Spatial & Temporal Issues

Energy Systems Models

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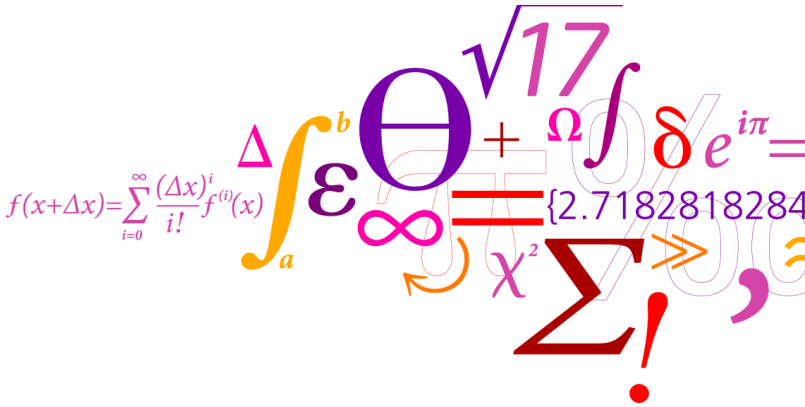


DTU Management Engineering
Department of Management Engineering

Introduction

My PhD Project (Energy Systems Group – DTU):

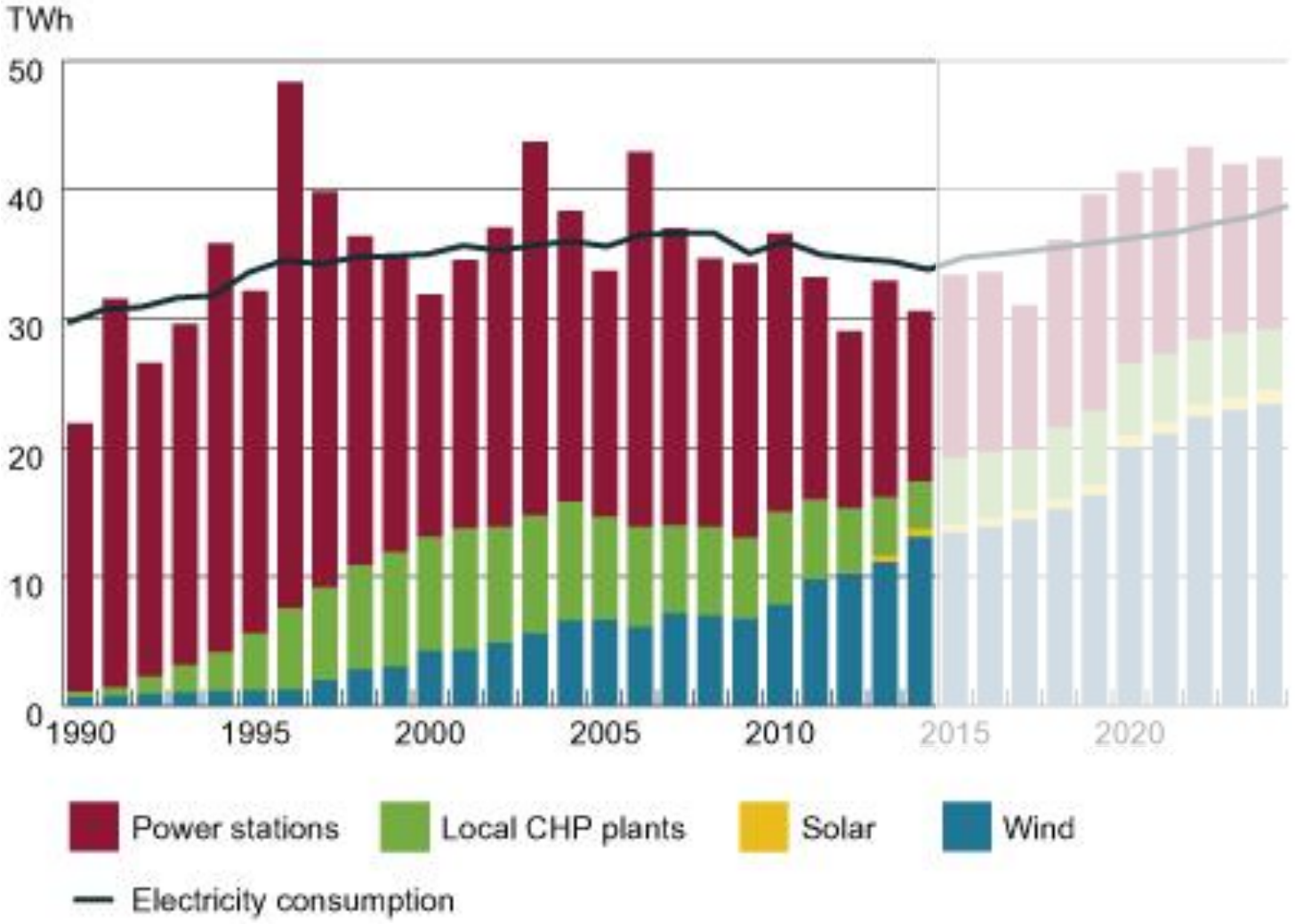
"Modelling of biomass, waste and gas in future energy systems"

Underlying framework – 2050 Carbon Neutral scenarios

- Fossil-free electricity and heating sectors by 2035 in Denmark
- Decarbonised electricity, heat and transport sectors by 2050 in Denmark

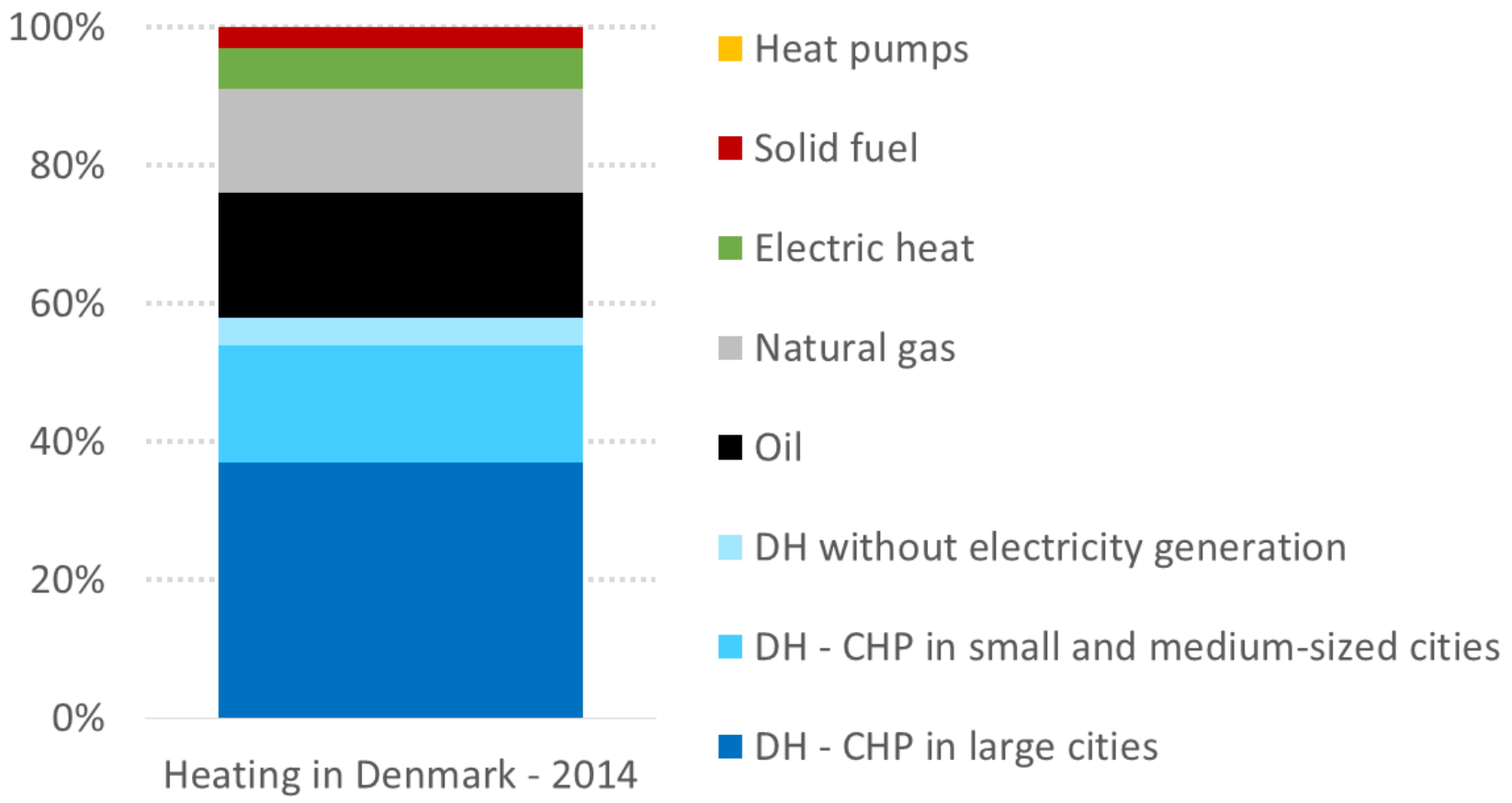
Why spatial and temporal issues are key on my research?

Developments in electricity generation from 1990 to 2024



Source: energinet.dk

Heat Generation in Denmark in 2014



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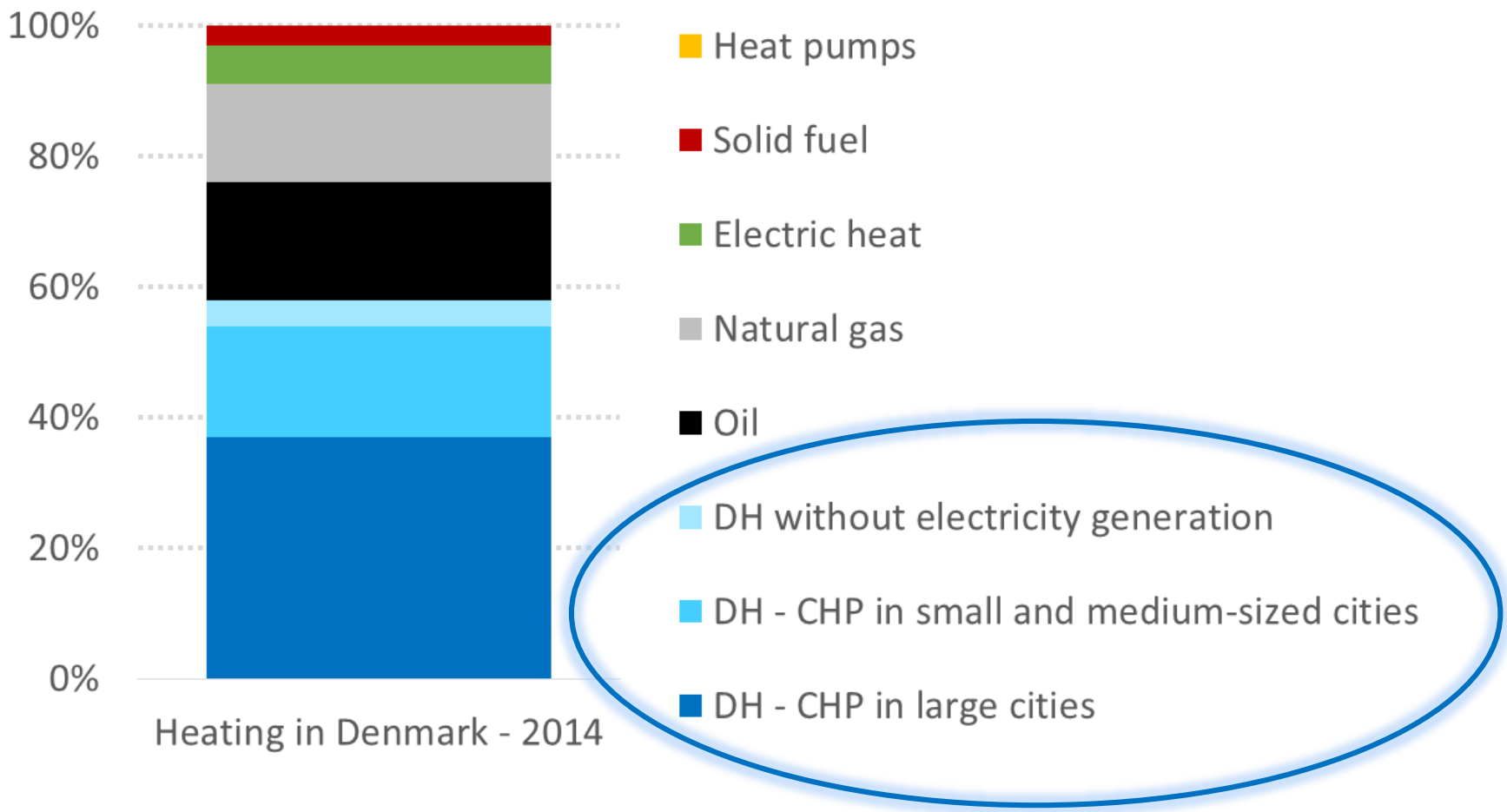
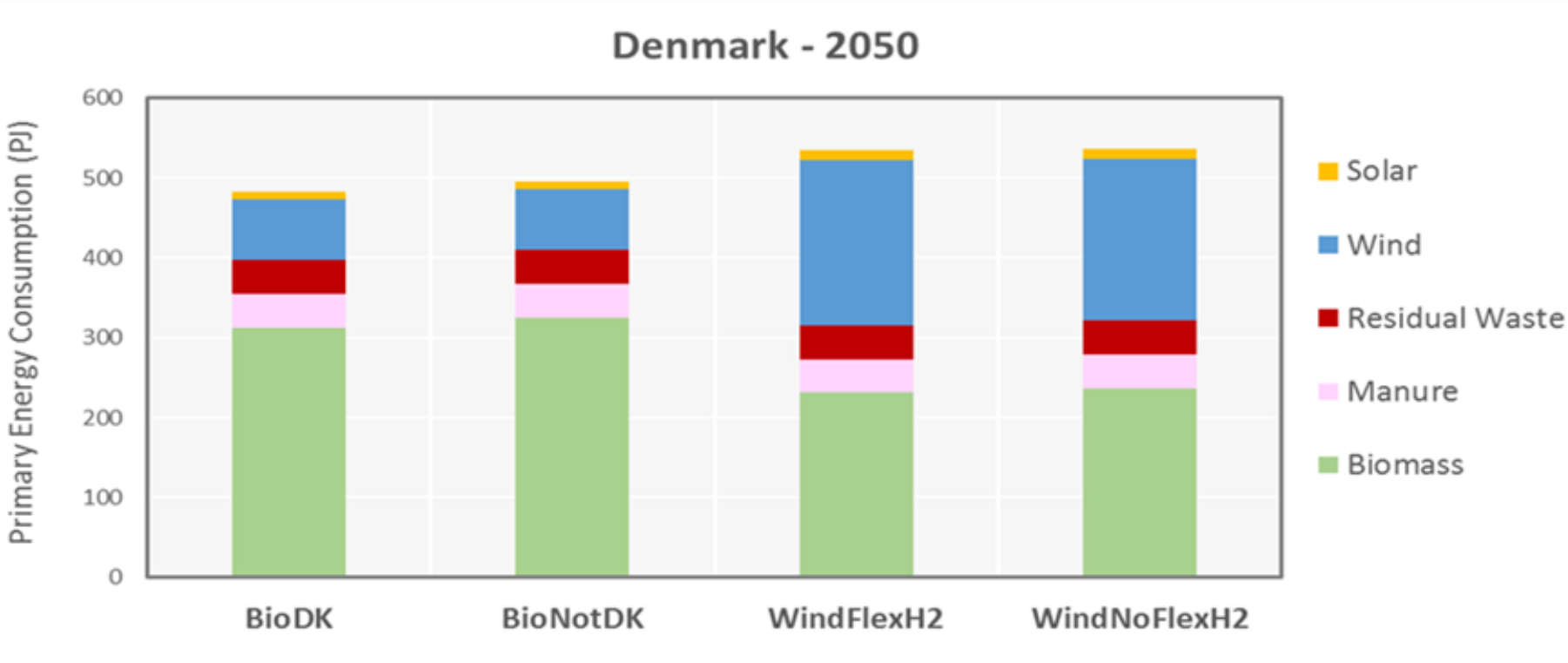


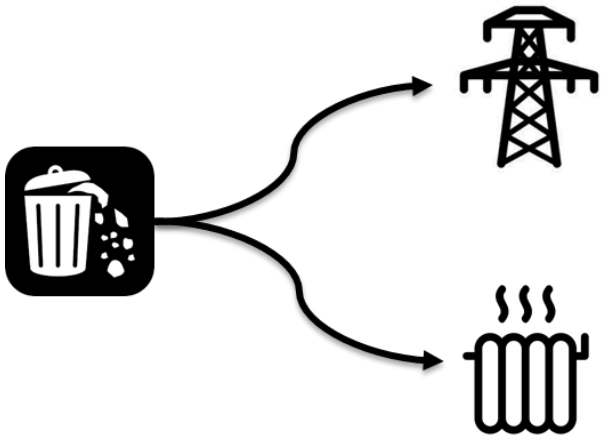
More than 500 DH networks in Denmark

How might the future look like?



How to maximize the value of local biomass and waste feedstocks taken into account the energy system? Their impact on the system cannot be considered marginal any more.

A particular case study – waste management optimization



5% of electricity consumption

20% of district heating consumption

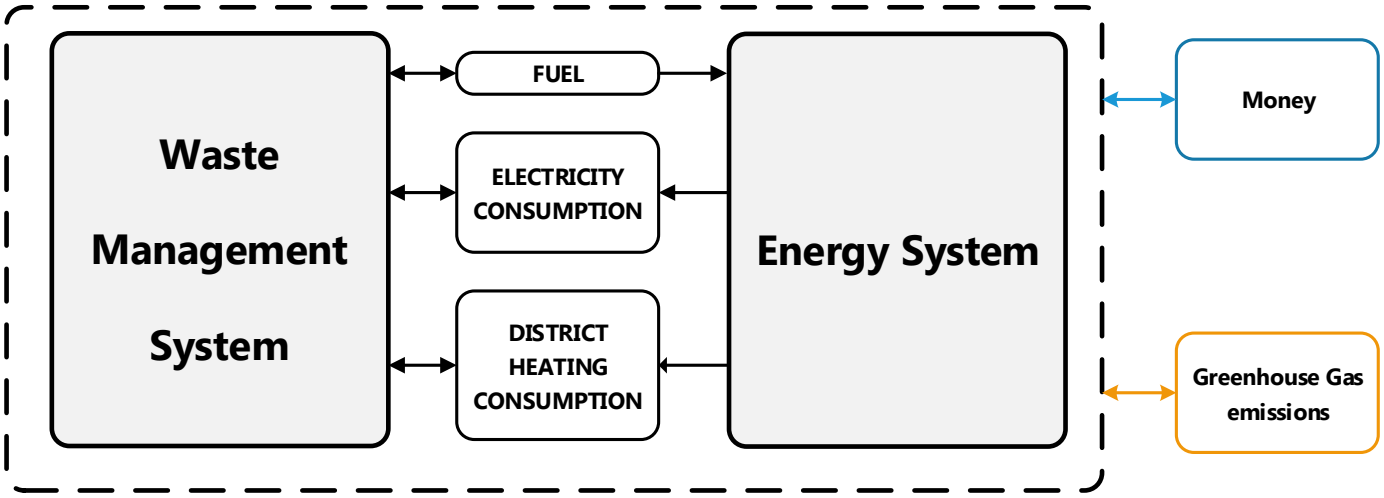
(District Heating supplies up to 60% of total heat demand for households and services)

- How to optimize the use of combustible waste in future energy systems?
- What is the role that storage devices might play?
  - Short-term storages: increase the flexibility of the system for power dispatching
  - Long-term storages: optimize capacity investments

Methodology

Holistic Approach between the waste and the energy system to evaluate the impact of the energy system on the waste sector and viceversa. Traditionally, an infinite market approach has been considered.

Soft-linking of both models in order to keep model size and computational time manageable.



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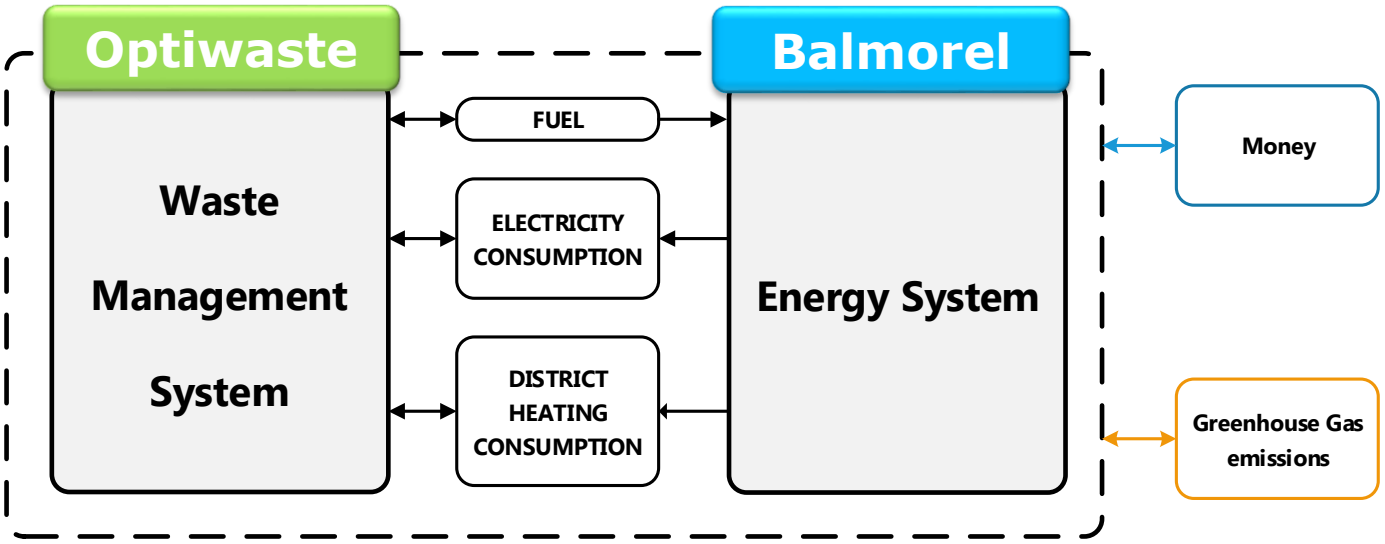

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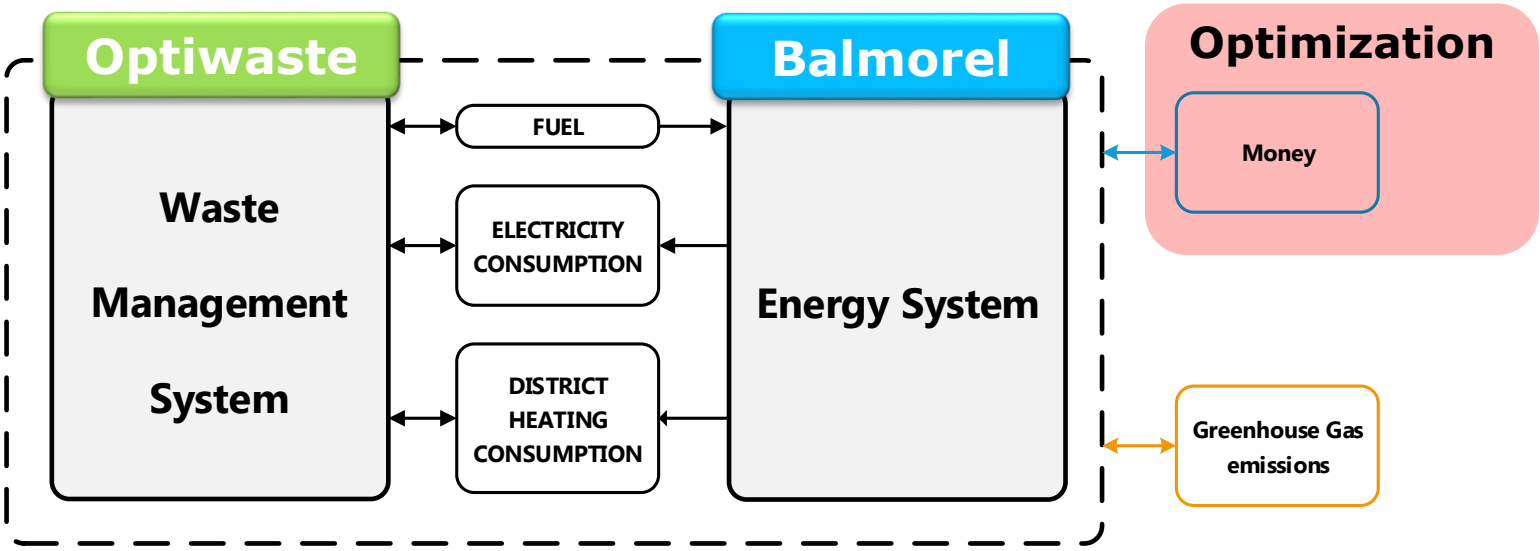
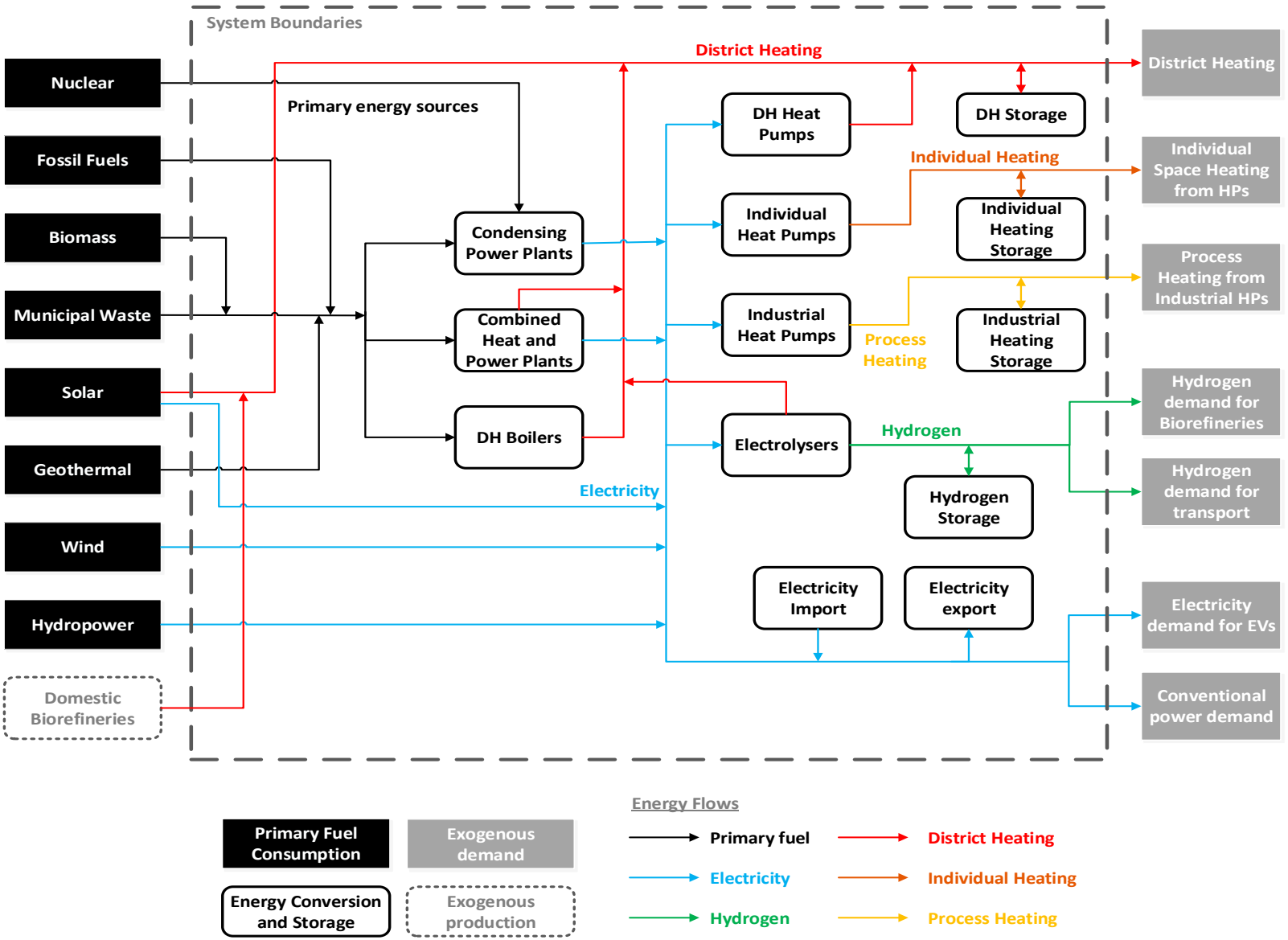


Balmorel – The Energy System model

- Written in GAMS
- Linear partial equilibrium model with a bottom-up approach (a MILP version is also available).
- Deterministic model
- A myopic or a perfect foresight approach might be adopted. The foresight is assumed to be perfect within the year, unless otherwise stated.
- Simulates and optimizes generation, transmission and consumption of electricity, district heating and hydrogen, including investments, given defined fuel prices.

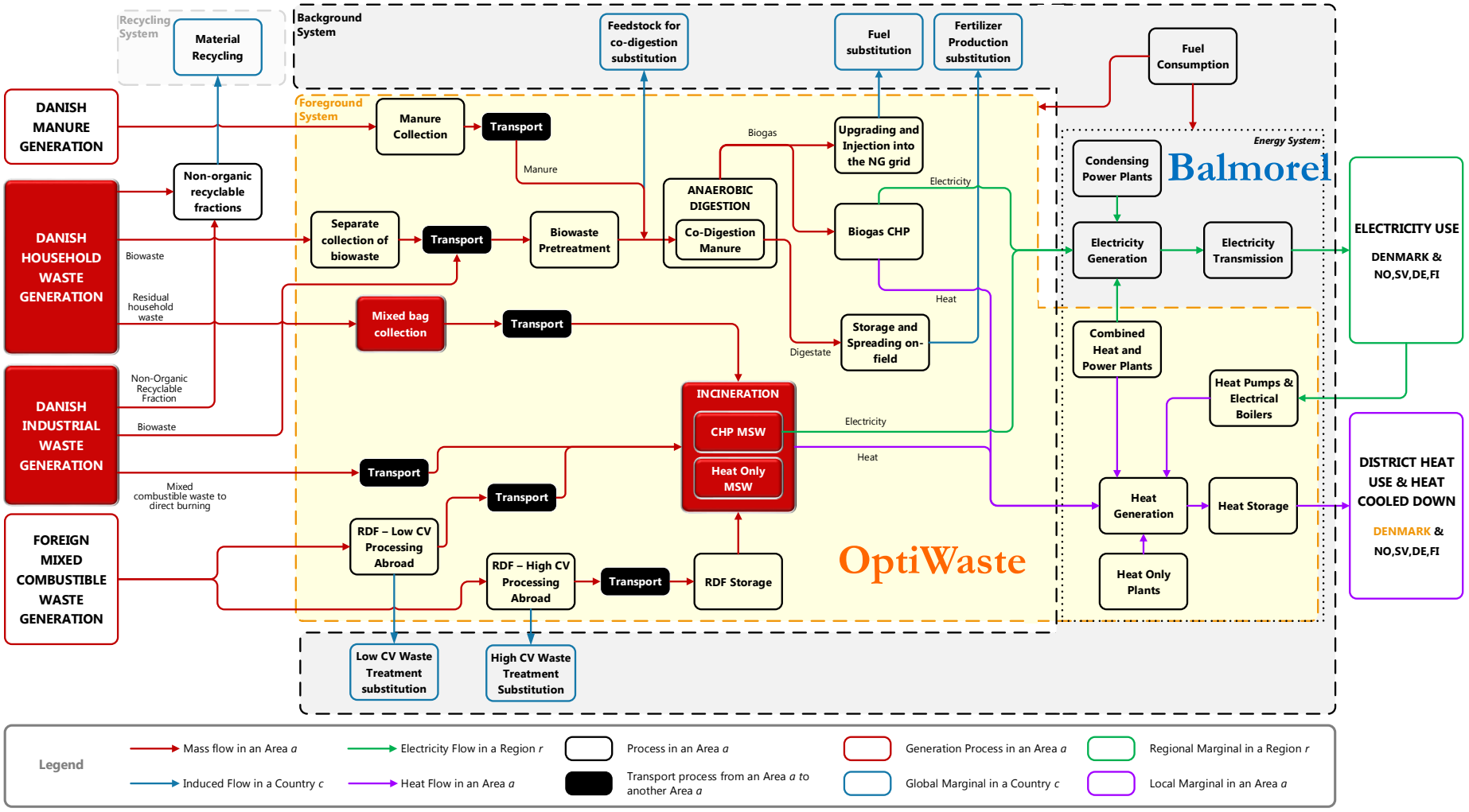
Balmorel – The Energy System model



OptiWaste – A Value Chain model

- Written in GAMS
- Network linear partial equilibrium model with a bottom-up approach
- It can represent any mass, energy, economic or environmental flow.
- Deterministic model
- Optimization might follow a Multi Criteria approach: Pareto optimality
- The model optimizes transport, treatment, investments and operation of combustible waste, given defined conditions of the energy system (soft-linking from Balmorel model).

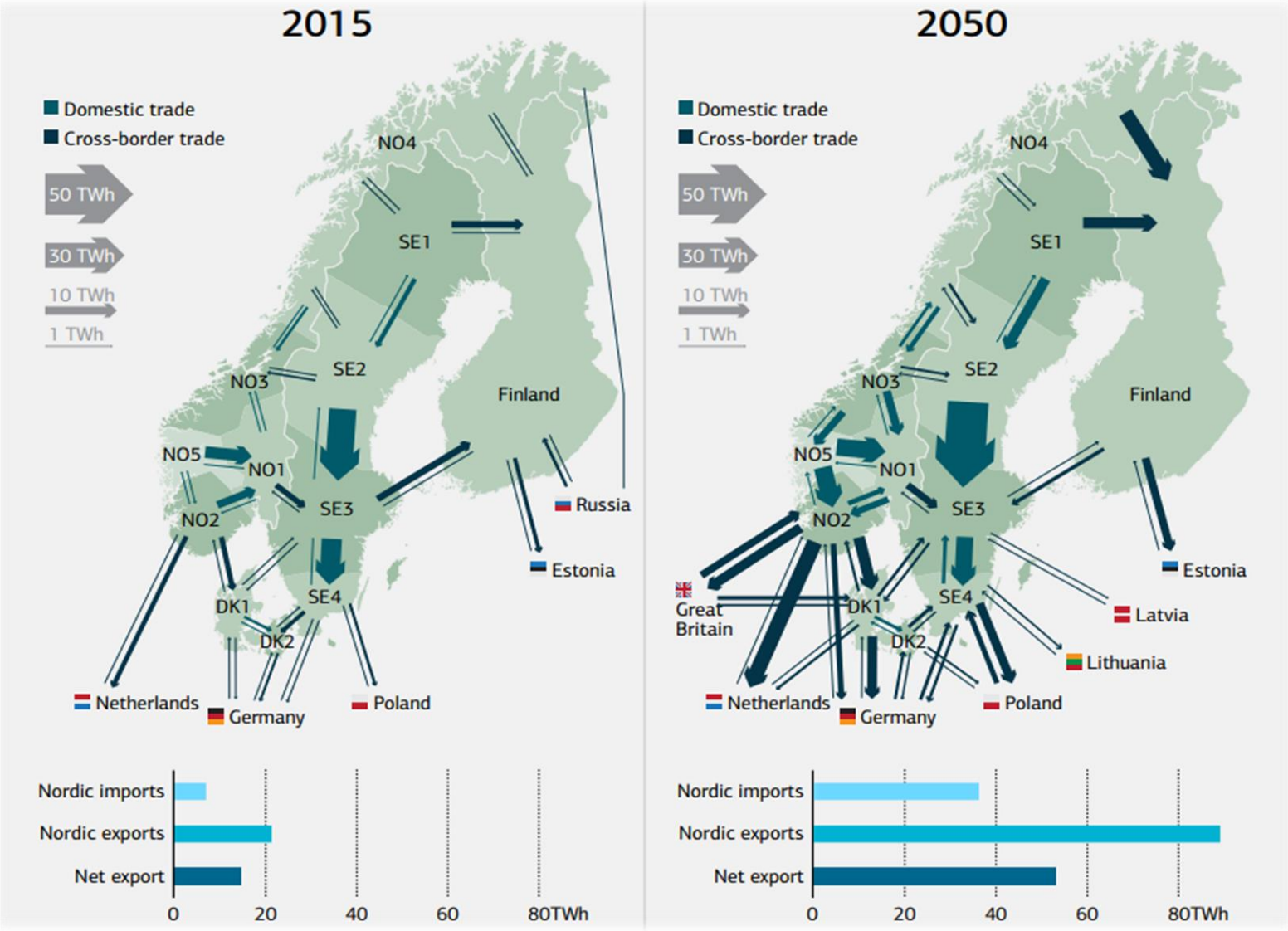
OptiWaste – A Value Chain model



How do we handle spatial and temporal issues in both models?

Spatial Resolution

Nordic electricity trade



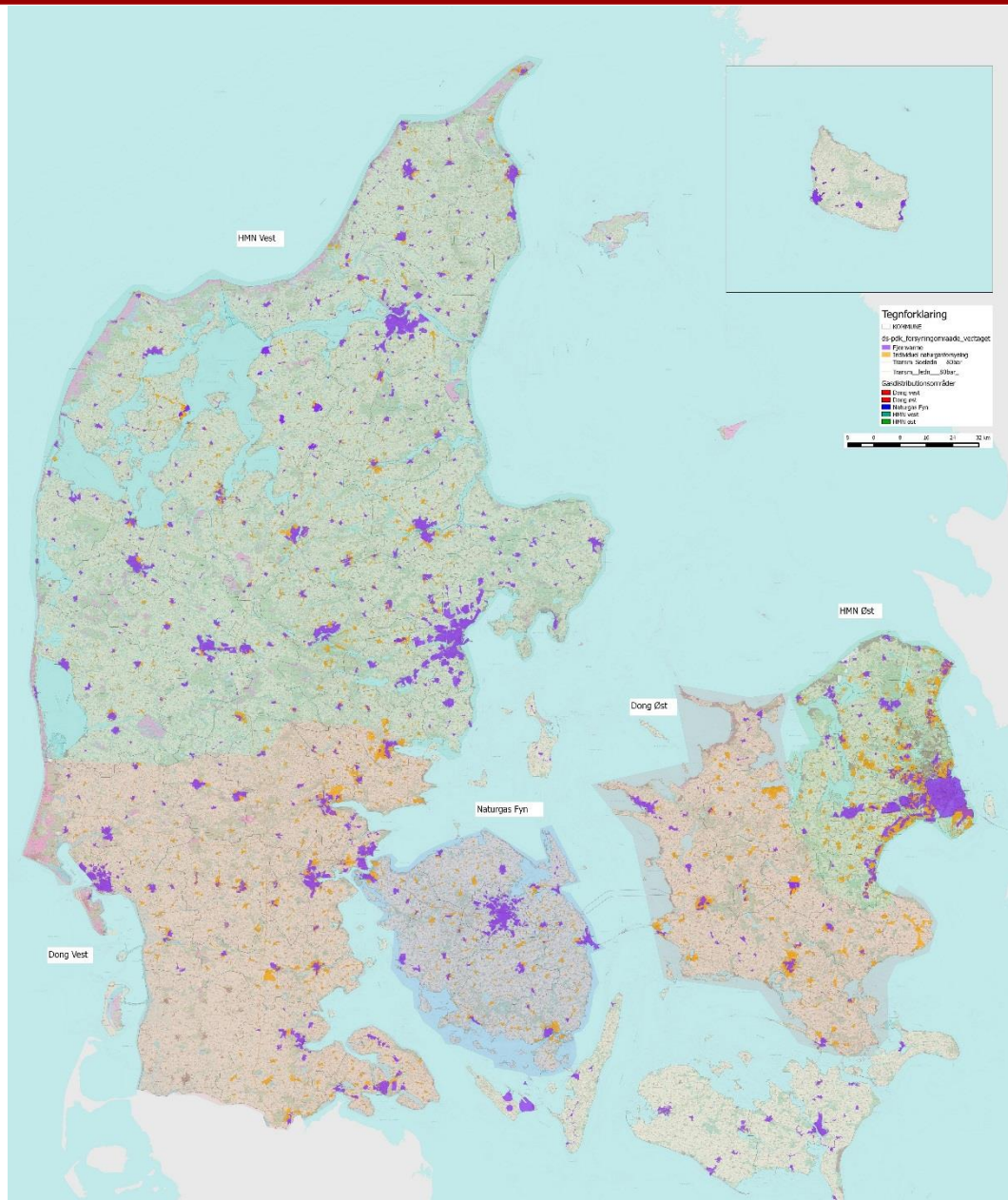
Source: Nordic Energy Technology Perspectives 2016 - IEA

District Heating Networks in Denmark

More than 500 **District Heating networks** in Denmark (42,925 km^2).

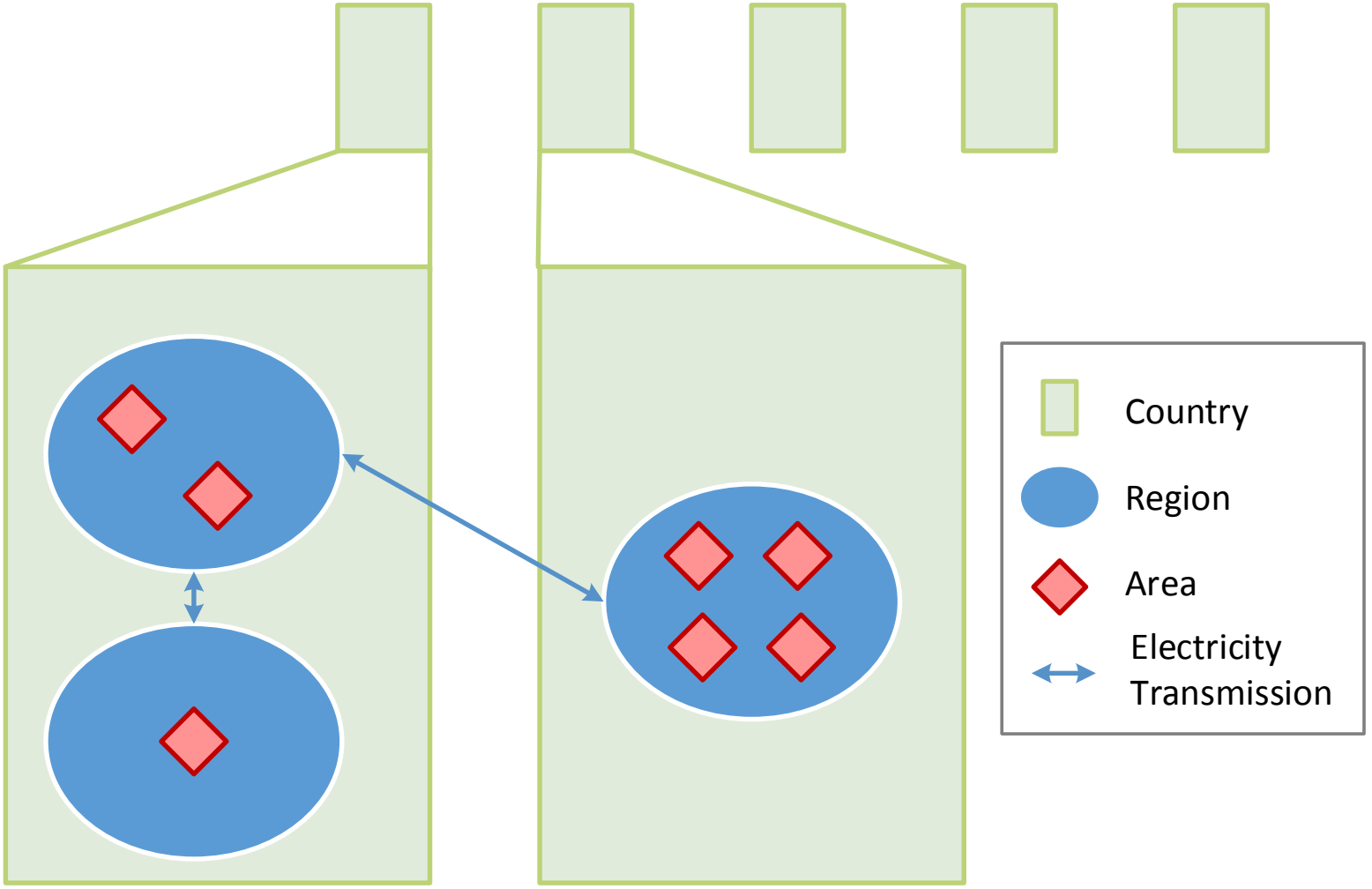
It is not possible to model 500 DH grids, therefore DH networks have been aggregated, following these criteria:

- Power grid location
- Size
- Urban or rural nature.

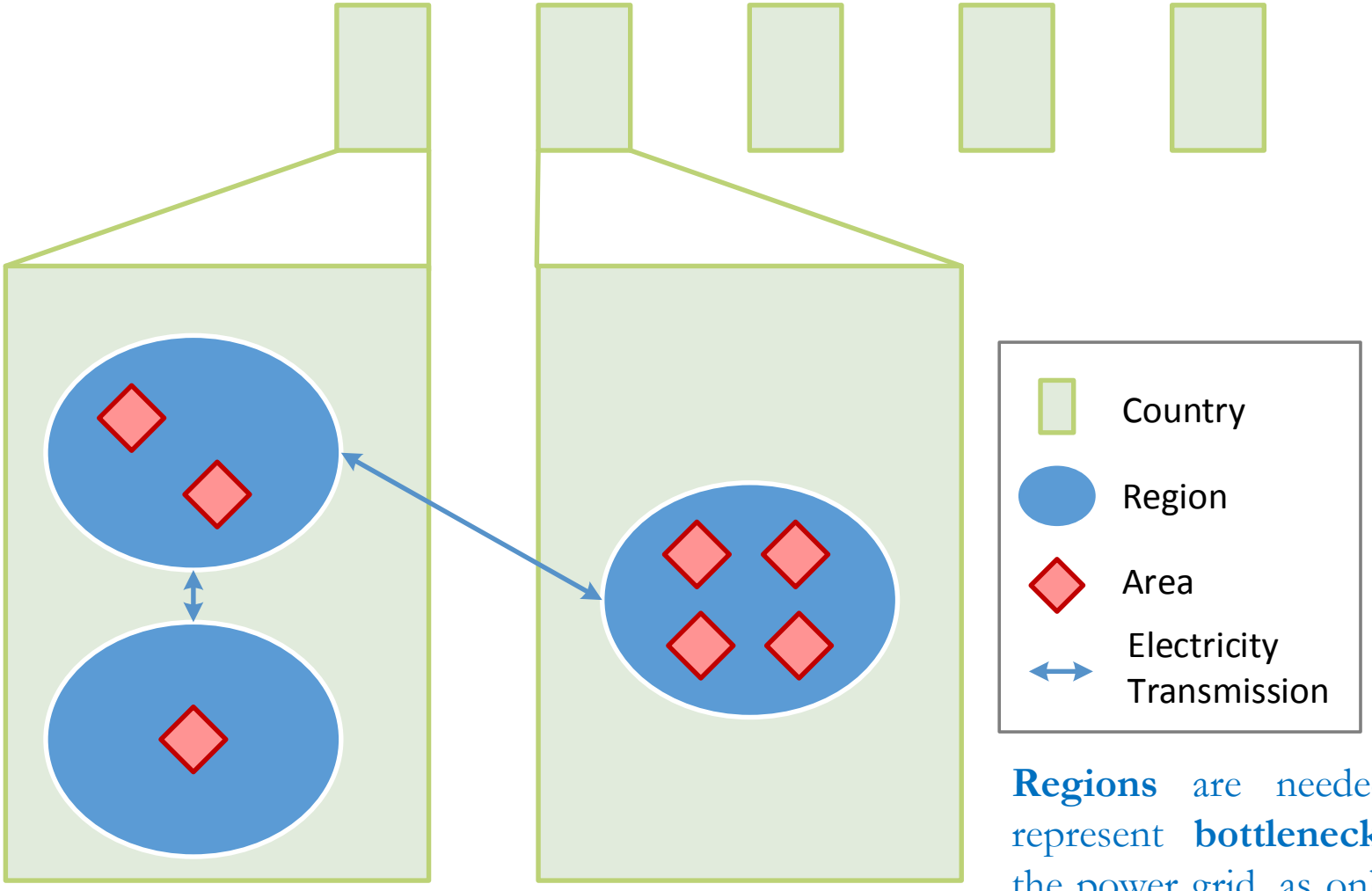


Source: Dansk Fjernvarme

Spatial Resolution in Balmorel – the energy model



Spatial Resolution in Balmorel – the energy model

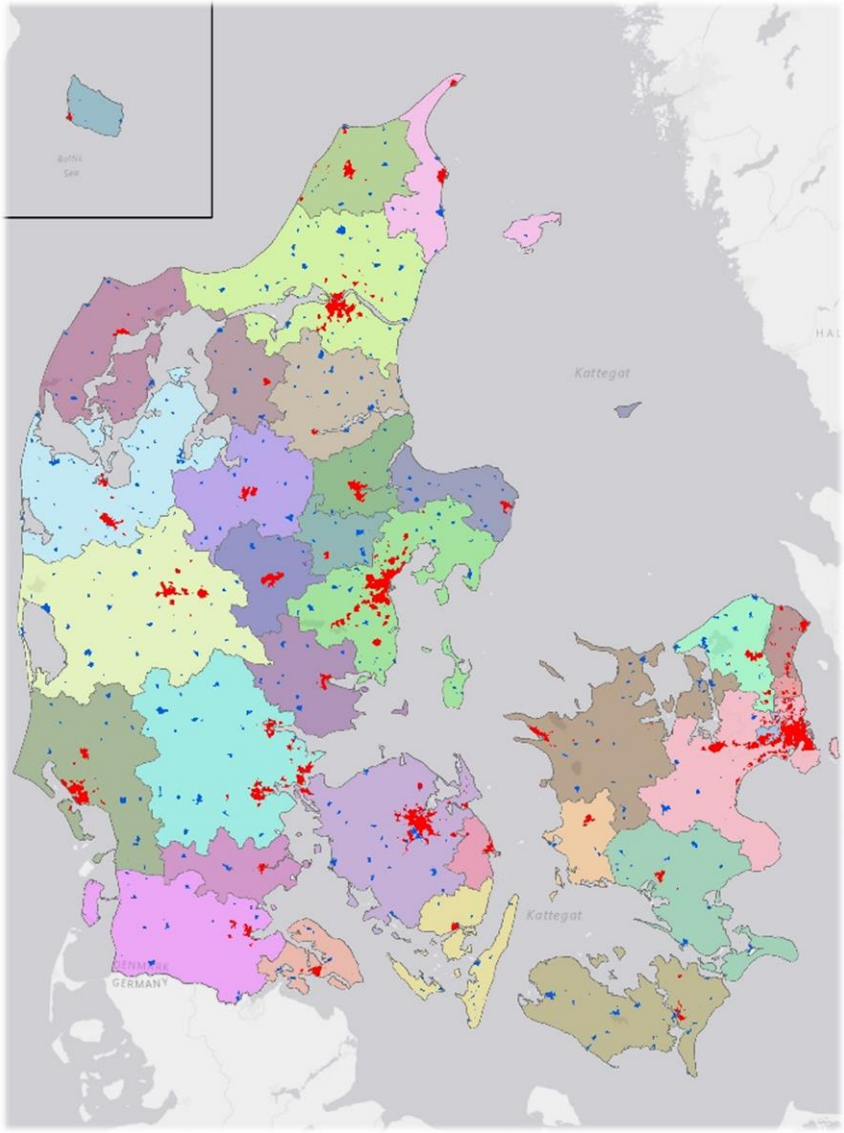


Regions are needed to represent **bottlenecks** in the power grid, as only the transmission grid is represented

Power Grids in Balmorel – the energy model

How much should the power network be expanded?

Waste management system: geographical resolution



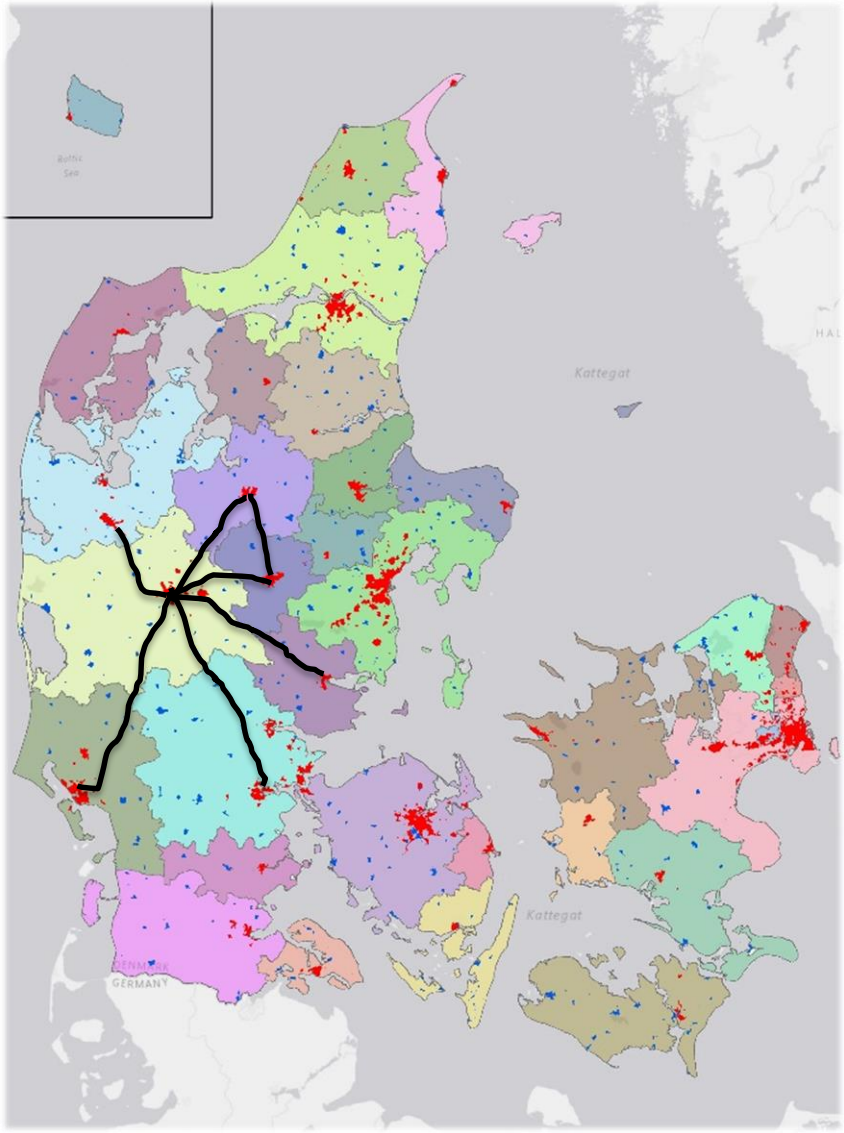
Waste is generated throughout the country and has to be transported.

Economy of scale will play an important role: longer transport vs. benefits from economy of scale vs. benefits from higher DH value

District Heating - Urban

District Heating - Rural

Waste management system: geographical resolution



Transportation is modelled as a network of connected nodes, where nodes are located in the geographical centre of each Urban District Heating.

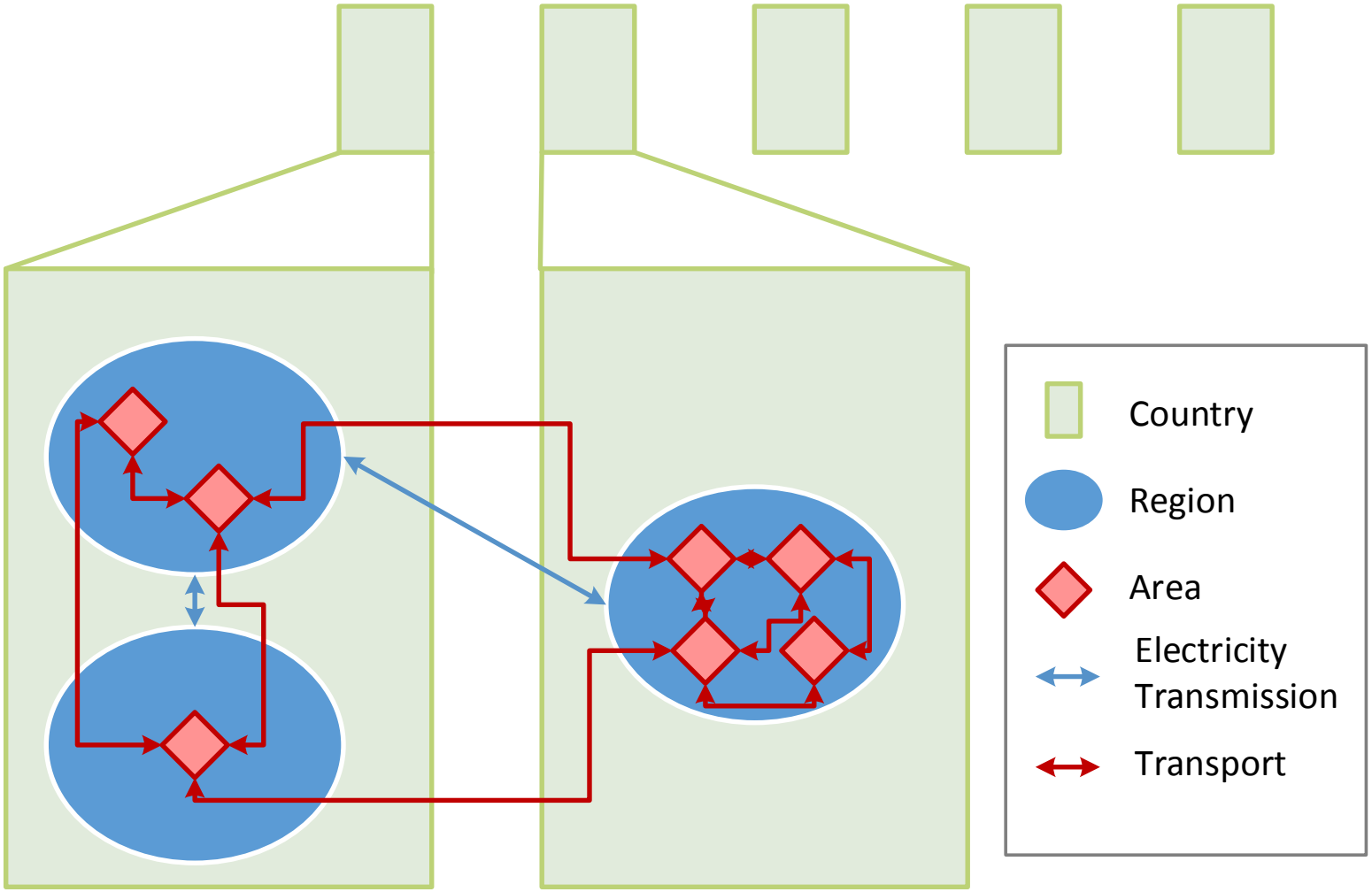
The transport network is the existing road and railway infrastructure and shipping lines

Average distance between two adjacent nodes: 50 km

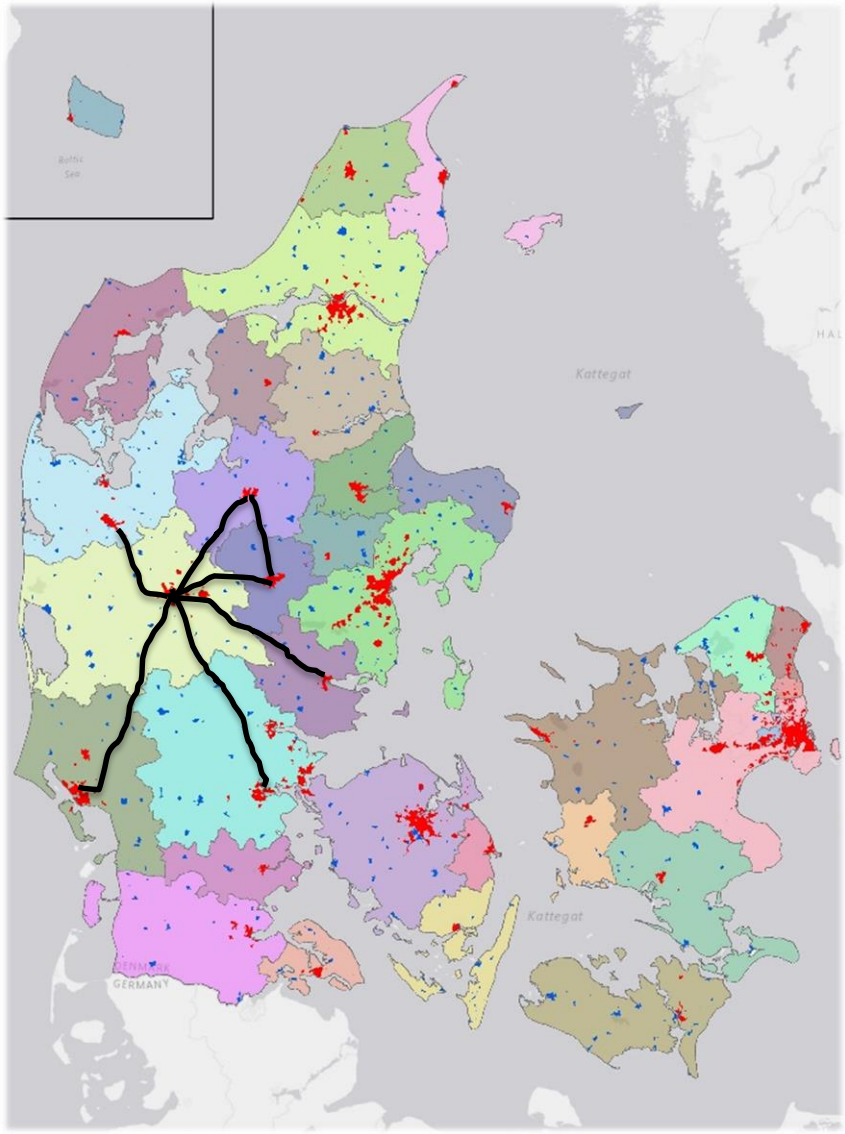
District Heating - Urban

District Heating - Rural

Spatial Resolution in Optiwaste – the waste model



Waste management system: geographical resolution



Problem!!! Waste is mainly generated in Urban areas; however, biomass, such as straw, is generated in rural and scattered areas.

Another spatial approach is needed when optimizing biomass use.

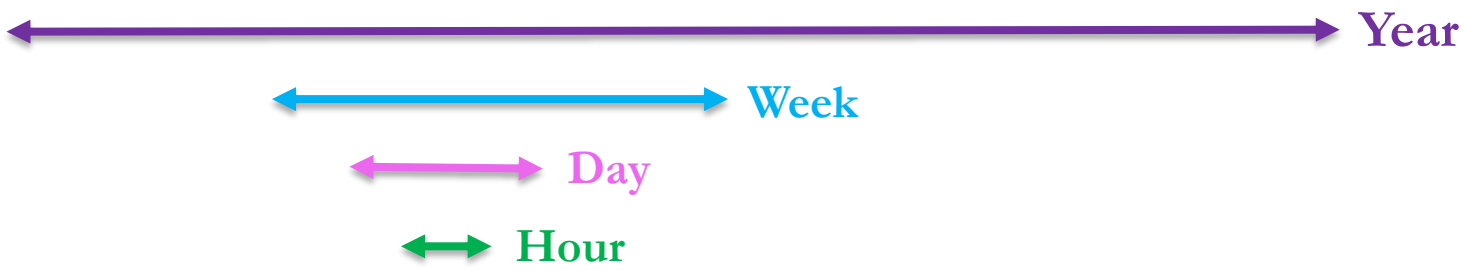
District Heating - Urban

District Heating - Rural

Temporal Resolution

Temporal resolution

There are four temporal levels in the energy and waste management models:



- Investments are optimized at an annual level.
- All the energy related processes are optimized at an hourly resolution.
- Waste management processes, which little linkage to the energy sector, are optimized at a weekly level.
- Flexible demand response occurs within a day.
- There are short-term storages between hours within the week, and long-term storages between weeks.

Hourly temporal resolution

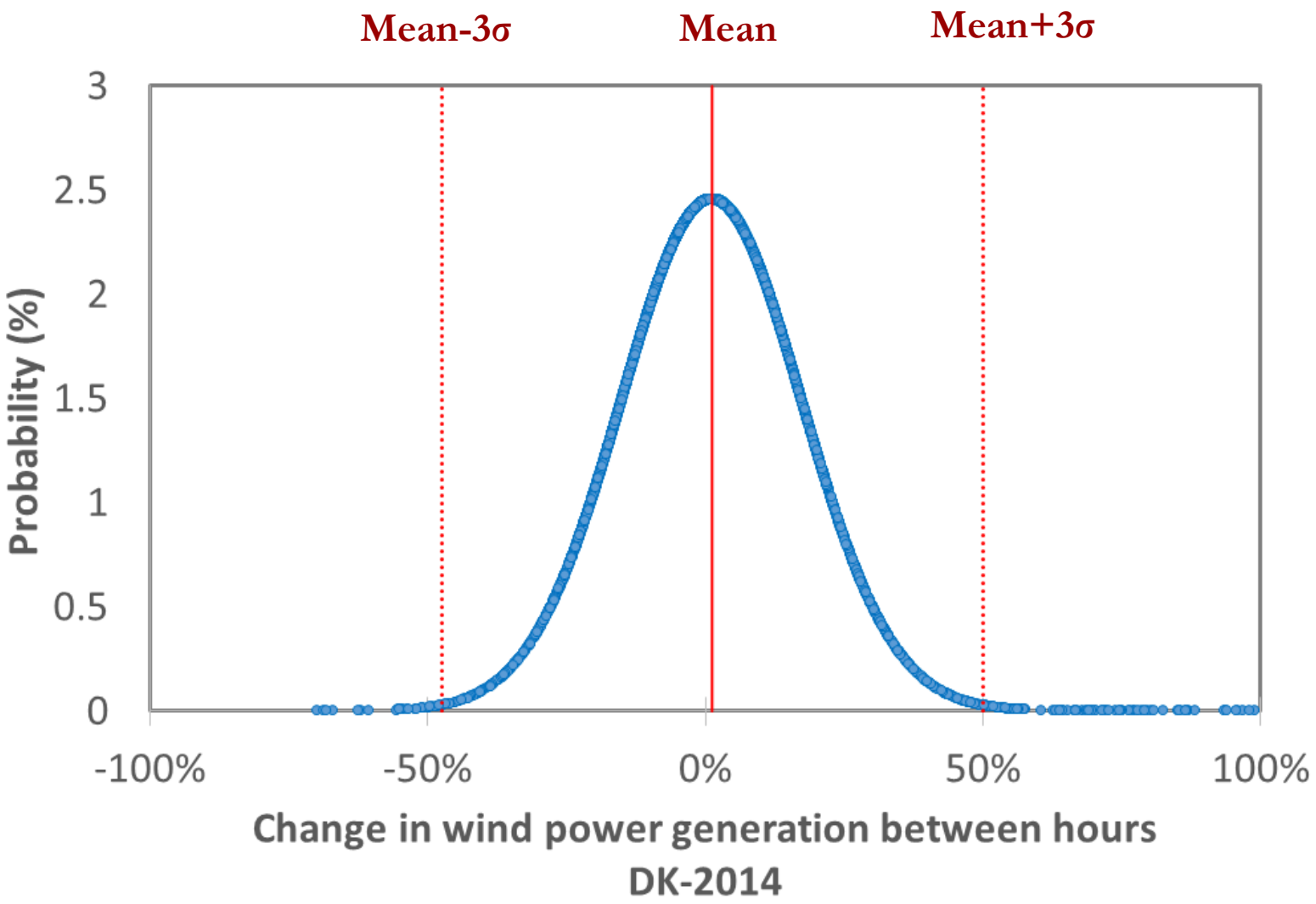
Challenge

Investment optimization
&
Operation optimization, including storage devices

The models are LP, and not MILP, and plants are aggregated per Area, in order to decrease the complexity of the problem.

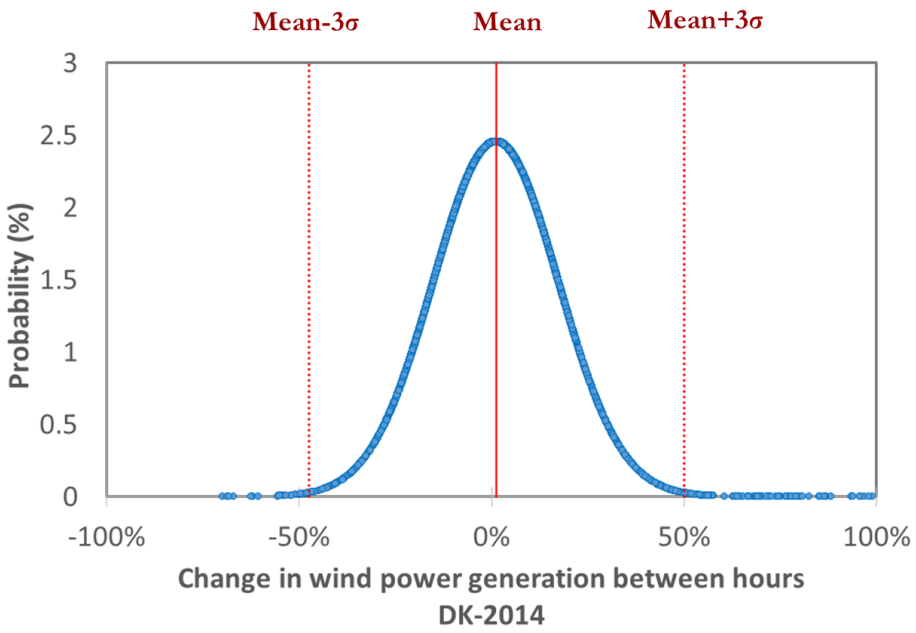
Data chronology is needed in order to take into account the dynamics of the system, the limited flexibility of some plants and the role of storage devices.

Hourly fluctuations in wind power generation



Hourly fluctuations in wind power generation

Flexible operation of thermal plants and storage devices is key to warranty a stable power grid.

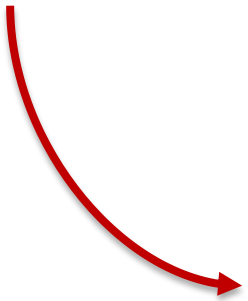


Ramp-up and **down constraints** are included, in order to limit the flexibility of some thermal plants, and to model the dynamics of the system in a simplified way in a LP model.

Our temporal aggregation

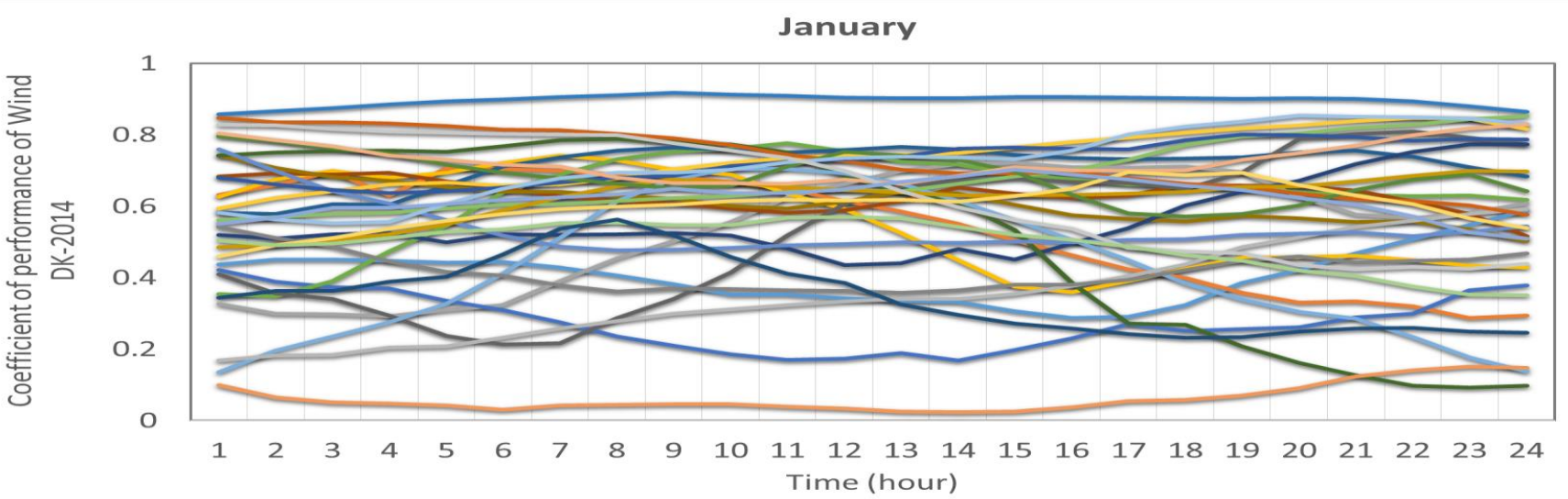
Our goal is to keep chronology of data in order to model required base and peak thermal plants and the role of storage devices (such as heat, hydrogen or waste) in the future energy system.

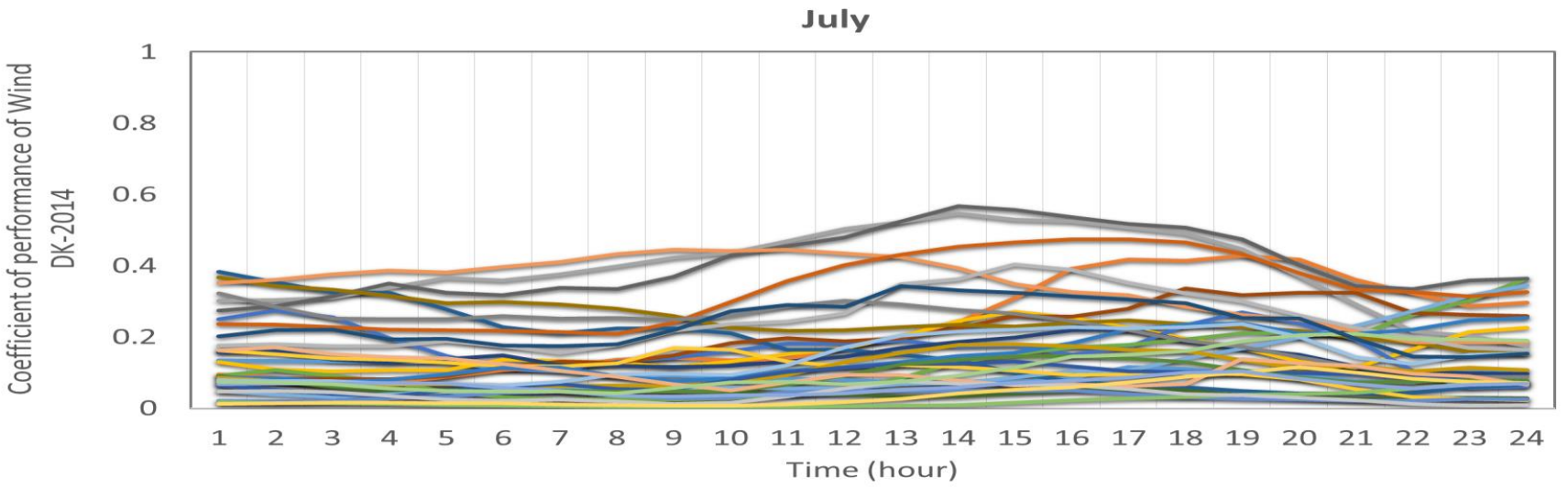
However, we only model selected time periods, in order to keep computational time low.



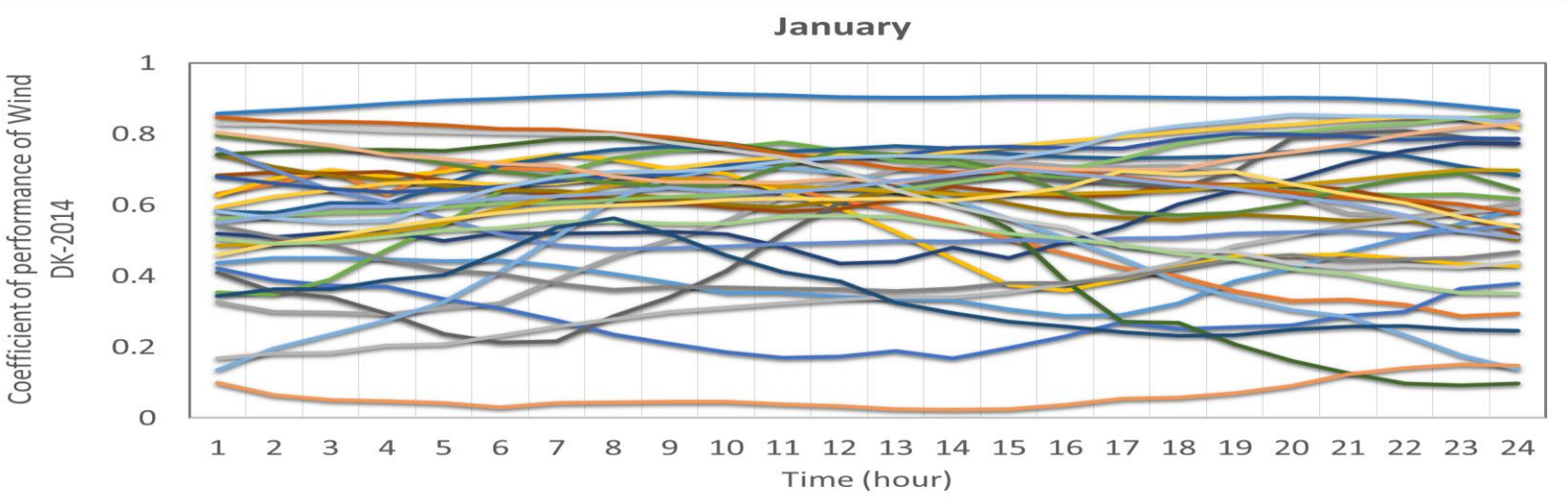
How to select representative time periods?

Selecting representative working days?





Selecting representative working days?



There is not an obvious daily pattern in wind generation. By selecting representative working days, we will not fully represent fluctuations in uncontrollable electricity generation; and therefore, the role that flexible plants or storage devices might play.

Our temporal approach

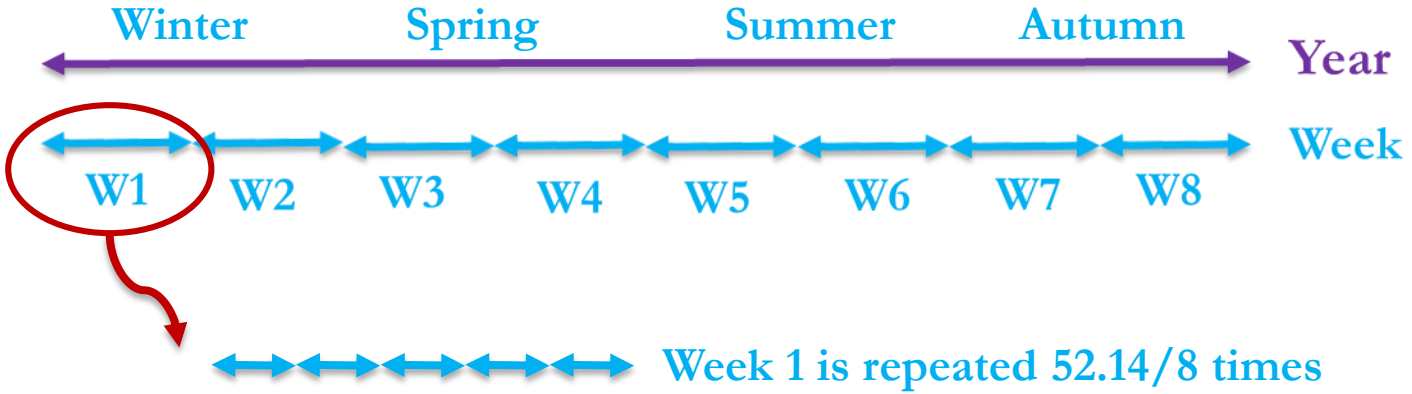
- Selection of representative Weeks, based on heuristics.

	Weeks	Weeks
Winter Spring Fall Autumn	Highest Dispatchable demand	Lowest Dispatchable demand

Main assumptions

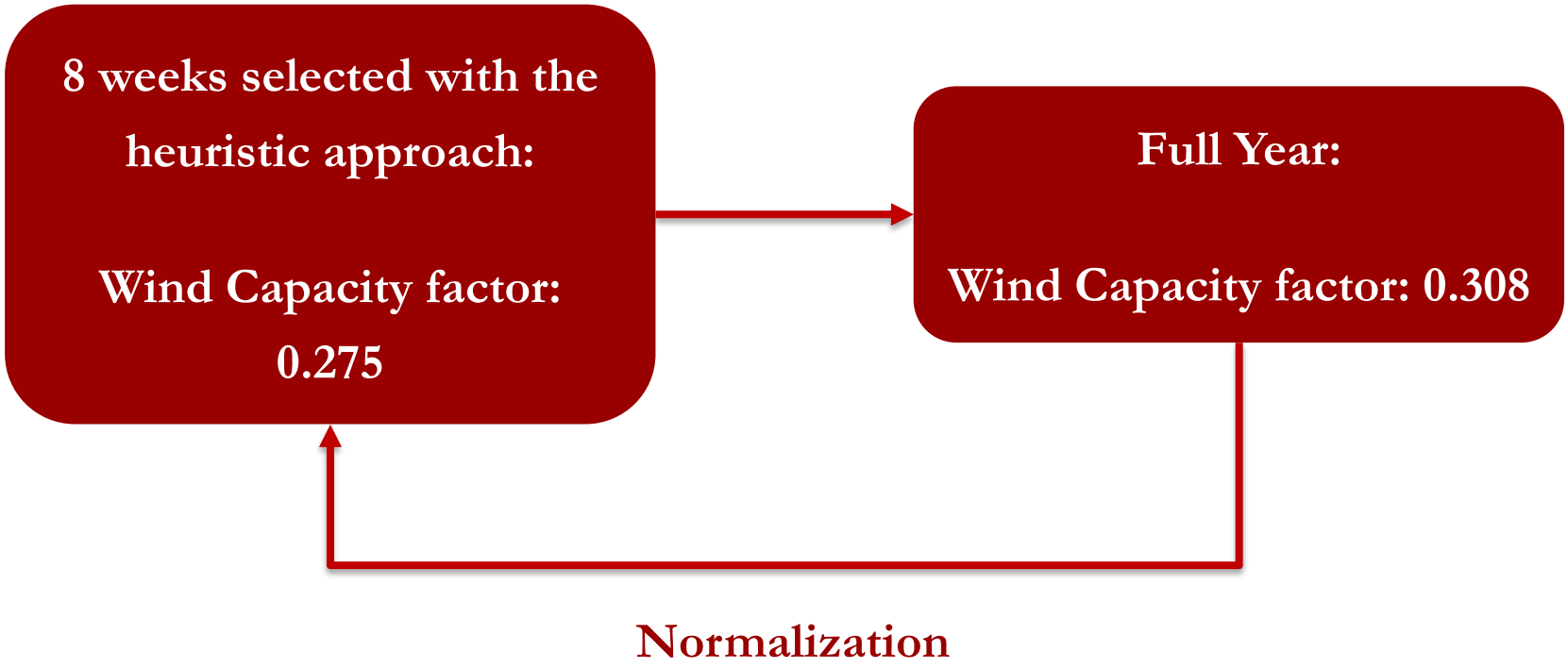
Chronology of data – Modelling of storage devices:

- The full year is modelled with the representative weeks, which are repeated in cycles.
- Weeks are chronological: we need to assume if the High Demand-Week happens before or after the Low Demand-Week within each season.
- There is no alternation between weeks with High and Low Demand within the same season.

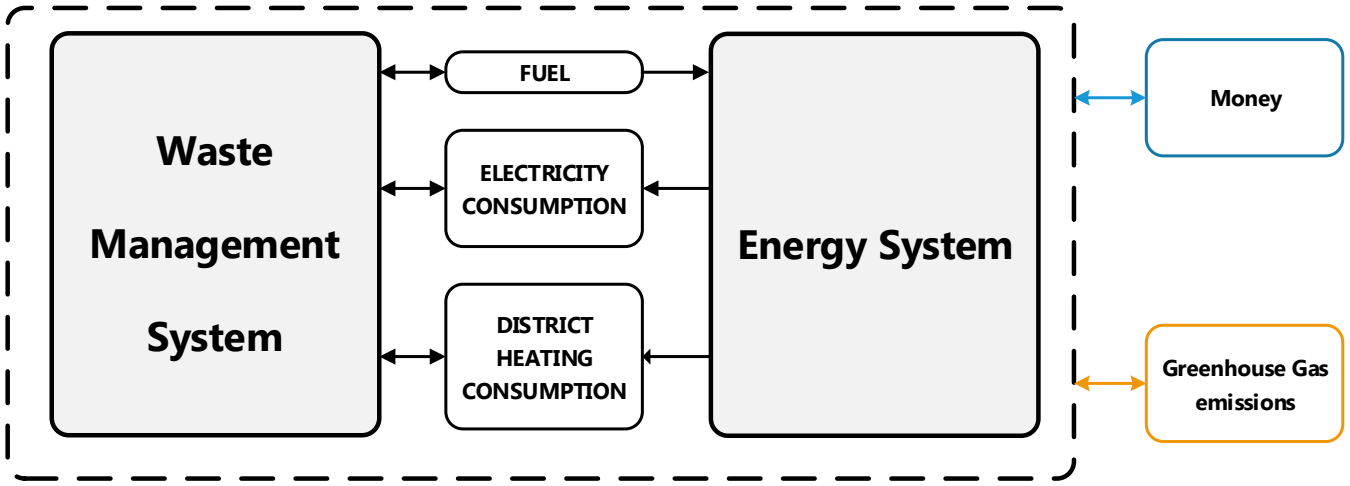


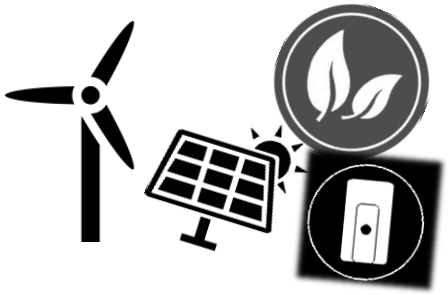
Our temporal approach

- Normalization of profiles for demand and generation, e.g..:



Our main computational problems





How a future fossil free energy system might look like?

How, where and when should we treat the waste?

Our main computational problems

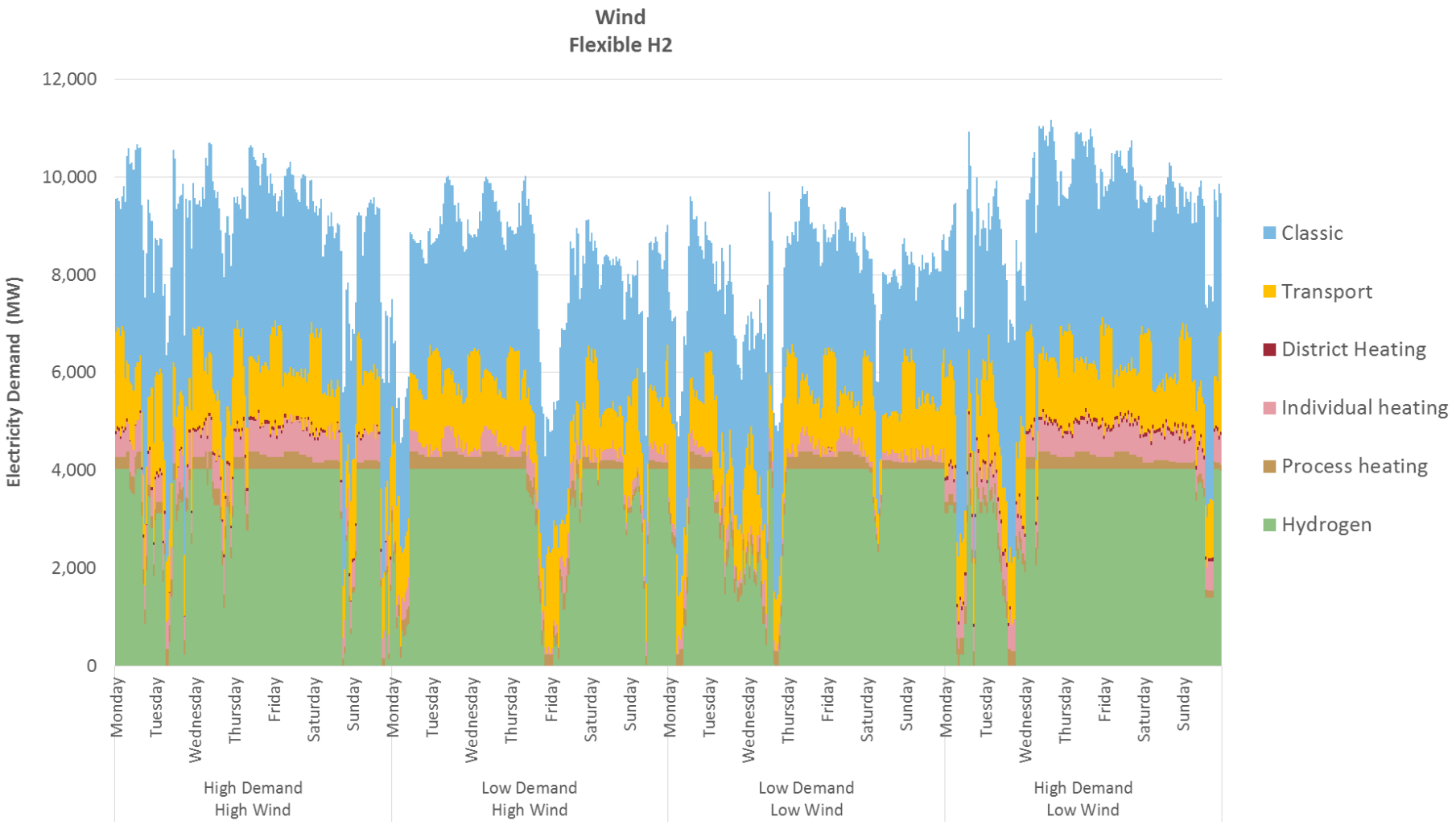
Balmorel – Energy Model

- Modelling 8 representative weeks, optimizing investments might require large computational time. Screening of investment options, with a smaller set of representative weeks is required.
- Solving time: 50 hours (Inter® Xeon® CPU E5-2440 v2 1.90 GHz, RAM 32 GB, GAMS 24.5 and CPLEX 12.6)

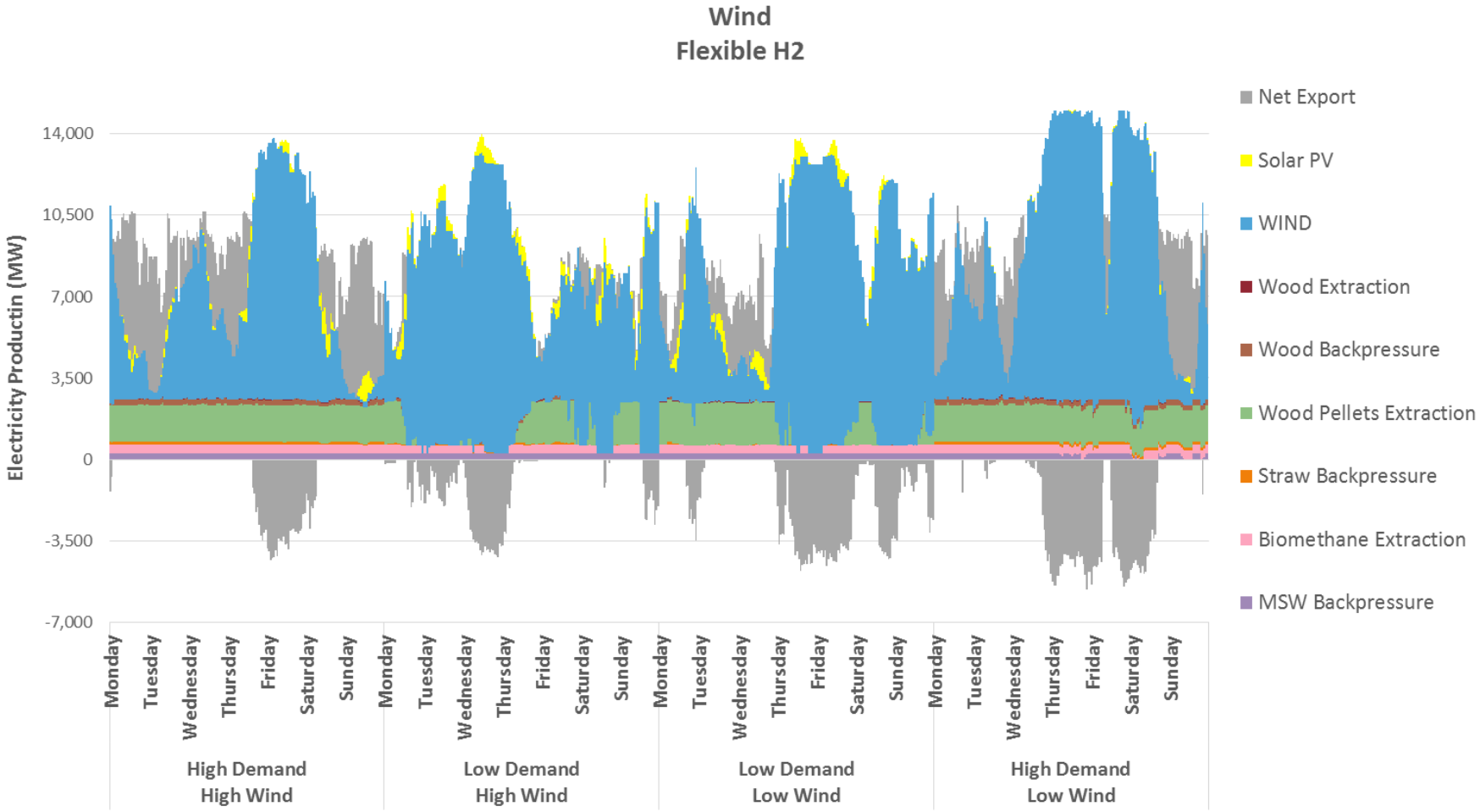
Optiwaste – Waste Management Model

- Modelling a high geographical resolution level generates a very large network model; however, once the model is generated, it is solved relatively fast.
- Solving time: 2 hours (Inter® Xeon® CPU E5-2440 v2 1.90 GHz, RAM 32 GB, GAMS 24.5 and CPLEX 12.6)

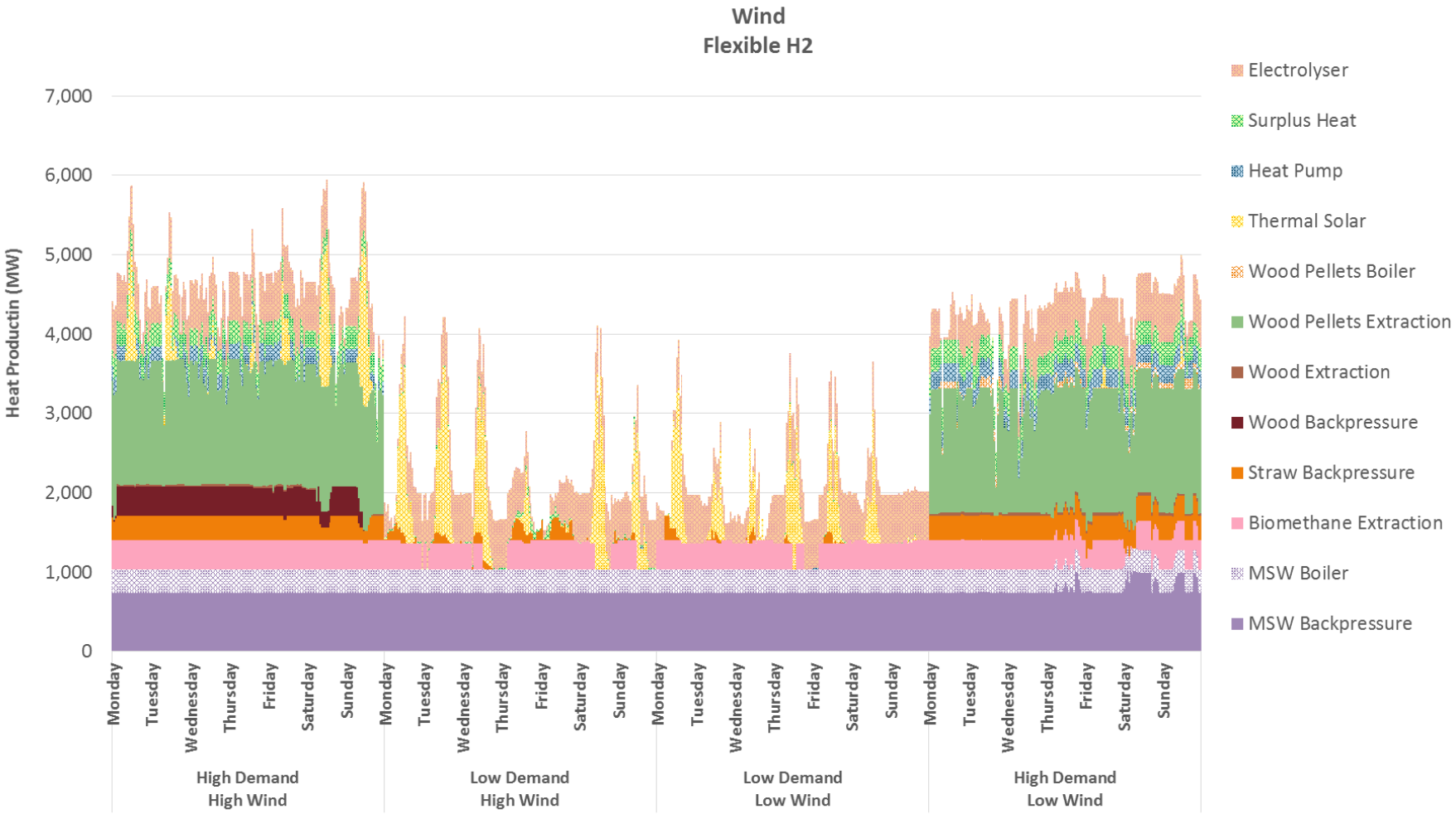
Results: Electricity Demand – Denmark 2050



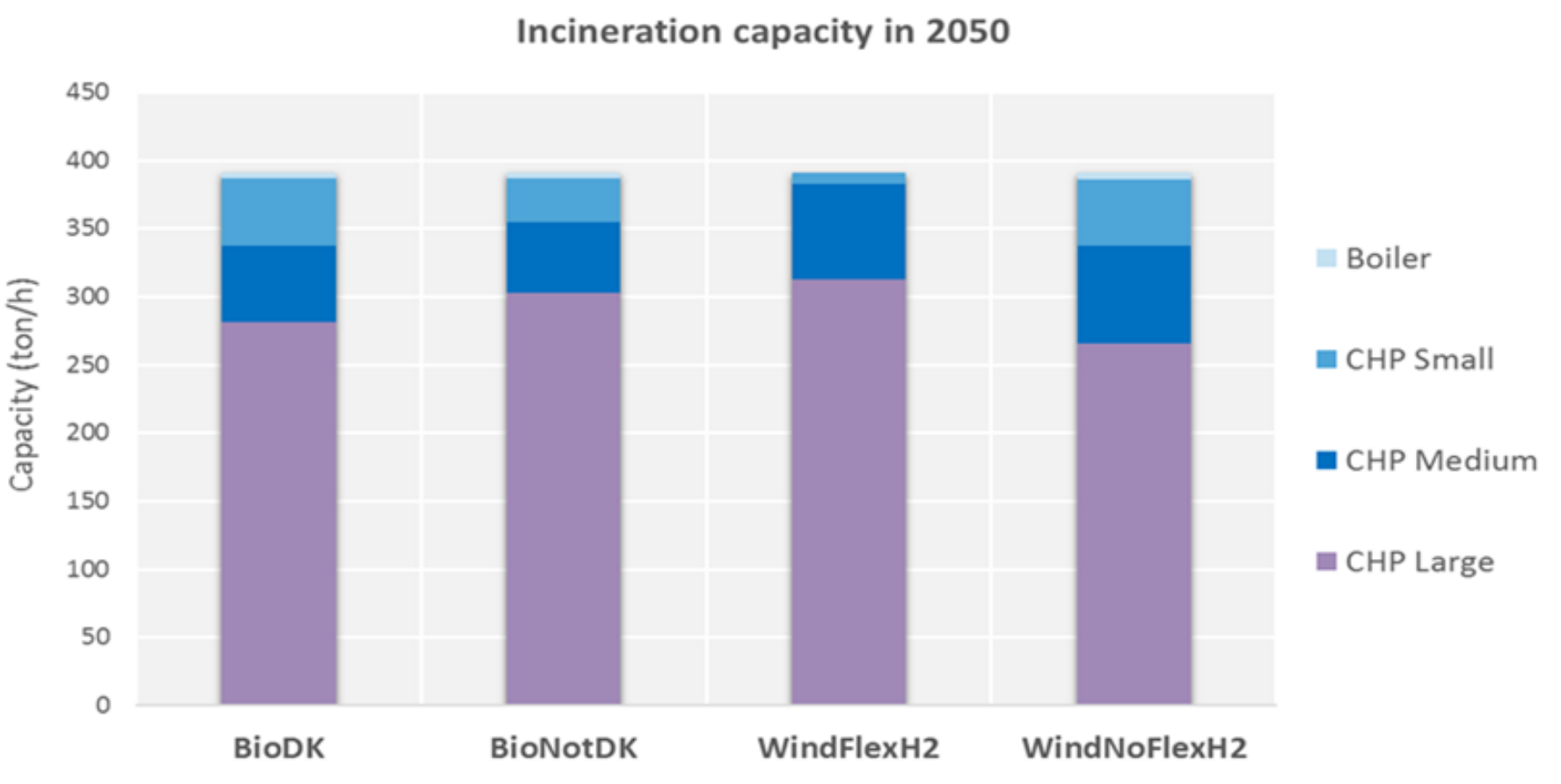
Results: Electricity Production – Denmark 2014



Results: Heat Production – Denmark 2050



Results: Waste-to-energy investments



Discussion

A large linear programming model, such as Balmorel and Optiwaste, used over a time span of approximately 35 years with an hourly resolution includes a substantial number of assumptions, simplifications and data aggregation.

"All models are wrong"

Steman, 2002

The robustness of the conclusions must be tested to the uncertainty in the parameters that seem most important, but often temporal and/or spatial issues are omitted.

Conclusions & Further Work

- Spatial and temporal issues are key in order to avoid sub optimal solutions of future decarbonised energy systems; such as biomass value chains, storage devices, peak power capacity requirements, etc.

- In order to decrease the level of spatial resolution, geographical aggregation and representation of simplified transport networks is required. Soft-linking of energy models and GIS models should be further analysed.

- Chronollogy is needed to represent properly the dynamics of the energy system. Larger knowledge of time series analysis might be useful to identify in a smart way representative weeks.

Thank you for your attention