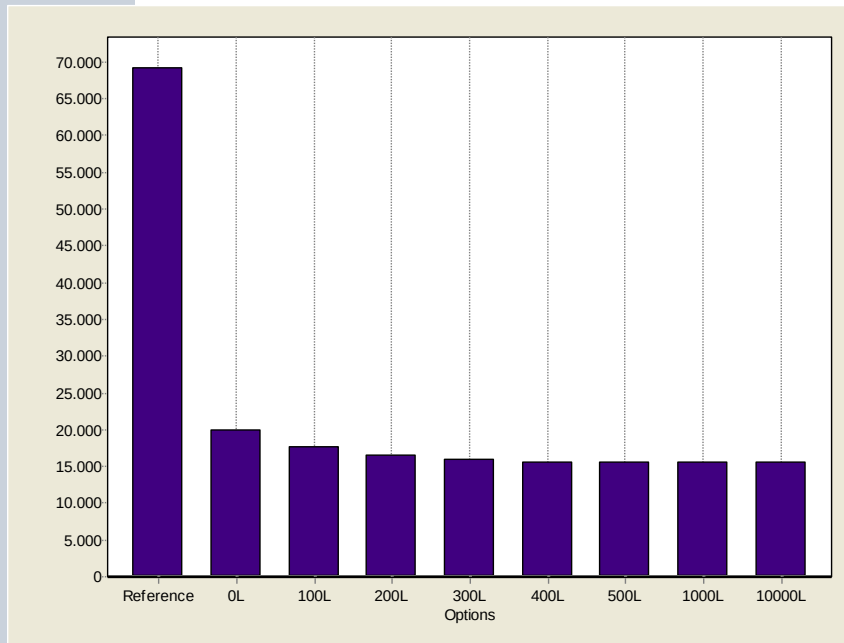
4.5 kW HP, 6 kW EB, 24h optimization



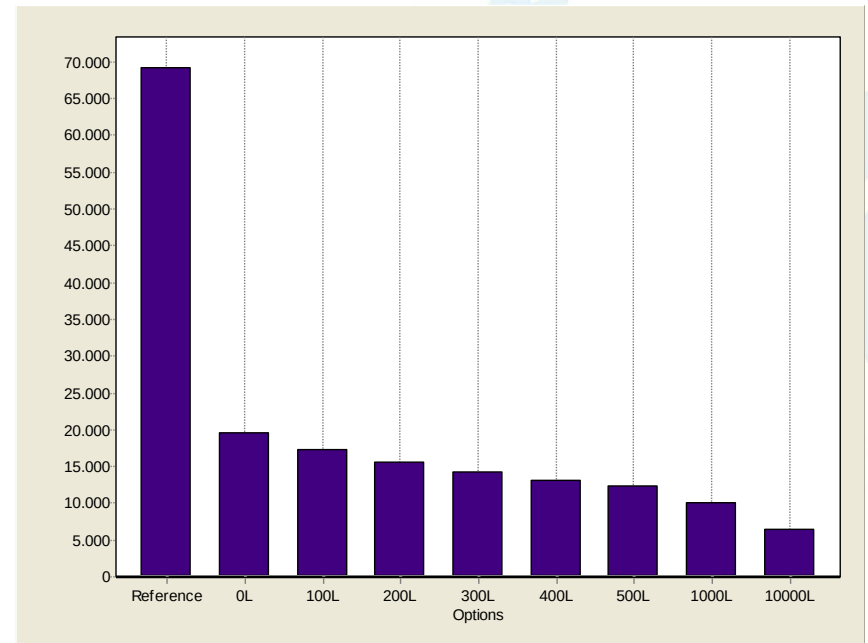
18 kW HP, 6 kW EB, 24h optimization



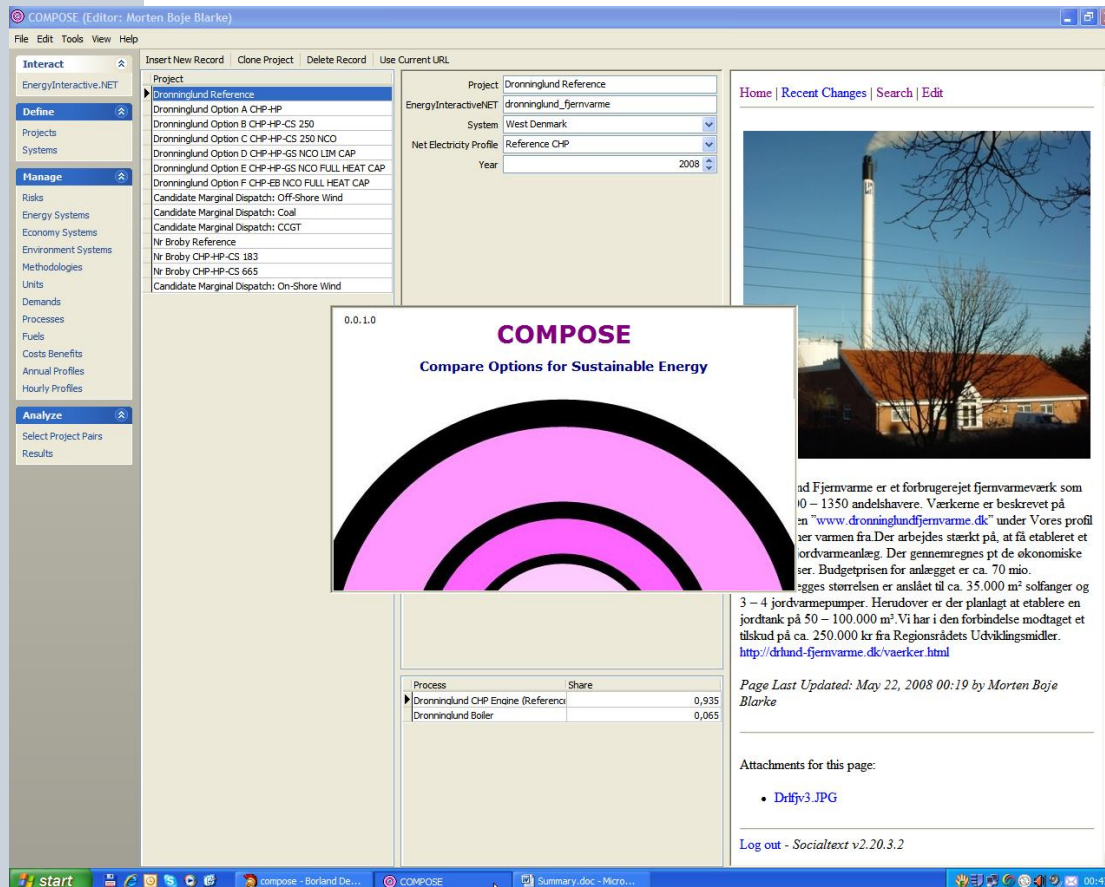
4.5 kW HP, 6 kW EB, 24h optimization



18 kW HP, 6 kW EB, 24h optimization



COMPOSE / EnergyInteractive.NET



Interactive planning framework

"Combinomics" (distributional analysis of costs and benefits)

System-wide energy, environmental, and economic consequences

The relocation efficiency ("intermittency-friendliness")

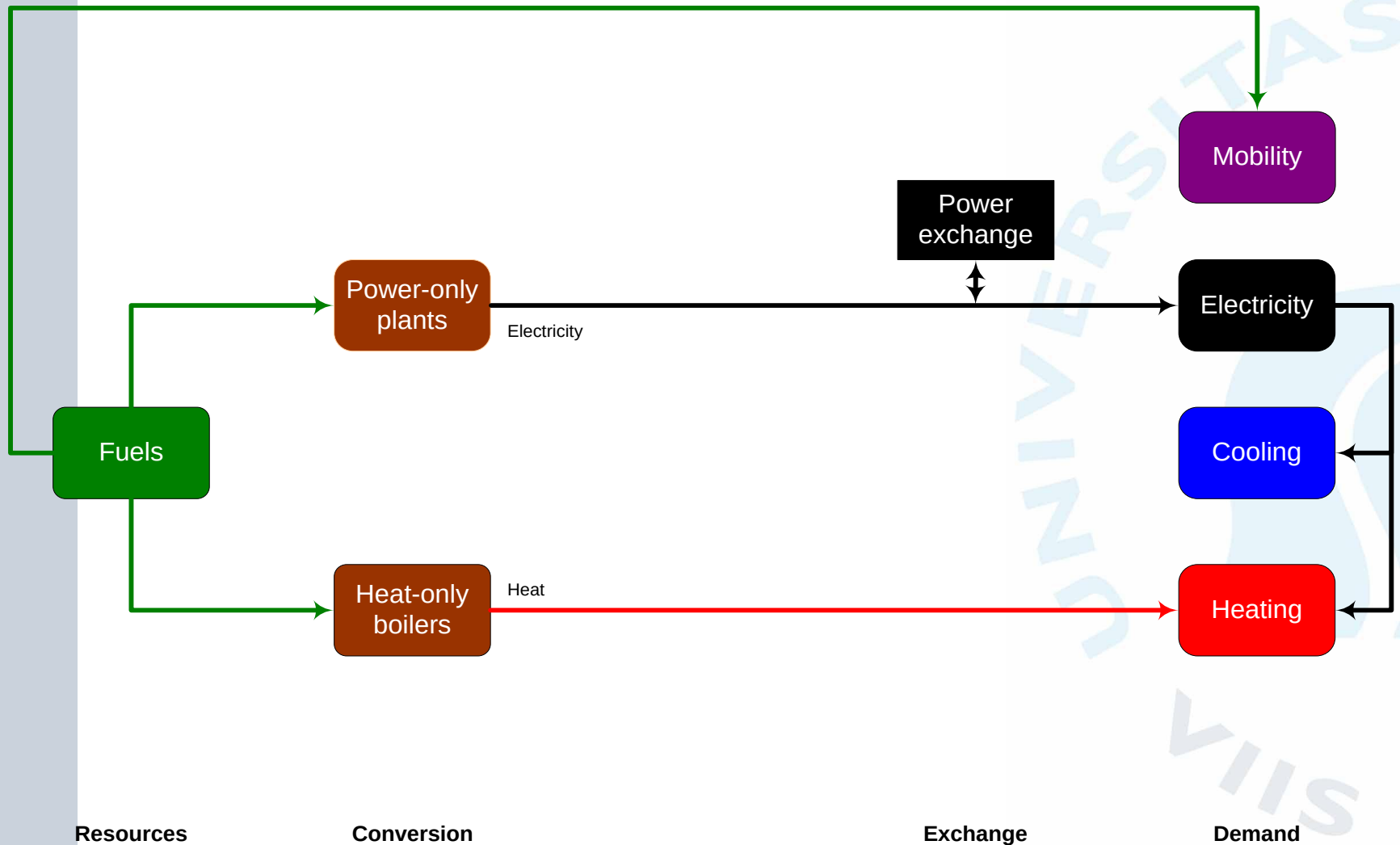
$$R_c = \frac{\sum (e - e_m)(d - d_m)}{\sqrt{\sum (e - e_m)^2 \sum (d - d_m)^2}}$$

Monte Carlo risk analysis on more than 20 variables

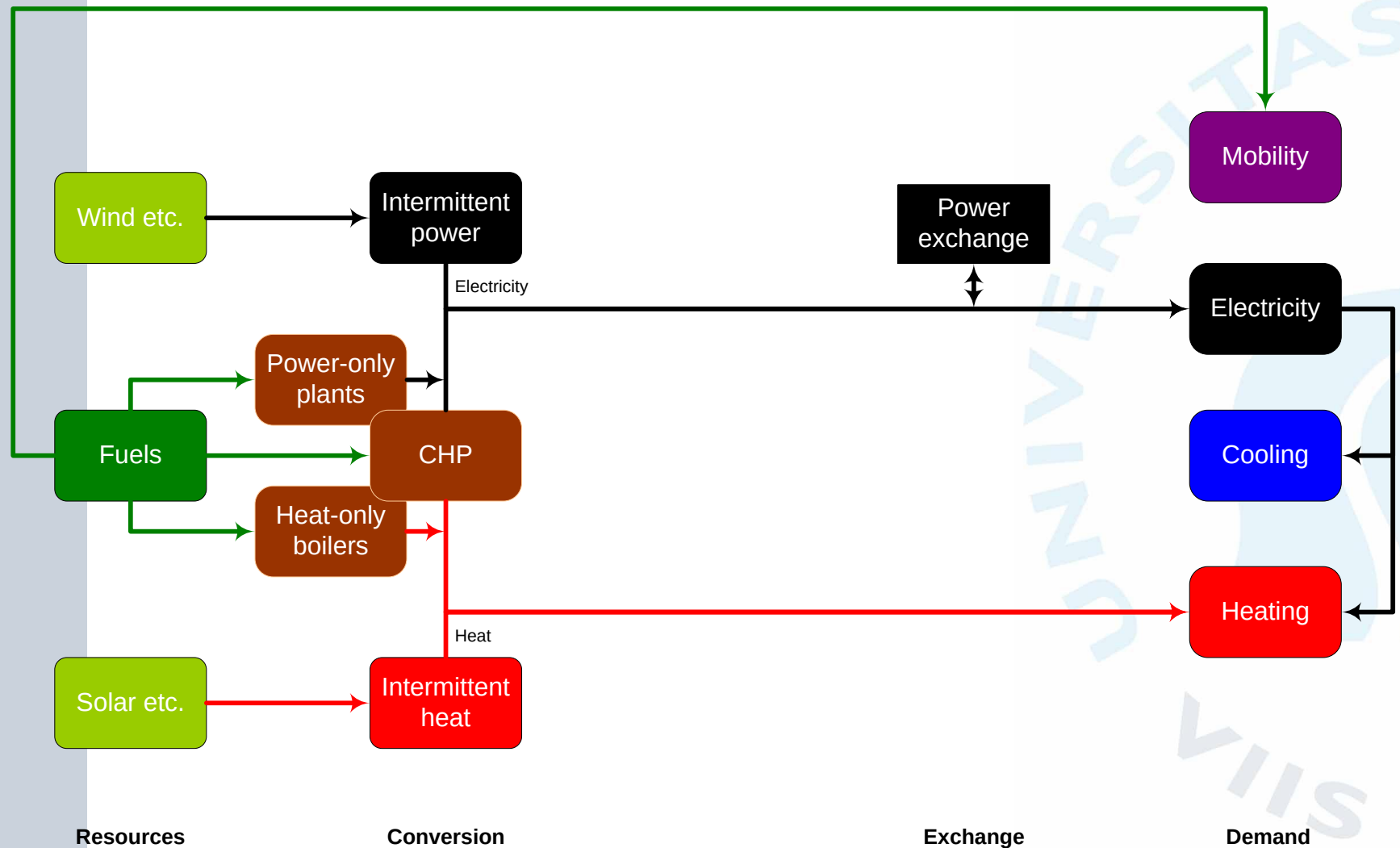
Linear programming model for operational optimization of projects

*** Break? ***

The pre-sustainable energy system

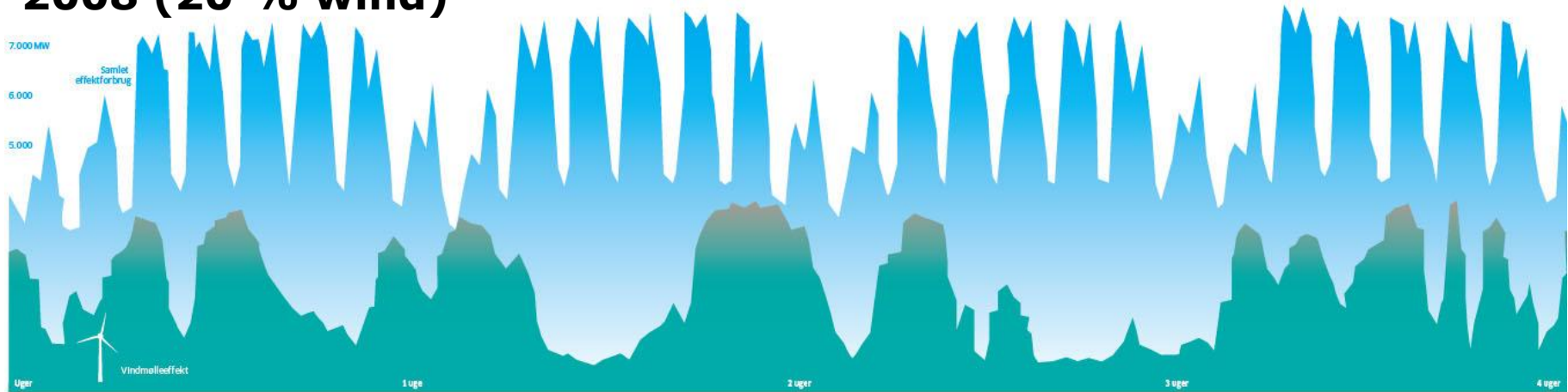


First generation sustainable energy system (1G)

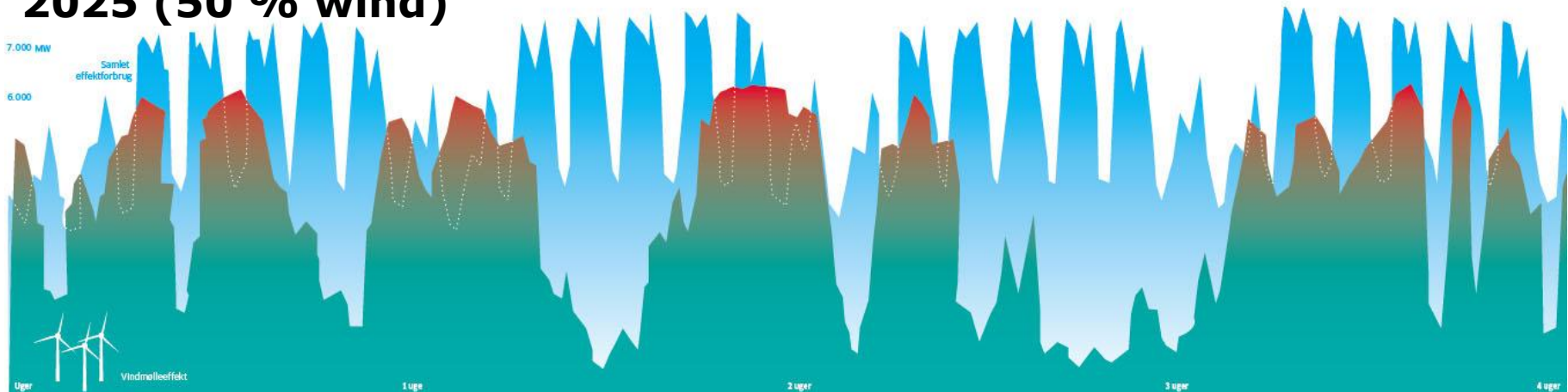


Intermittency calls for supply-demand intelligence

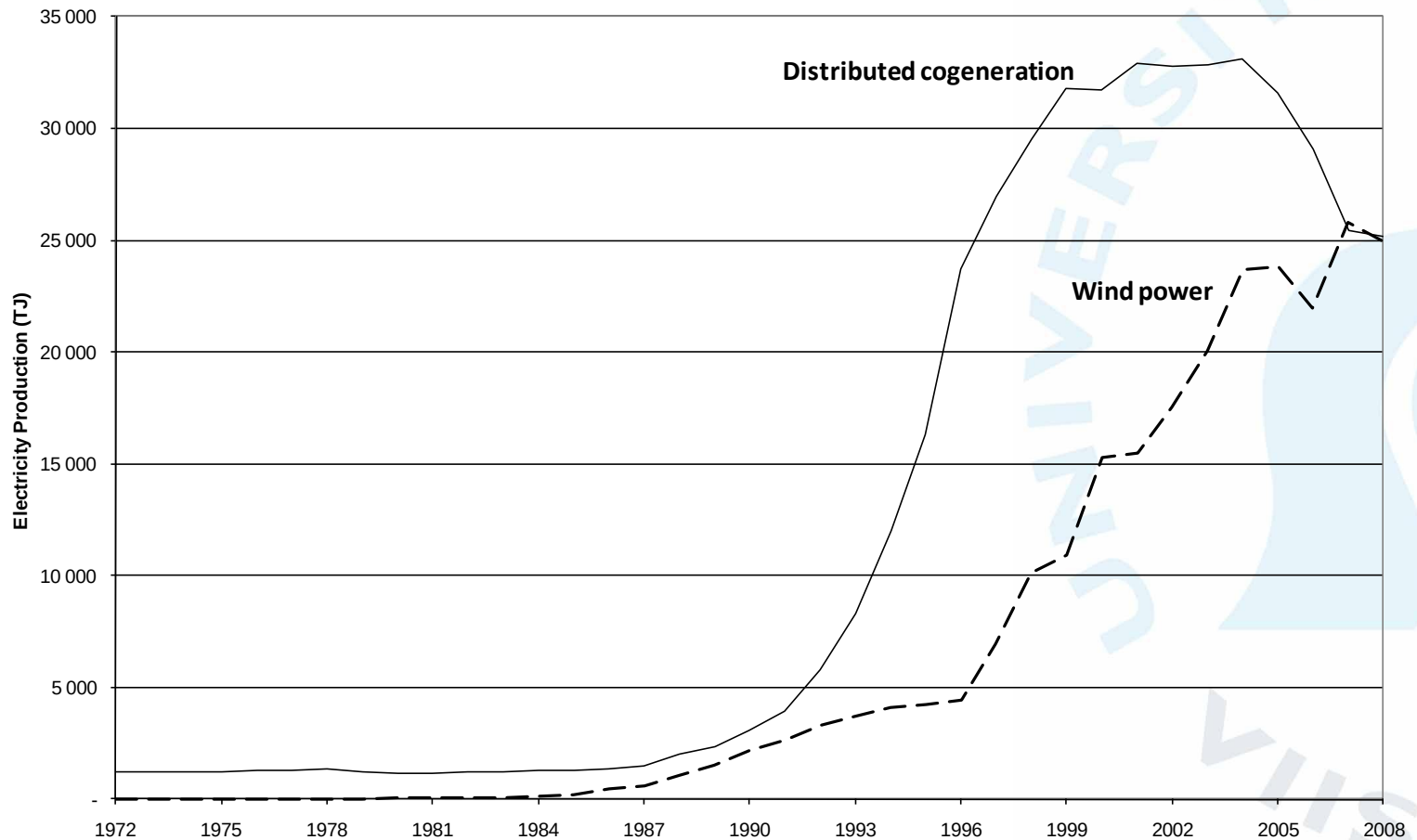
2008 (20 % wind)



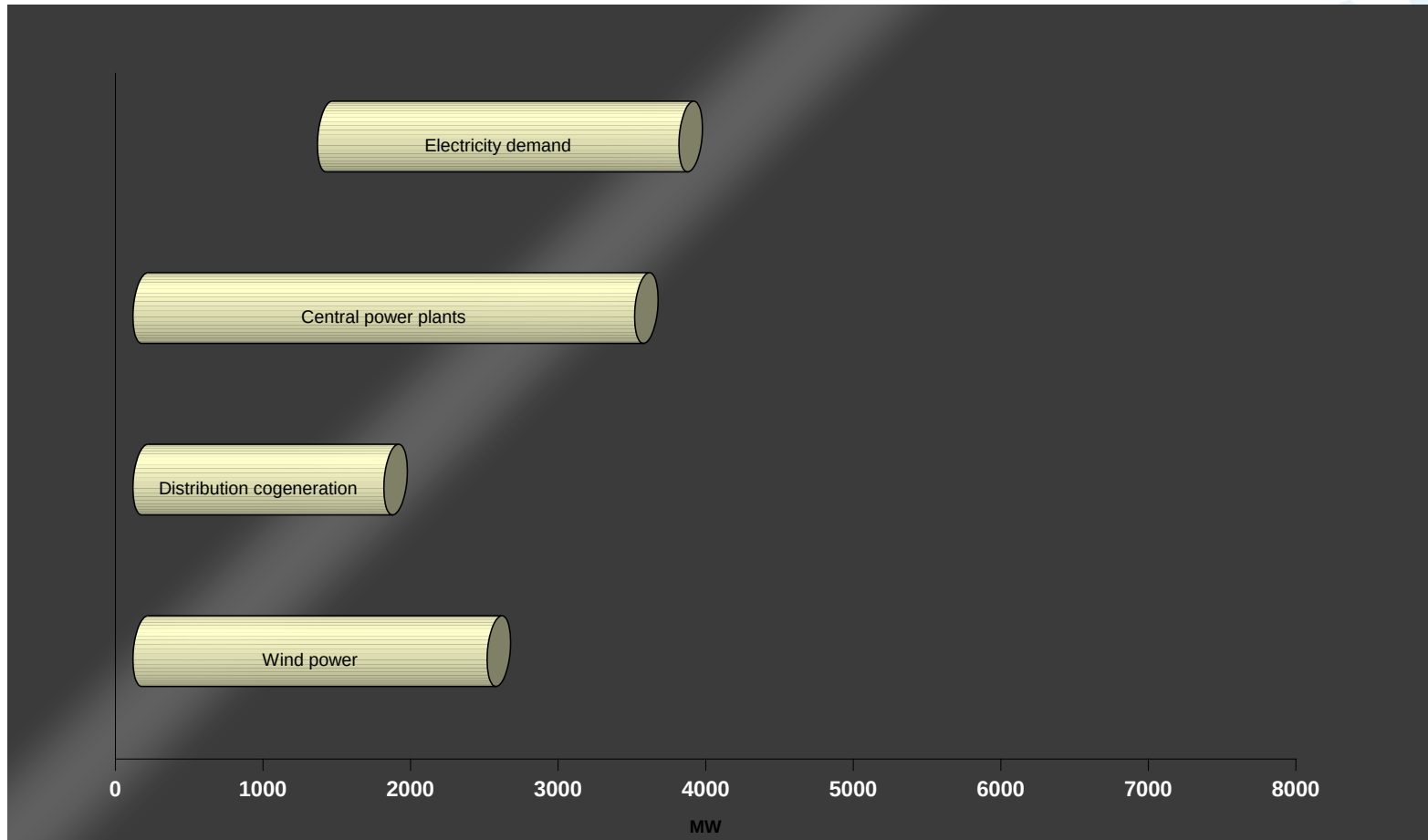
2025 (50 % wind)

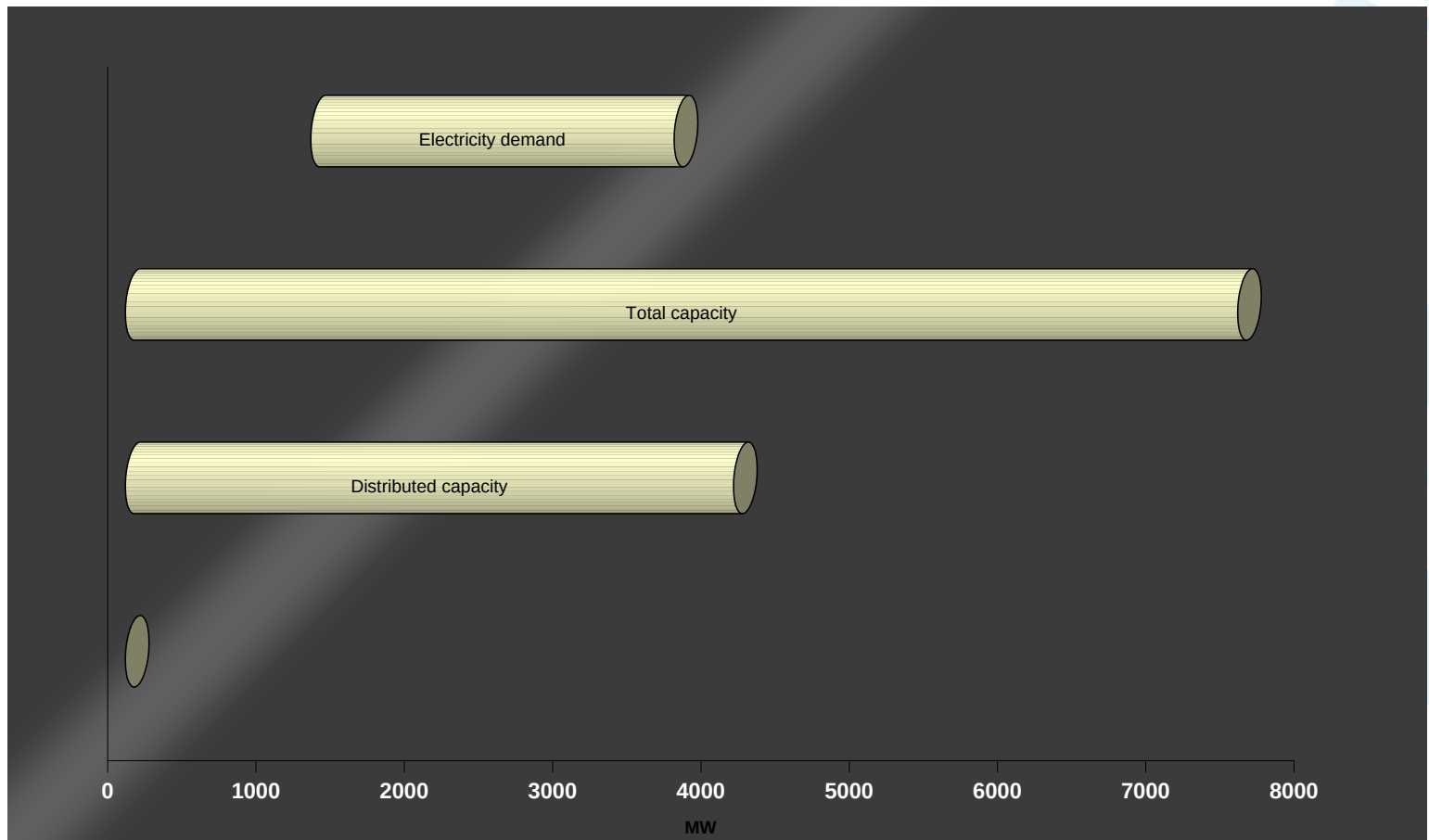


A challenge for distributed co-generation



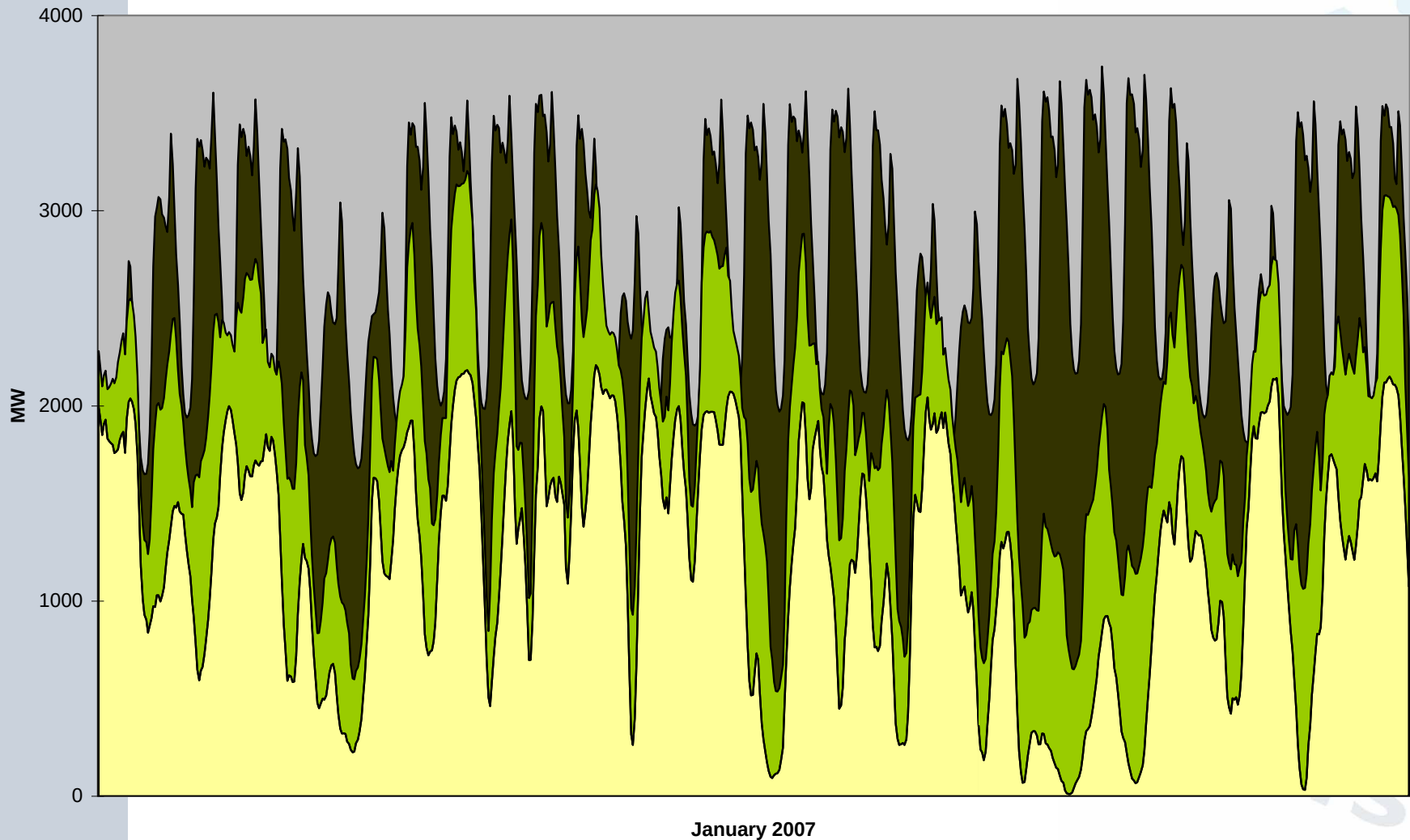
8
550
4100



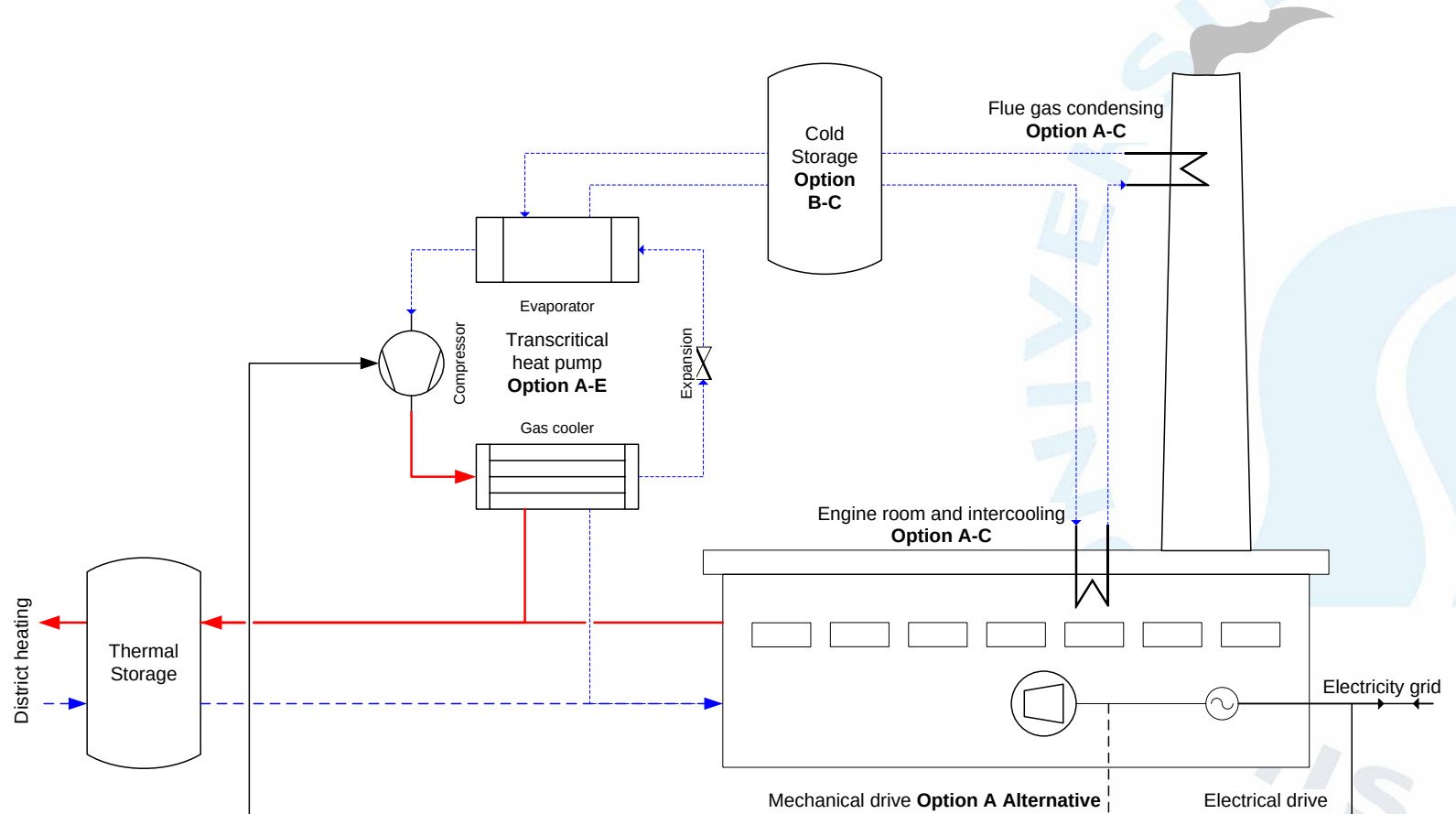


Wind, Distributed Generation, Demand

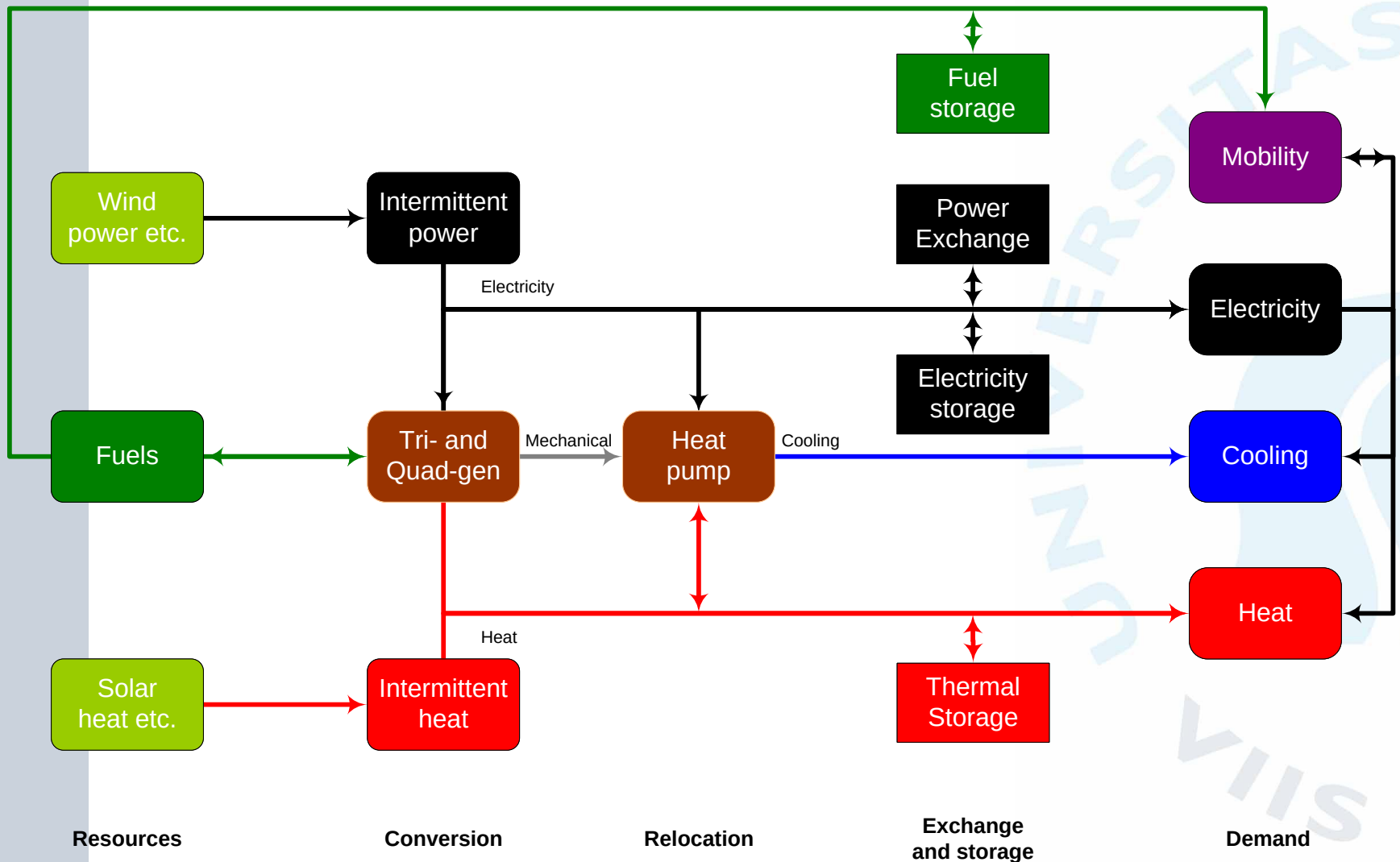
West Denmark, January 2007



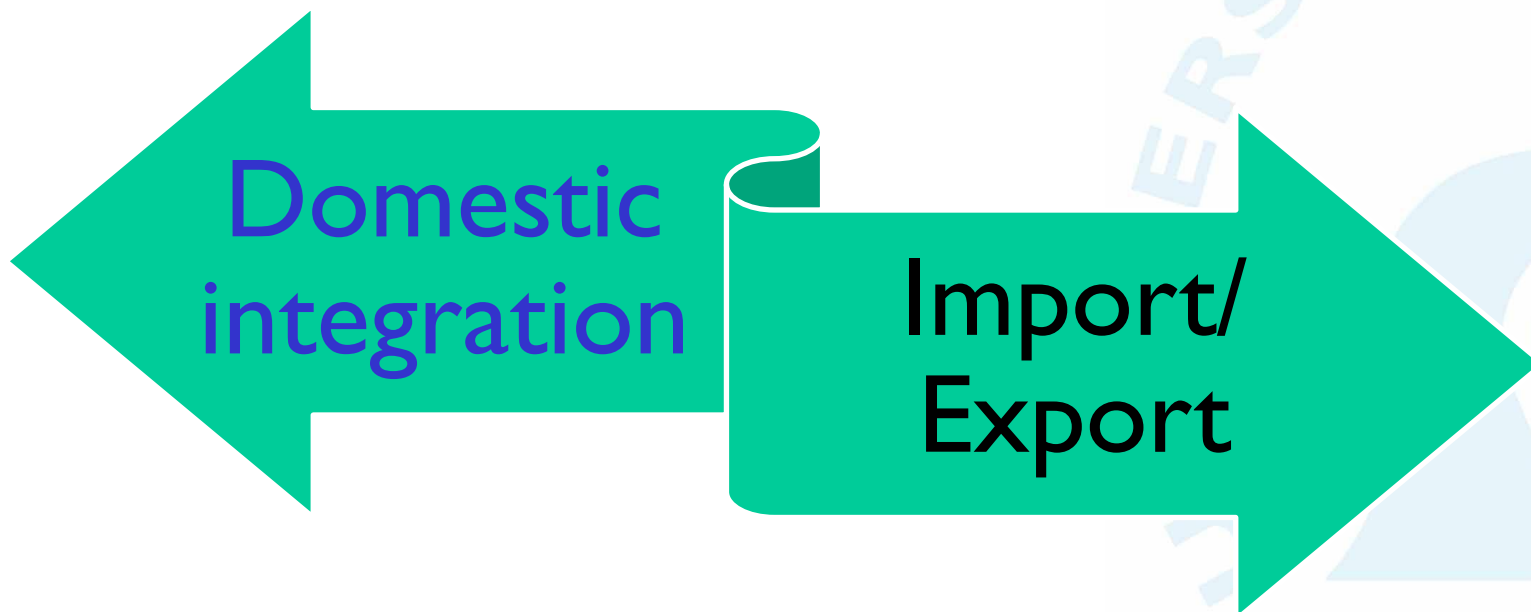
Wind-friendly cogenerator with heat pump, heat recovery, and “cold storage”



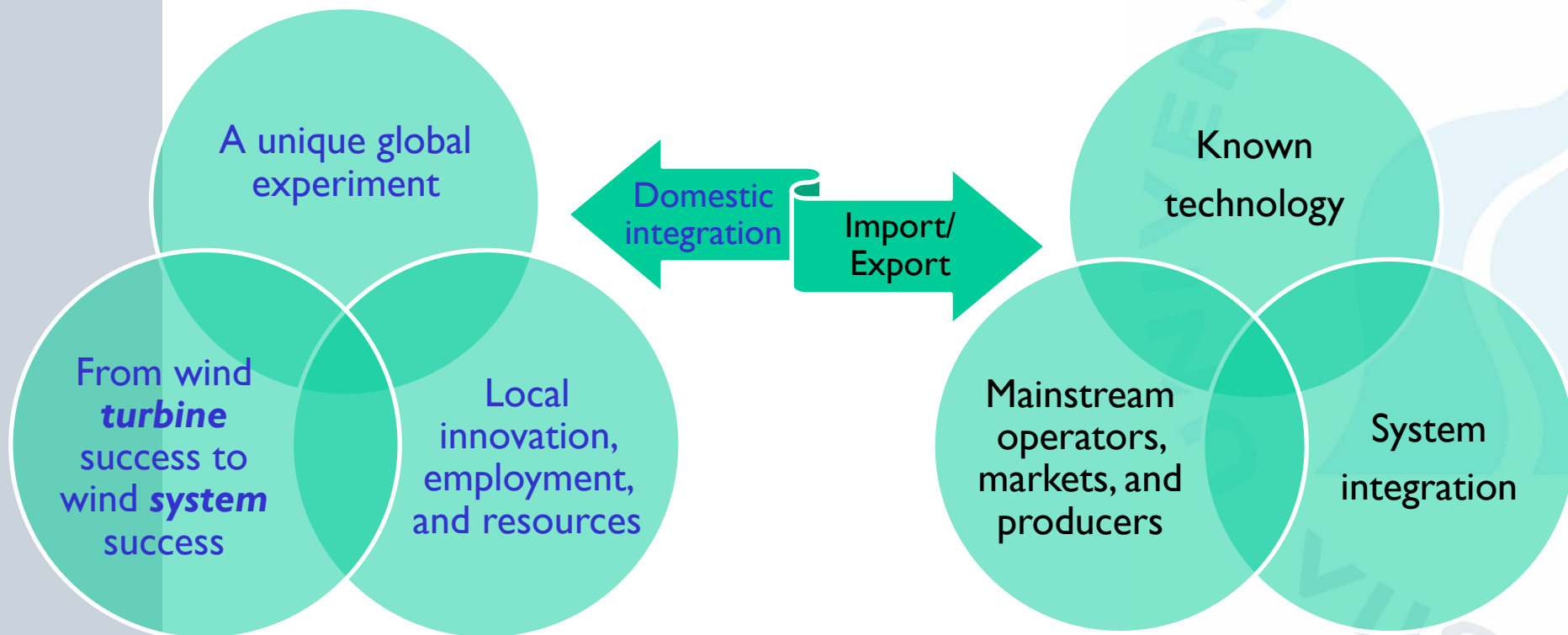
Next generation sustainable energy system (2G)



Strategic Challenge 2010-2025



Choosing the best strategy for Denmark: A choice that has potential global implications



*** Thank you ***