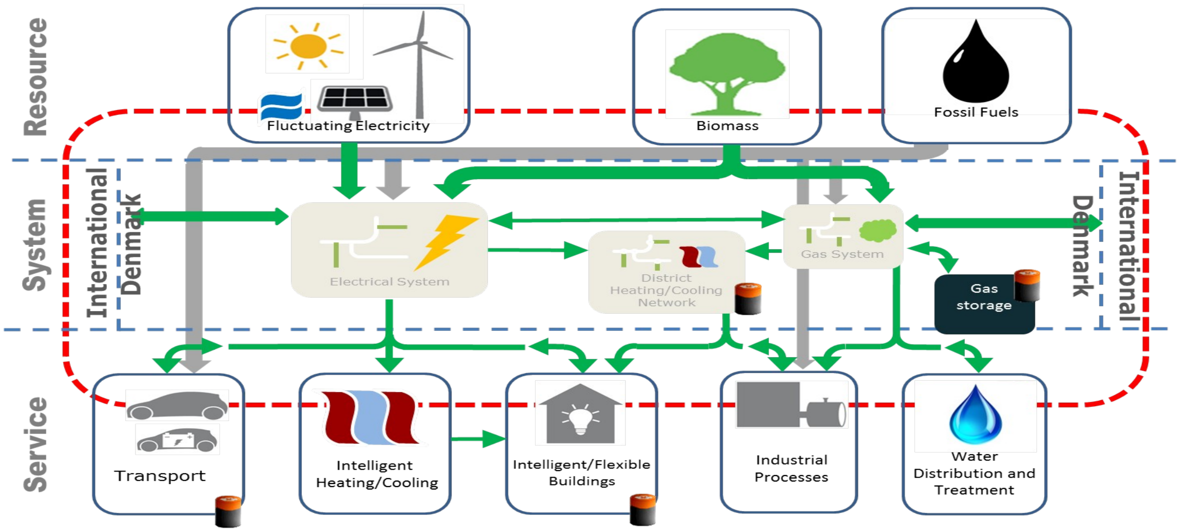
Intelligent Energy Systems Integration in Cities



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Danish Climate and Energy Policy / Goals

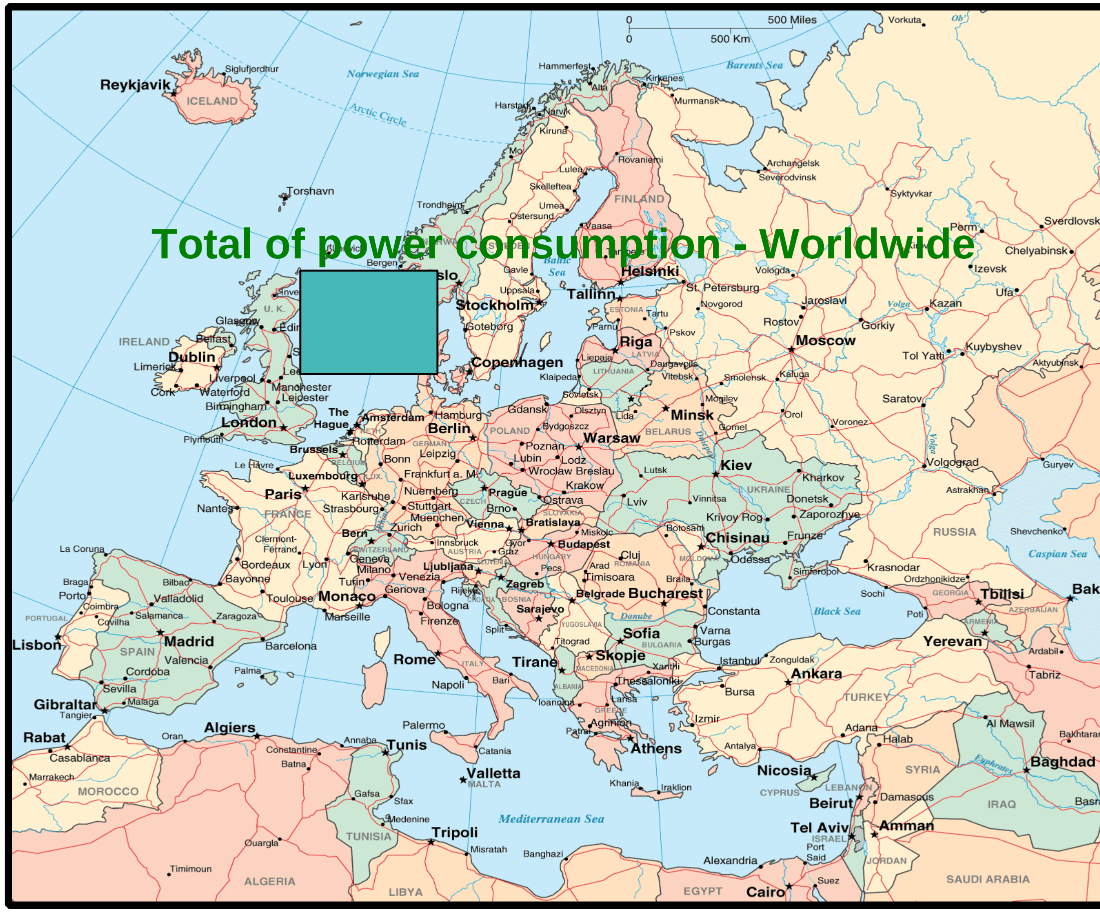
- 2020: 50 pct of electricity from wind power, and 35 pct of total energy consumption from renewable sources
- 2035: 100 pct of electricity and heating from renewable sources
- 2050: 100 pct of all (electricity, heating, transport, industry) from renewable sources

Potentials for renewable energy

- **Scenario**: We want to cover the worlds entire need for power using wind power.
- How large an area should be covered by wind turbines?

Potentials for renewable energy

- **Scenario:** We want to cover the worlds entire need for power using wind power.
- How large an area should be covered by wind turbines?
- **Conclusion**: Use intelligence ....
- Calls for **Smart Cities** Solutions.

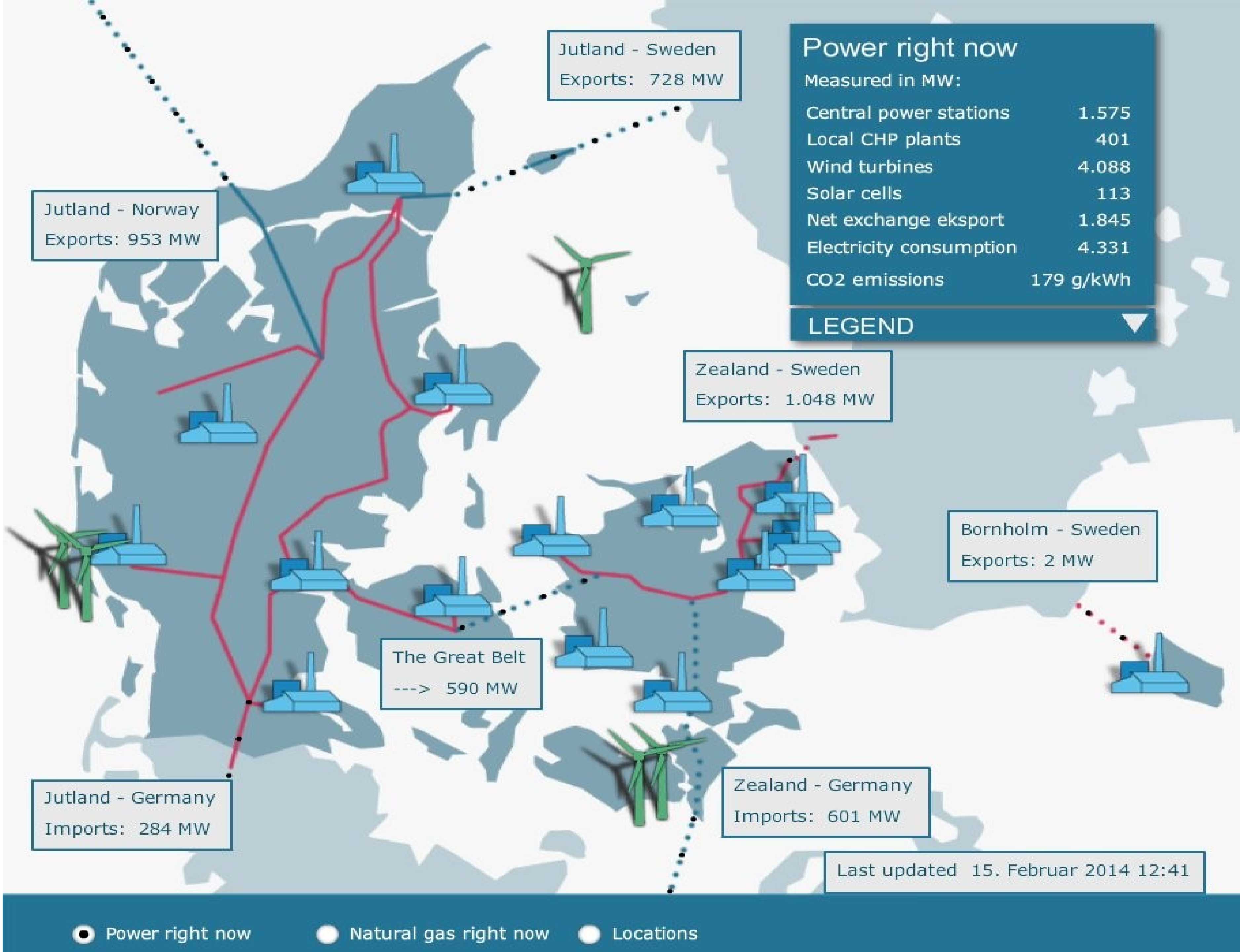


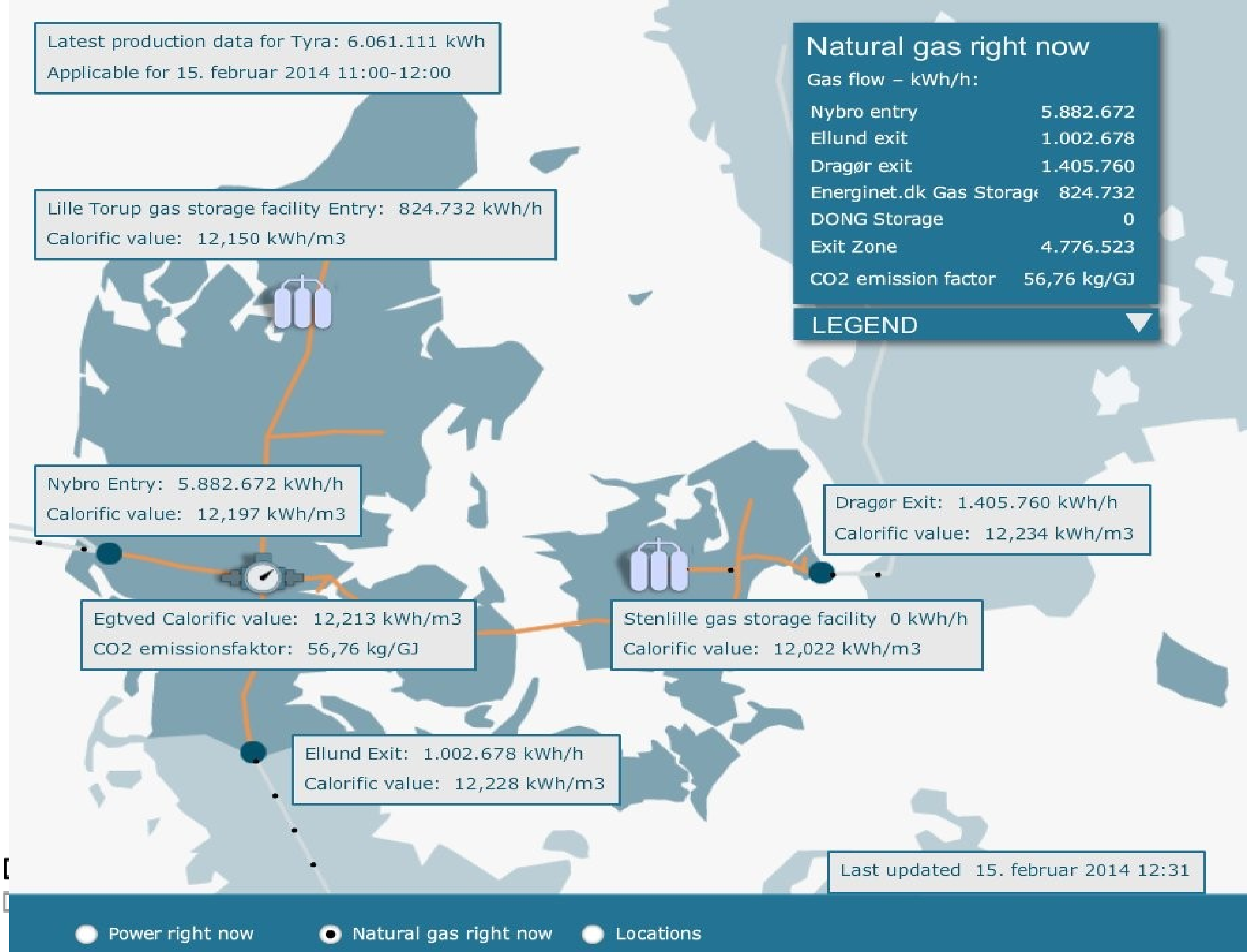
Wind integration in Denmark

- Notice – wind only:

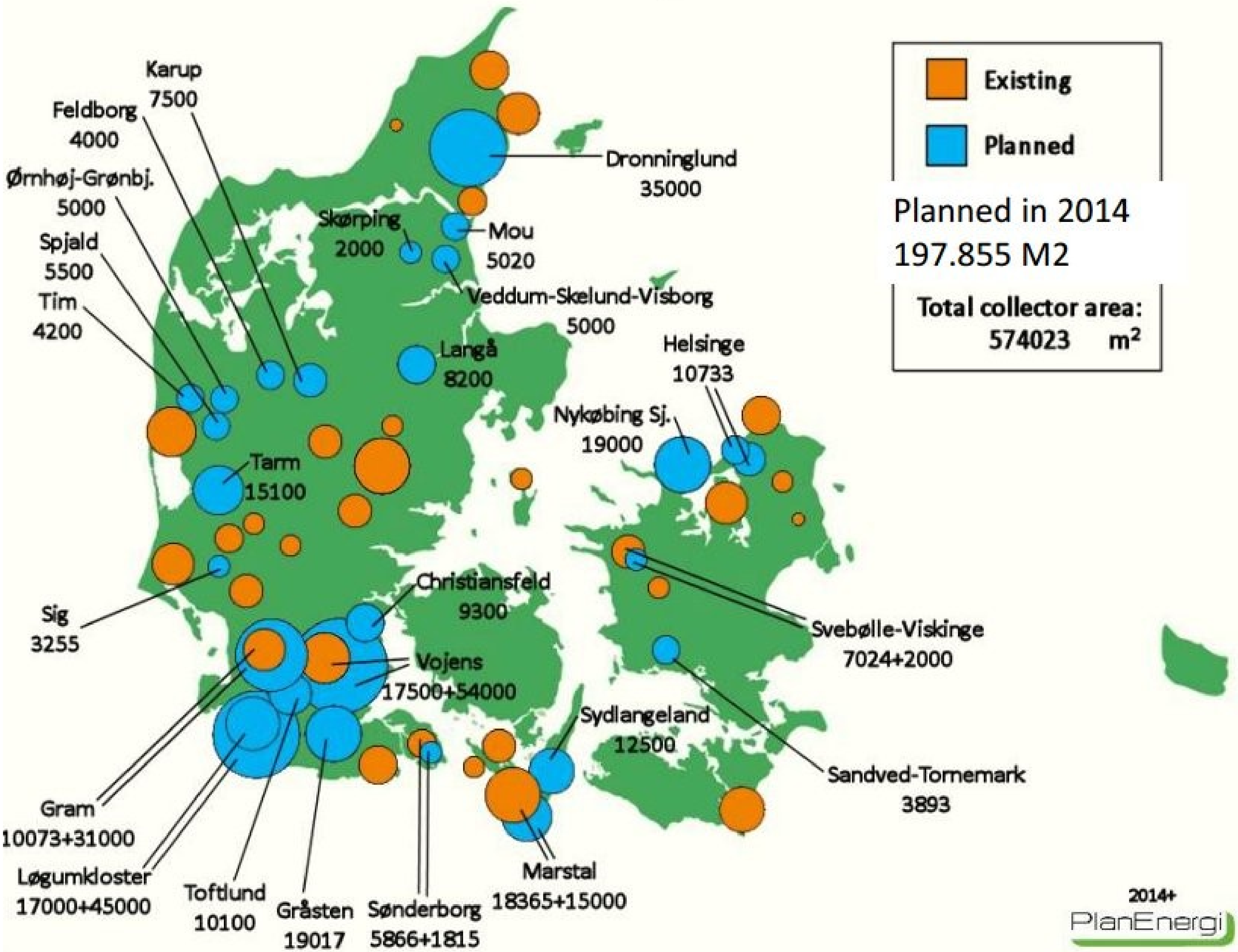
Key figures for wind power*

	2013	2012
Wind power generation	11.1 billion kWh	10.3 billion kWh
Electricity consumption (including loss in the electricity grid)	33.5 billion kWh	34.1 billion kWh
Wind power share of electricity consumption the entire year	33.2%	30.1%
Wind power share of electricity consumption in December	54.8%	33.5%
Wind power capacity at the end of the year	4,792 MW	4,166 MW
Energy content of the wind	Approx. 93% of a standard year	Approx. 102% of a standard year

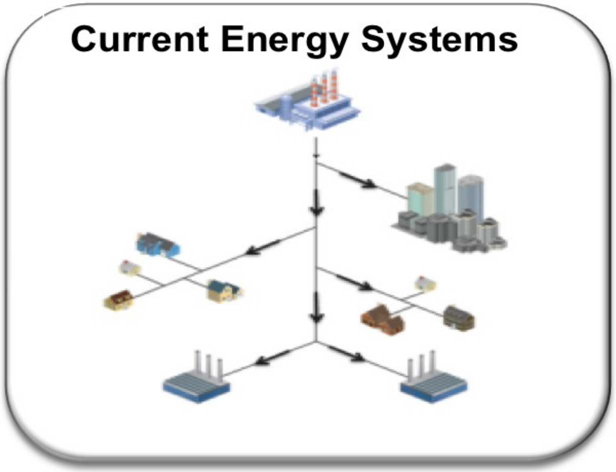

Power right now
Measured in MW:
Central power stations 1.575
Local CHP plants 401
Wind turbines 4.088
Solar cells 113
Net exchange eksport 1.845
Electricity consumption 4.331
CO2 emissions 179 g/kWh
LEGEND
Jutland - Sweden
Exports: 728 MW
Jutland - Norway
Exports: 953 MW
Zealand - Sweden
Exports: 1.048 MW
Bornholm - Sweden
Exports: 2 MW
The Great Belt
---> 590 MW
Jutland - Germany
Imports: 284 MW
Zealand - Germany
Imports: 601 MW
Last updated 15. Februar 2014 12:41
Power right now
Natural gas right now
Locations

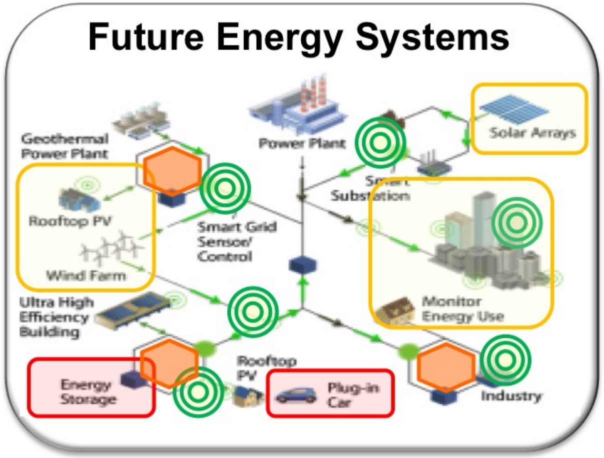

Latest production data for Tyra: 6.061.111 kWh
Applicable for 15. februar 2014 11:00-12:00
Natural gas right now
Gas flow – kWh/h:
Nybro entry 5.882.672
Ellund exit 1.002.678
Dragør exit 1.405.760
Energinet.dk Gas Storag 824.732
DONG Storage 0
Exit Zone 4.776.523
CO2 emission factor 56,76 kg/GJ
LEGEND
Lille Torup gas storage facility Entry: 824.732 kWh/h
Calorific value: 12,150 kWh/m3
Nybro Entry: 5.882.672 kWh/h
Calorific value: 12,197 kWh/m3
Dragør Exit: 1.405.760 kWh/h
Calorific value: 12,234 kWh/m3
Egtved Calorific value: 12,213 kWh/m3
CO2 emissionsfaktor: 56,76 kg/GJ
Stenlille gas storage facility 0 kWh/h
Calorific value: 12,022 kWh/m3
Ellund Exit: 1.002.678 kWh/h
Calorific value: 12,228 kWh/m3
Last updated 15. februar 2014 12:31
Power right now
Natural gas right now
Locations

Solar district heating in Denmark



Transition in the Energy World





The rapidly changing energy world calls for a the next generation of tools for simulation, planning, optimization, decision support, control and operation in Cities. These tools calls for research focusing on:

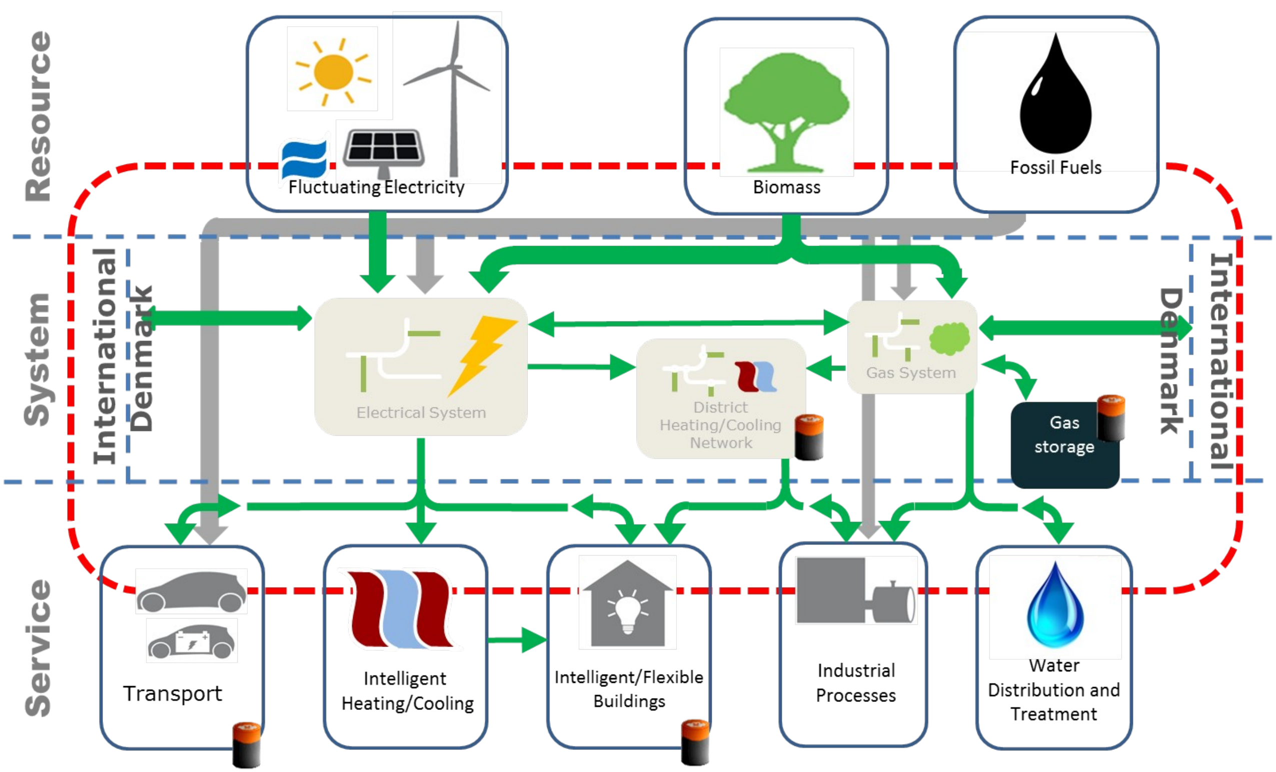
- Increasing penetration of variable RE in Cities
- Increasing ultra high energy efficiency buildings and controllable loads
- New data, information, communications and controls
- Electrification of transportation and alternative fuels
- Enable (virtual) energy storage by energy systems integration
- Interactions between electricity/thermal/fuels/data pathways
- Increasing system flexibility and intelligence

Project Ideas

Background, Concepts, Methodology, Objectives and Partners

Concept

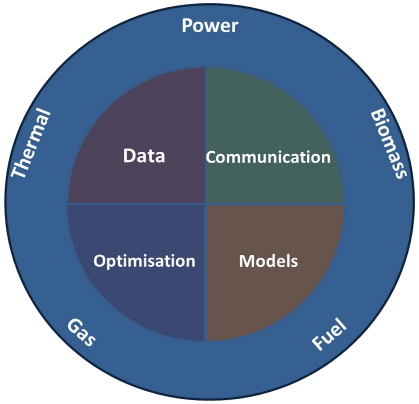
Integration based on city ***data and IT solutions*** leading to methods for *operation* of future energy systems in cities



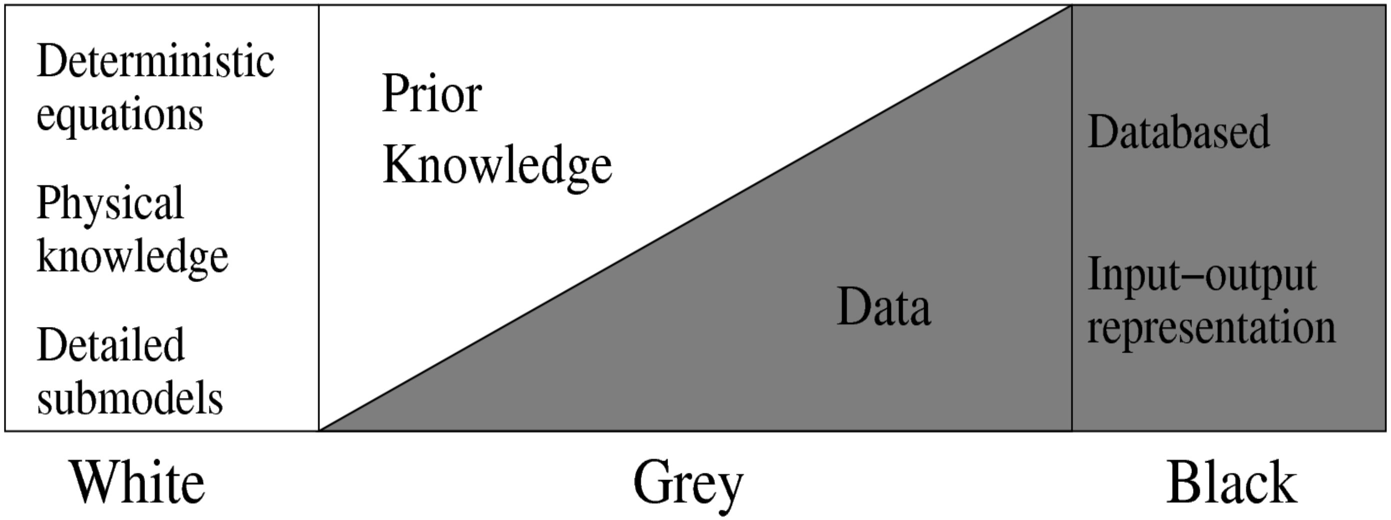
CITIES – Hypothesis

The **central hypothesis** of CITIES is that by **intelligently integrating** currently distinct energy flows (heat, power, gas and biomass) in urban environments we can enable very large shares of renewables, and consequently obtain substantial reductions in CO2 emissions.

Intelligent integration will enable lossless ‘virtual’ storage on a number of different timescales.

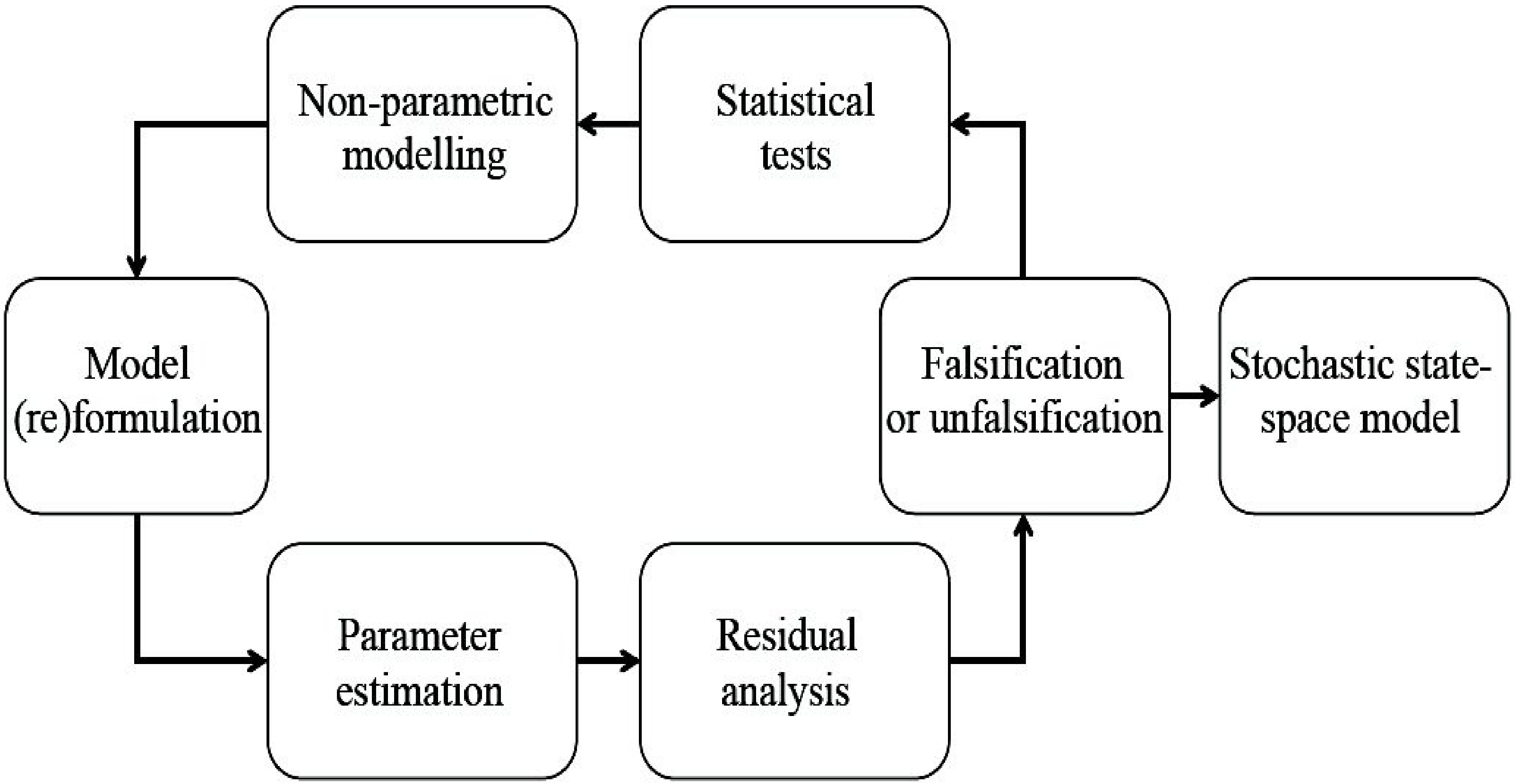


Grey-box modelling concept



- Combines prior physical knowledge with information in data
- Equations and parameters are physically interpretable

Grey-box model building

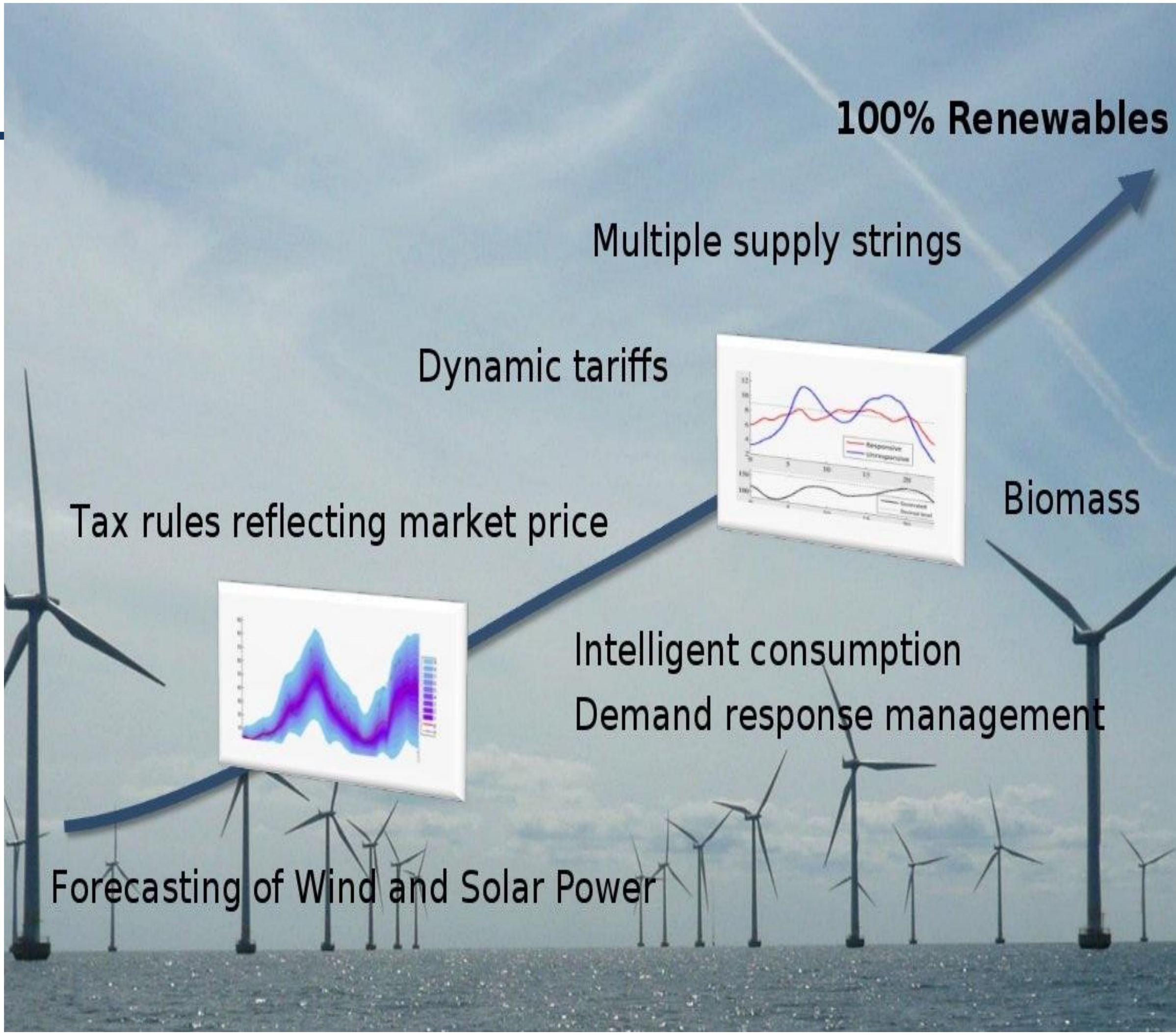


Grey-Box Modelling

- Bridge the gap between physical and statistical modelling
- Provides methods for model identification
- Provides methods for model validation
- Provides methods for pinpointing model deficiencies
- Enables methods for a reliable description of the uncertainties, which implies that the same model can be used for k-step forecasting, simulation and control

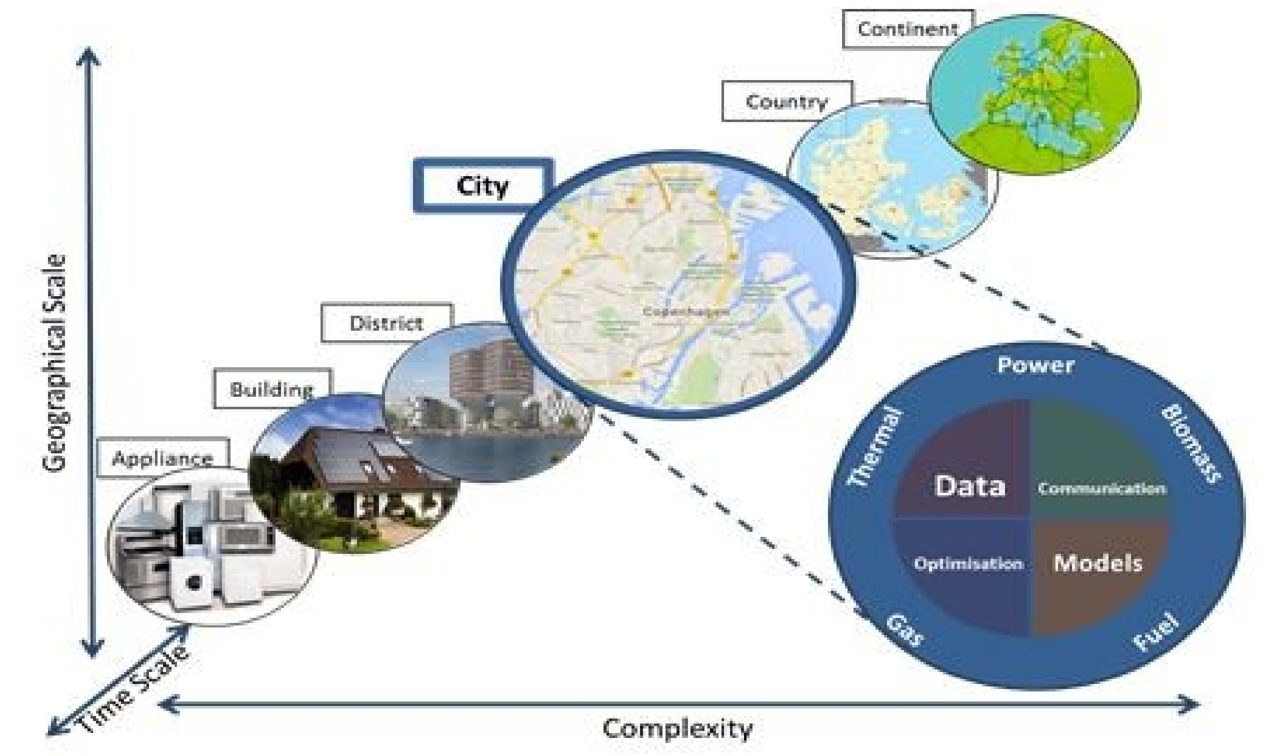
Societal Objectives

To establish methods and realistic scenarios for ultimately achieving independent from fossil fuels by harnessing the latent flexibility of energy systems in Cities through *intelligence, integration*, and *planning*.

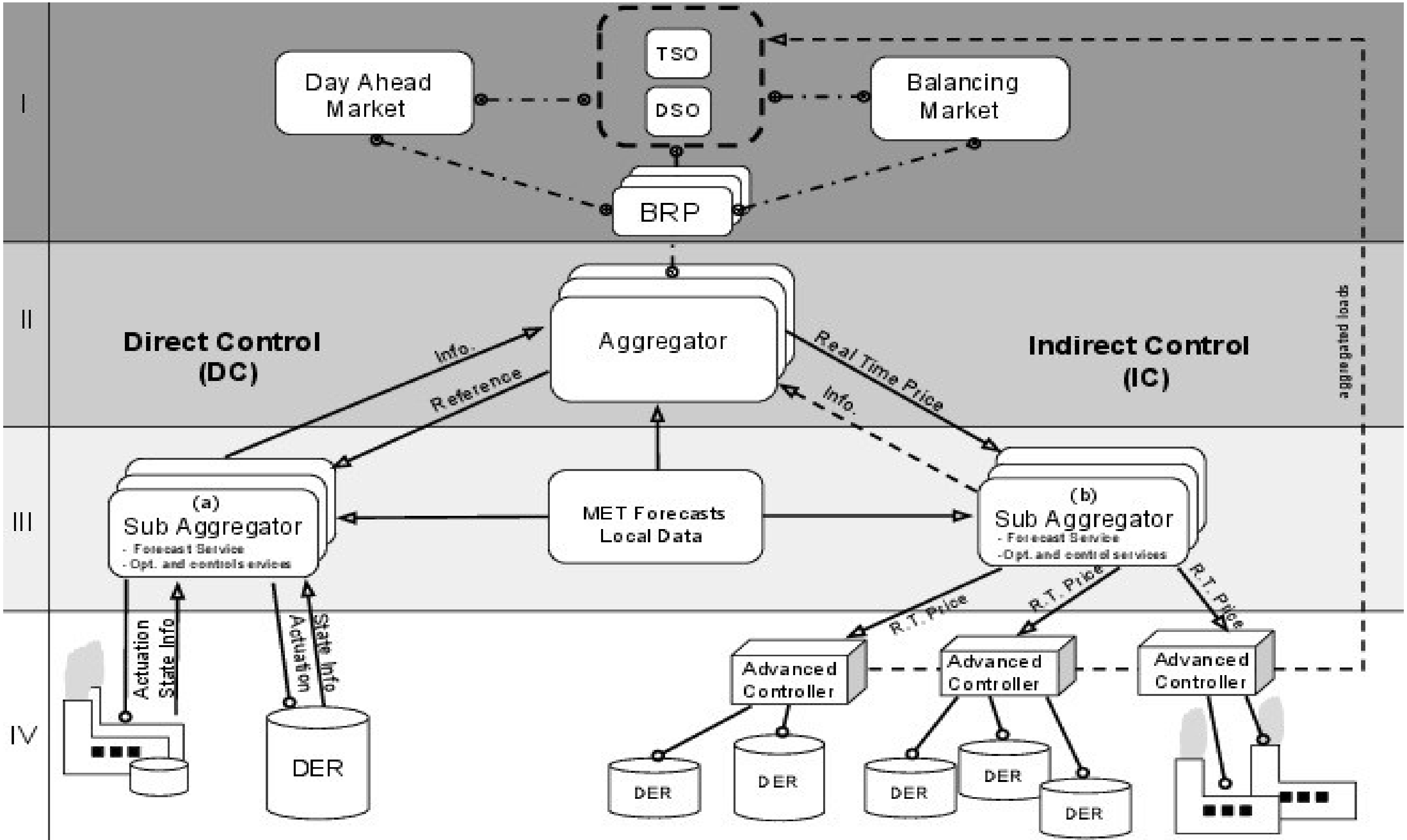


Scientific Objectives

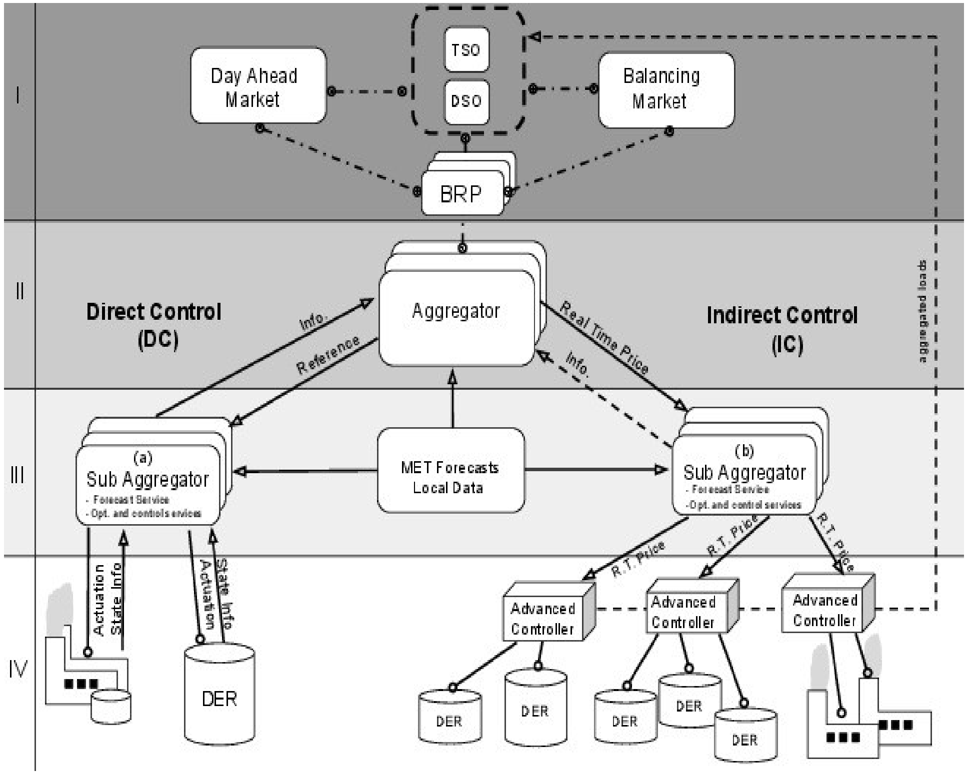
To establish methodologies and models for design and operation of integrated electrical, thermal, fuel pathways at all scales using data



Systems Control Hierarchy



Control Hierarchy



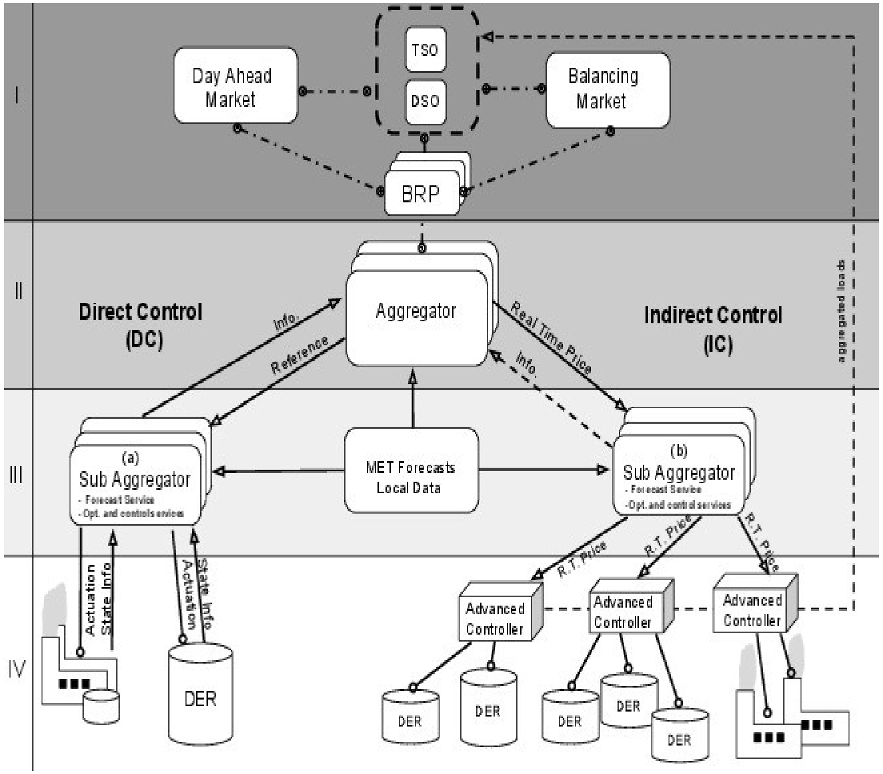
- **Day Ahead:**
  - Stoch. Programming based on eg. Scenarios
  - Cost: Related to the market (one or two levels)
  - Operational optimization – also for the grid
- **Direct Control:**
  - Actuator: **Power**
  - Cost: eg. MV, LQG, EMPC, ... (a single large problem)
  - Two-way communication
  - Models for DERs are needed
  - Constraints for the DERs (calls for state est.)
  - Contracts are complicated
- **Indirect Control:**
  - Actuator: **Price**
  - Cost: GPC, LQG at **high level**, VaR-alike
  - Cost: E-MPC at **low (DER) level**, ..
  - One-way communication
  - Models for DERs are not needed
  - Simple 'contracts'

Direct vs Indirect Control

<table>
<tr><th>Level</th><th>Direct Control (DC)</th><th>Indirect Control (IC)</th></tr>
<tr><td>III</td><td rowspan="2">$\min_{x,u} \sum_{k=0}^{N} \sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k})$
$\downarrow_{u_1} \cdots \downarrow_{u_J} \quad \uparrow_{x_1} \cdots \uparrow_{x_J}$
s.t. $\quad x_{j,k+1} = f_j(x_{j,k}, u_{j,k}) \quad \forall j \in J$</td><td>$\min_{\hat{z},p} \sum_{k=0}^{N} \phi(\hat{z}_k, p_k)$
s.t. $\quad \hat{z}_{k+1} = f(p_k)$</td></tr>
<tr><td>IV</td><td>$\min_u \sum_{k=0}^{N} \phi_j(p_k, u_k) \quad \forall j \in J$
s.t. $\quad x_{k+1} = f_j(x_k, u_k)$</td></tr>
</table>

Table 1: Comparison between direct (DC) and indirect (IC) control methods. (DC) In direct control the optimization is globally solved at level III. Consequently the optimal control signals u_j are sent to all the J DER units at level IV. (IC) In indirect control the optimization at level III computes the optimal prices p which are sent to the J-units at level IV. Hence the J DERs optimize their own energy consumption taking into account p as the actual price of energy.

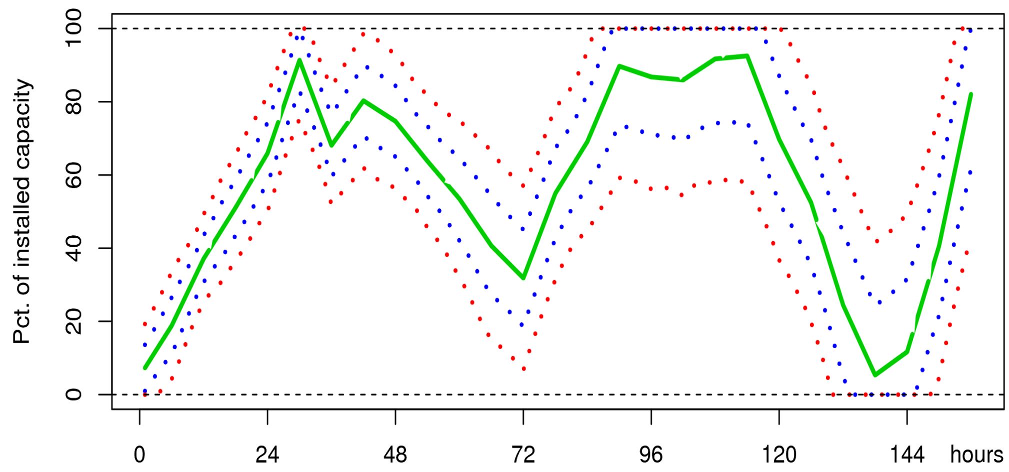
Forecast requirements

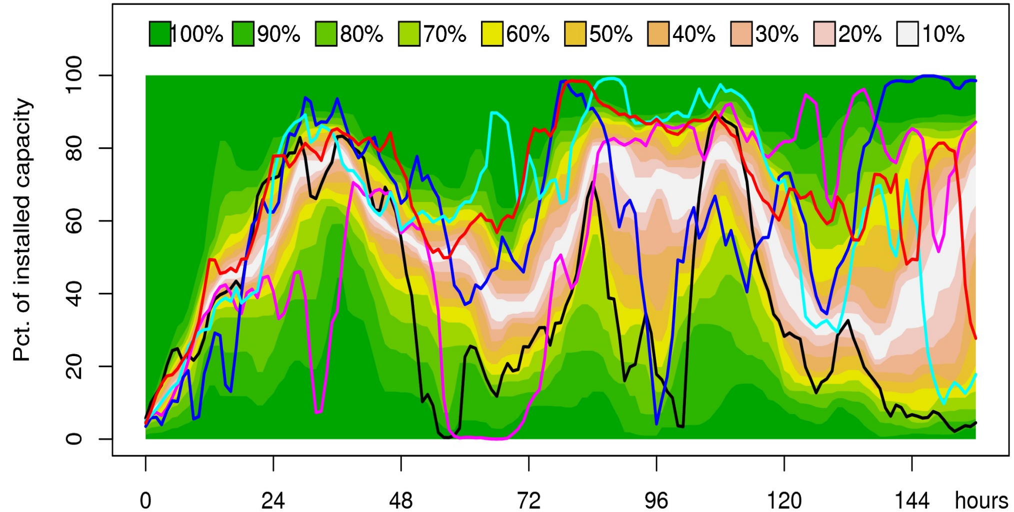


- **Day Ahead:**
  - Forecasts of loads
  - Forecast of Grid Capacity (using eg. DLR)
  - Forecasts of production (eg. Wind and Solar)
- **Direct Control:** .
  - Forecasts of states of DERs
  - Forecasts of load
- **Indirect Control:**
  - Forecasts of prices
  - Forecasts of load

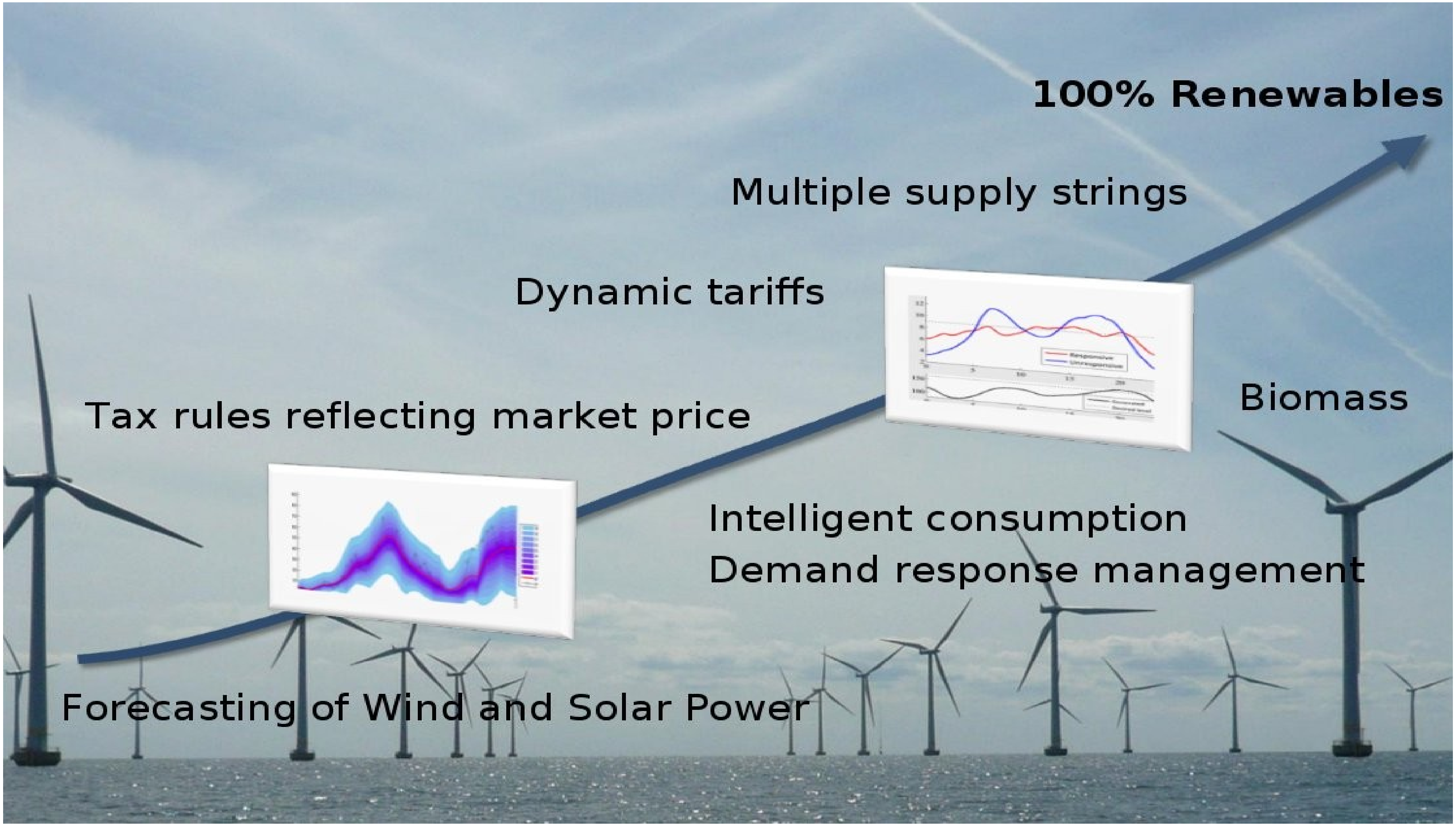
Which type of forecast to use?

- Point forecasts
- Conditional mean and covariances
- Conditional quantiles
- Conditional scenarios
- Conditional densities
- Stochastic differential equations

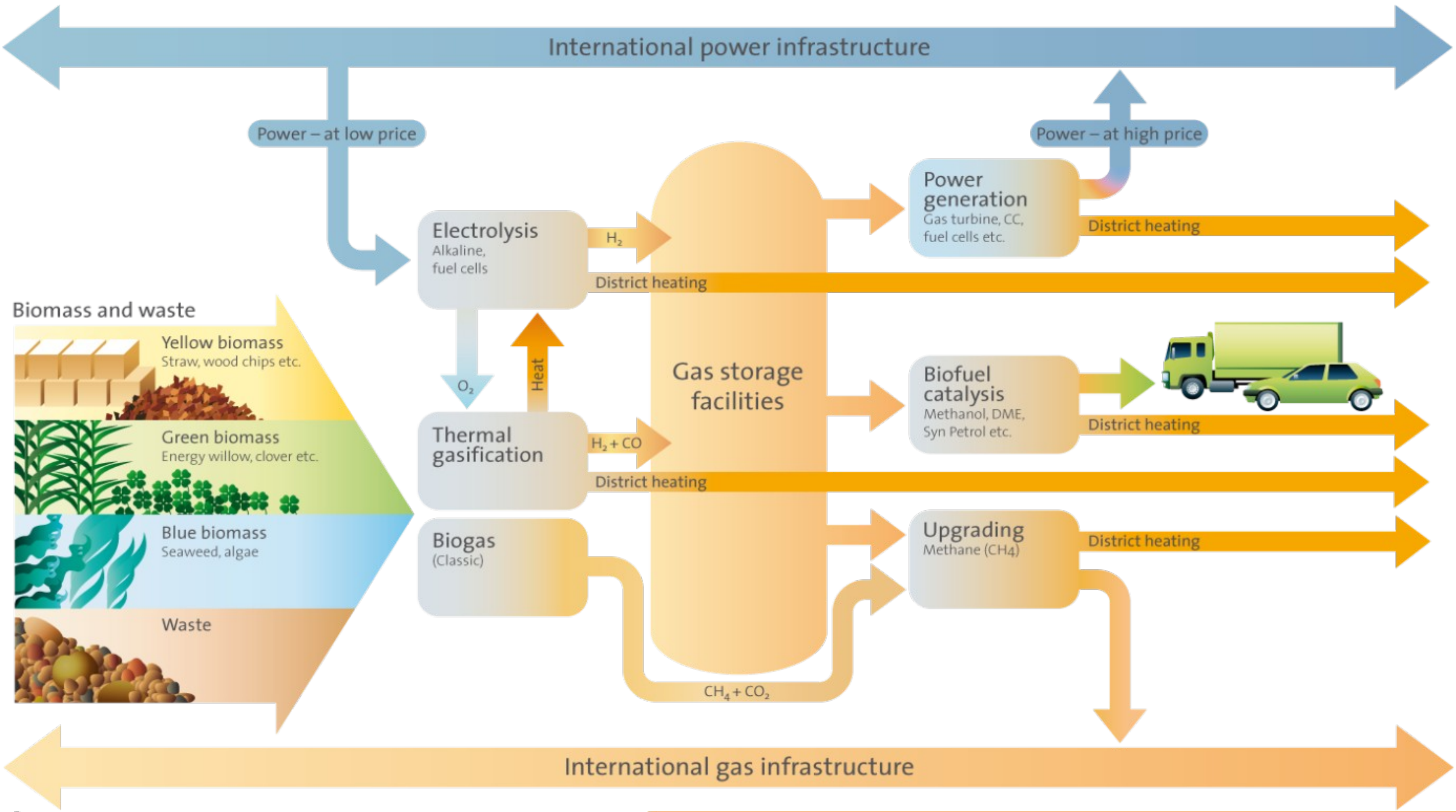




Measures to obtain the goal



Interactions between power, gas, DH, and biomass systems

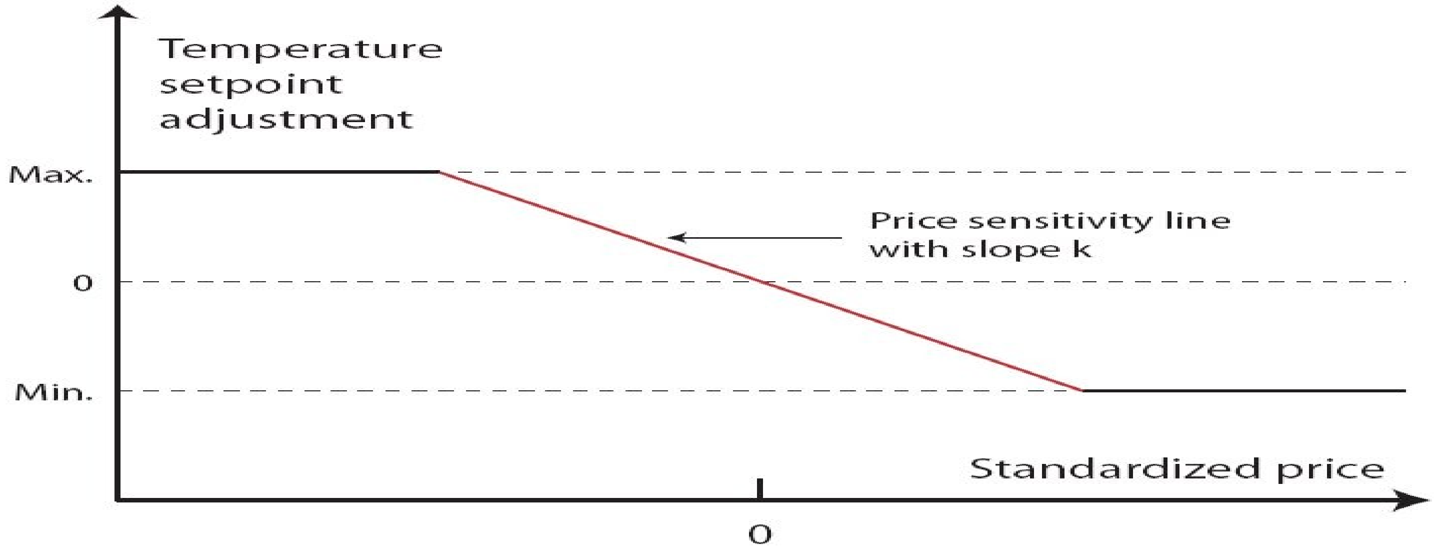


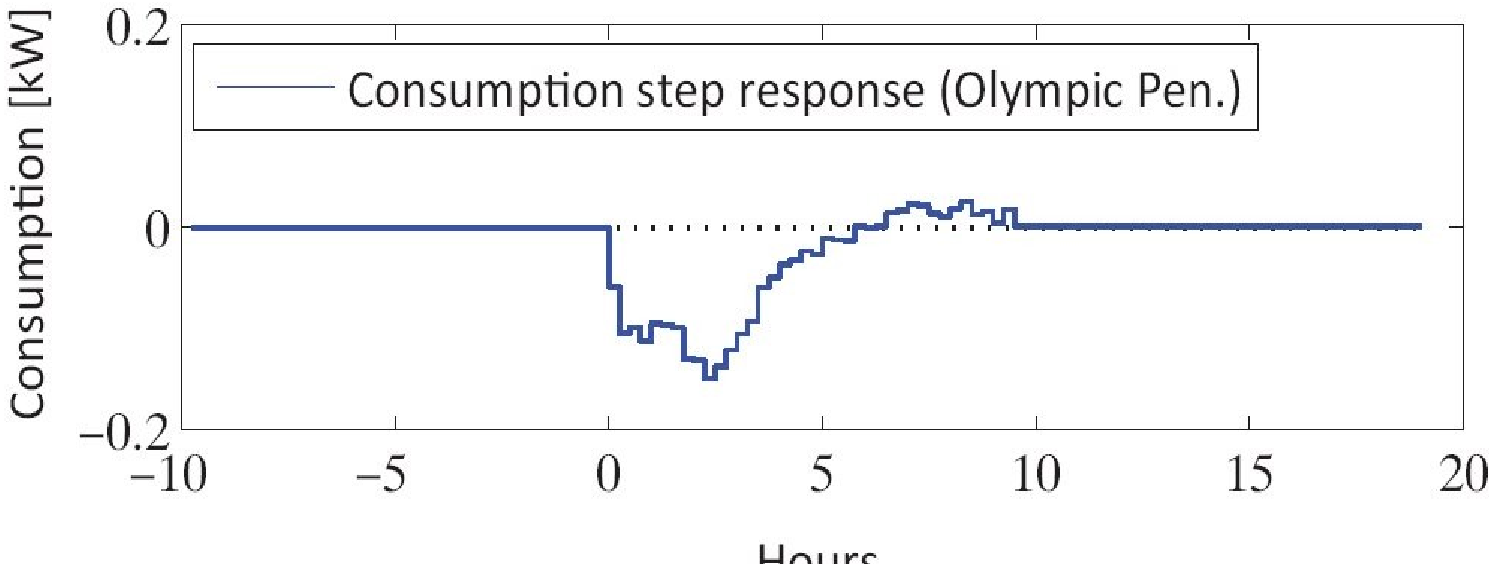
Case study

Electrical Heating of Buildings

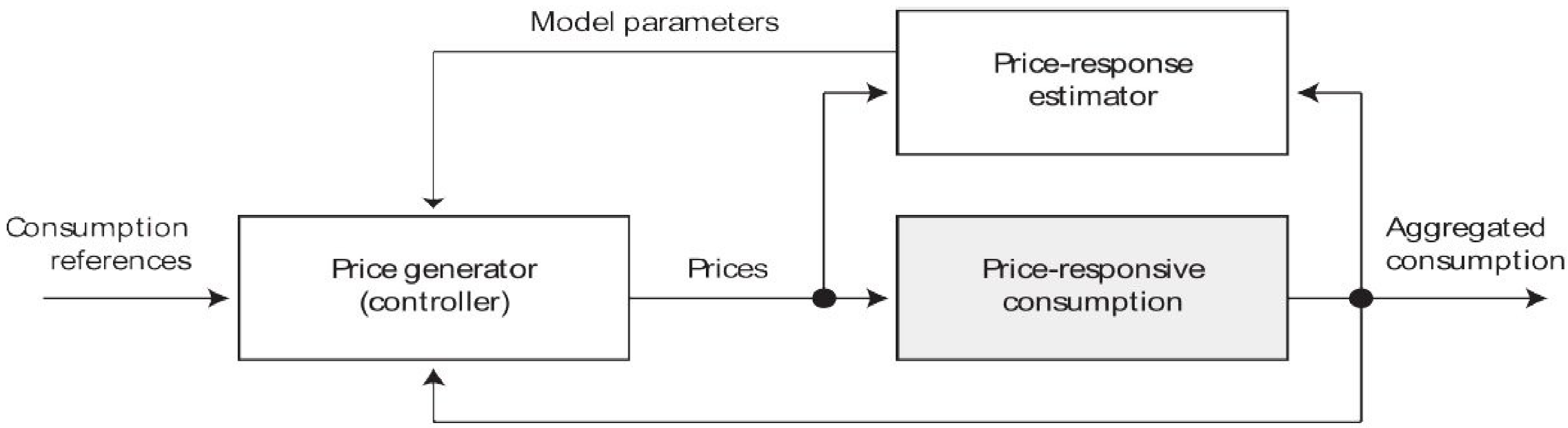
Control of Load by Price

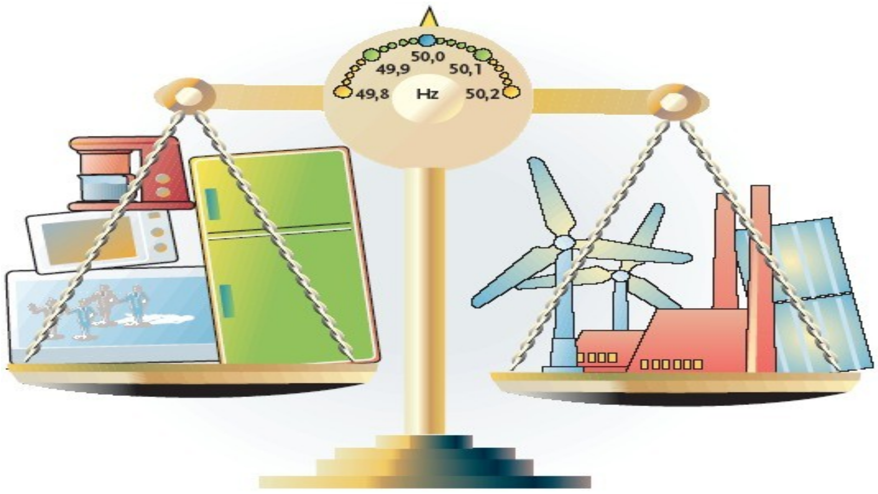
CITIES Solution:
Demand Side Management





Control of Energy Consumption

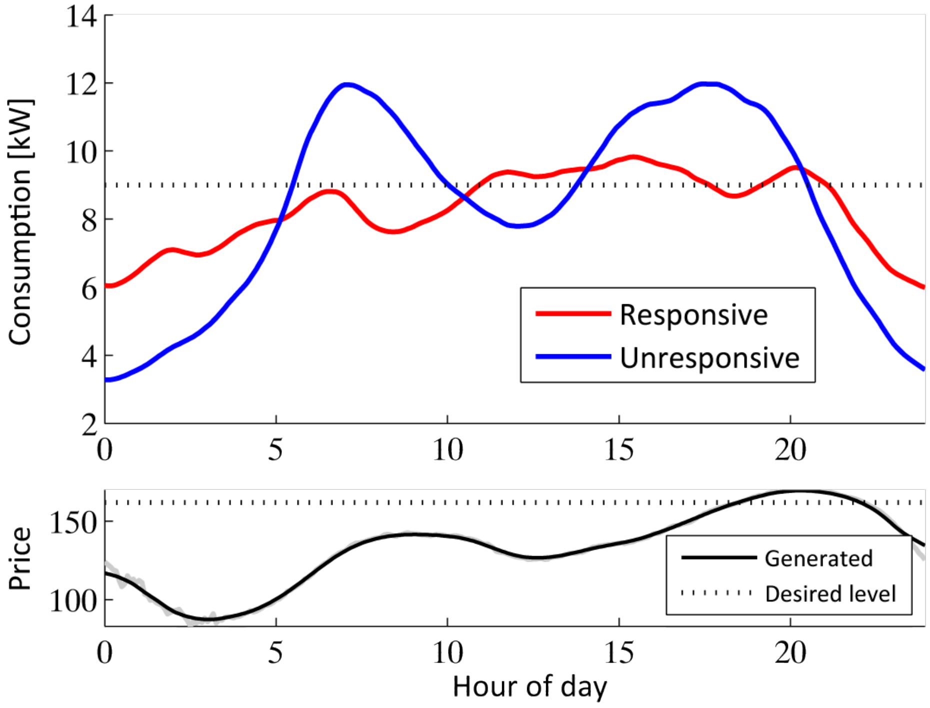




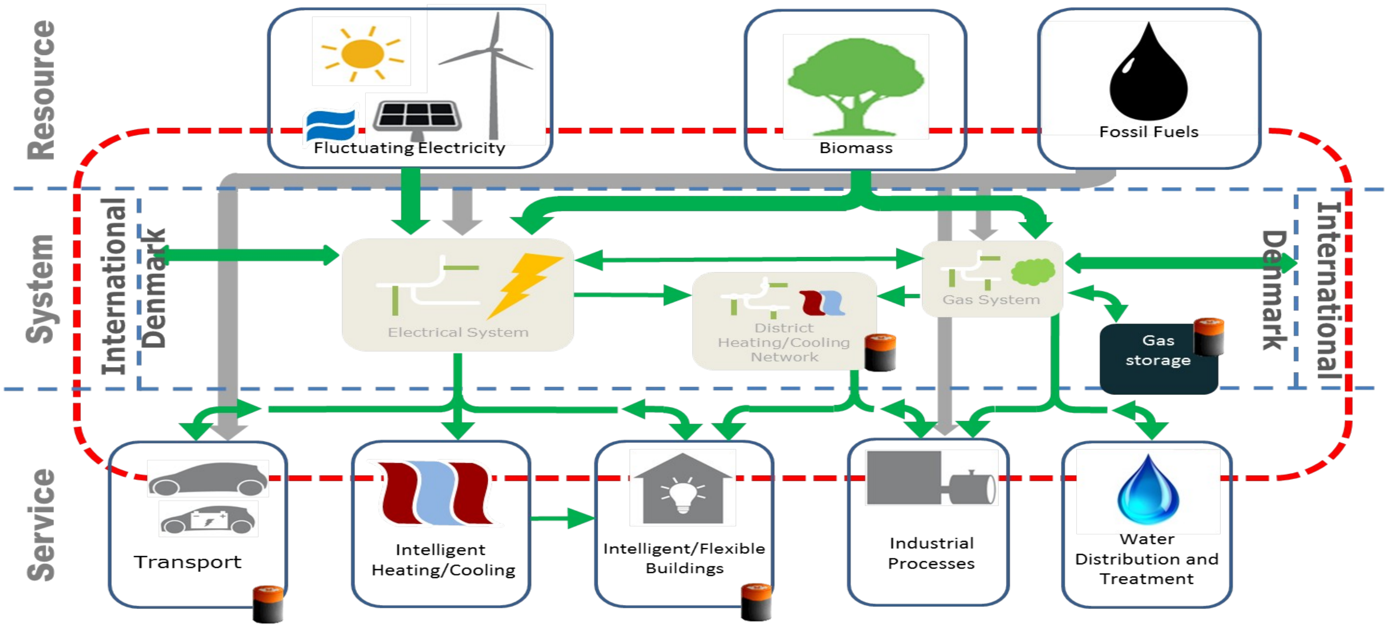
Control performance

With a price penality avoiding its divergence from power reference

- Considerable reduction in max consumption
- Mean daily consumption shift



Control and Storage by Energy Systems Integration



- Operational (simplified) models, optimization and control
- (Virtual) storage principles:
  - Buildings provide storage up to, say, 10 hours ahead
  - District heating systems lead provide storage up to 2-3 days ahead
  - Gas systems provide seasonal storage

DSM – Examples (from DK)

- Temperature control in houses (Samsung)
- HVAC systems (Grundfos, Samsung)
- Supermarket cooling (Danfoss)
- Electricity consumption in family houses (Saseco)
- District heating/cooling networks (EMD International)
- Combined Heat and Power plants (Dong Energy)
- Intellingent use of biomass
- Wastewater treatment plants (Kruger, Veolia)
- ....

Thanks to DSF

(DSF – 1305-00027B)

For more information:

www.smart-cities-centre.org