Analysis of Various **Spatial Resolutions** for Modelling **Sector-Coupled** Energy Systems

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Abstract

Large-scale energy system modelling plays a large role in the debate on energy system decarbonisation. It is common to use a bidding zone representation to model the European energy system due to the structure of the electricity market. However, this may underestimate infrastructure constraints at higher spatial resolutions. This question is explored using the sector-coupled energy system model Balmorel, modelling a case study of the Danish energy system, where detailed geo-spatial data of most power plants exist. This data is combined with the atlite module for generating variable renewable energy (VRE) production profiles, and the effect of applying various spatial resolutions is thus investigated from a bidding zone, NUTS2-3, to municipal spatial resolution. These results will be discussed and inform a similar investigation on a European level, to advance the modelling of sector-coupled energy system models with high penetrations of VRE.

Methods

A general methodology is developed that utilise attributes of geospatial data to disaggregate or aggregate various data into the desired spatial resolution.

The Balmorel model of Kountouris et al [1] is applied. Industrial point sources from Manz et al [2] are used to disaggregate industrial electricity and heat demand, while detailed district heating demand from the FutureGas project is aggregated [3]. All power- and CHP-plants are reported by the Danish Energy Agency [4] and aggregated. A python module (atlite) developed by Hofmann et al [5] is utilised to create VRE timeseries for each scenario.

Denmark is modelled in various spatial resolutions, while surrounding countries (Norway, Sweden and Germany) are kept at the same spatial resolution.

Scenarios

4 x 2 scenarios are prepared based on four spatial resolutions and optimising Denmark isolated or together with Germany, Norway and Sweden (only spatial resolution of DK is altered)

	Municipal	NUTS3	NUTS2	Bidding Zones
Denmark +DE NO SE	4CMU	4CN3	4CN2	4CBZ
Denmark	DKMU	DKN3	DKN2	DKBZ

Co-optimising Investments and Dispatch of...

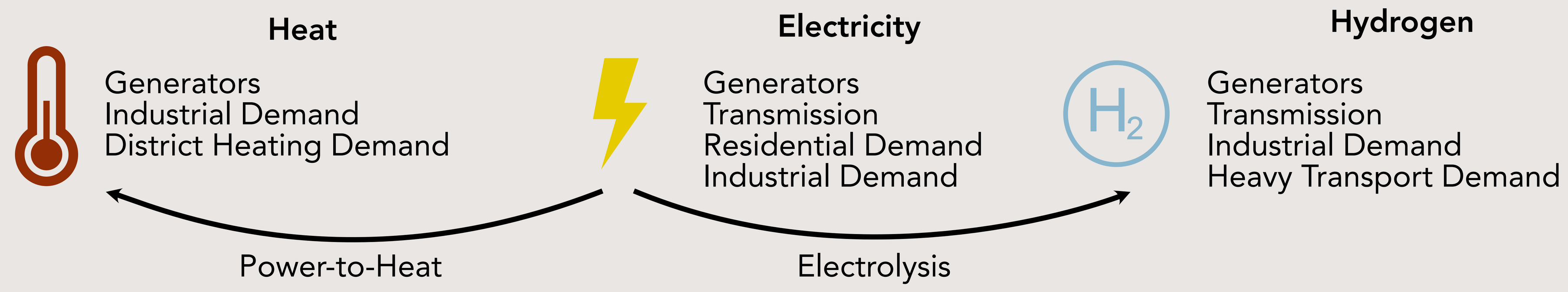


Figure 1: Detailed geospatial energy system data is utilised

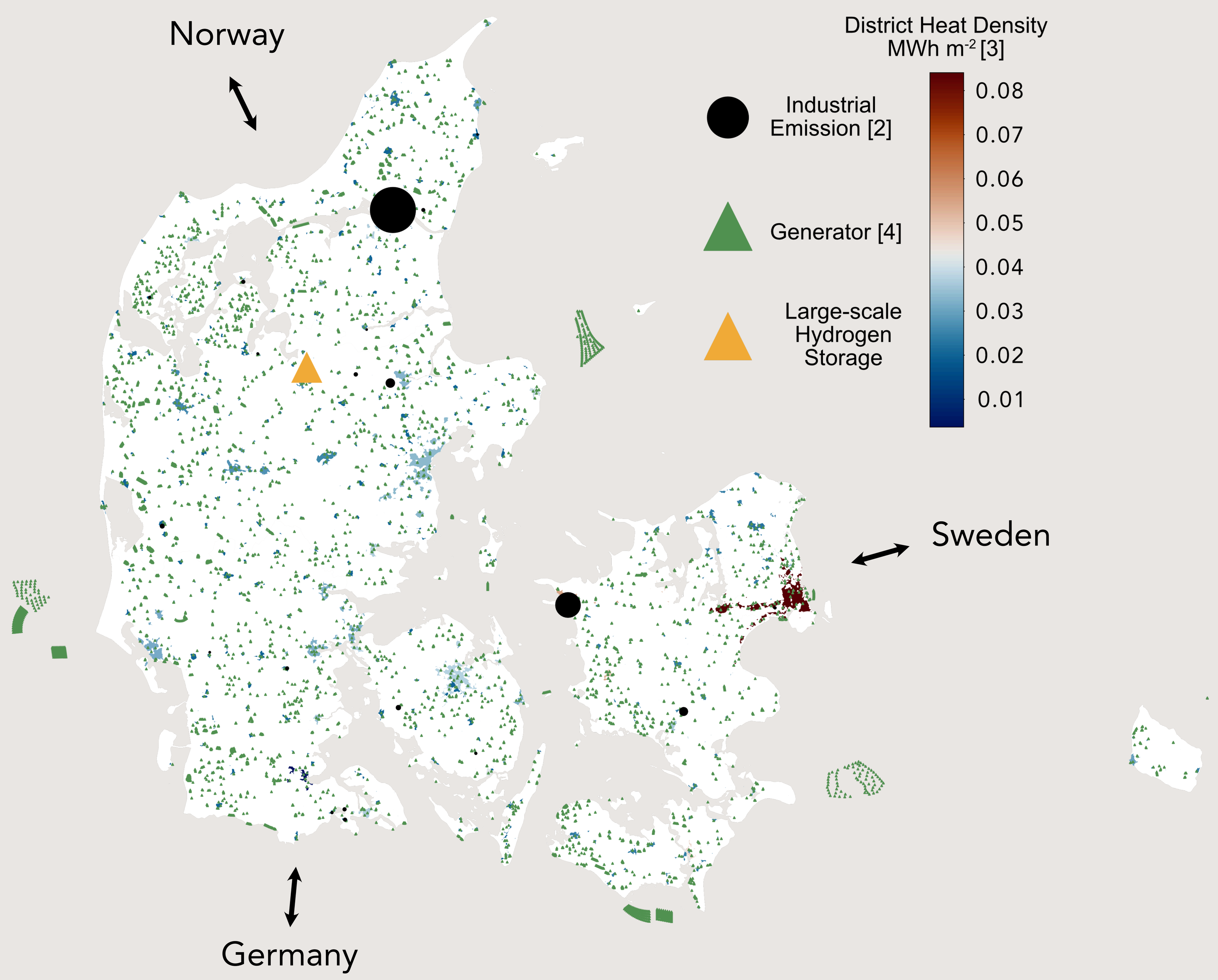
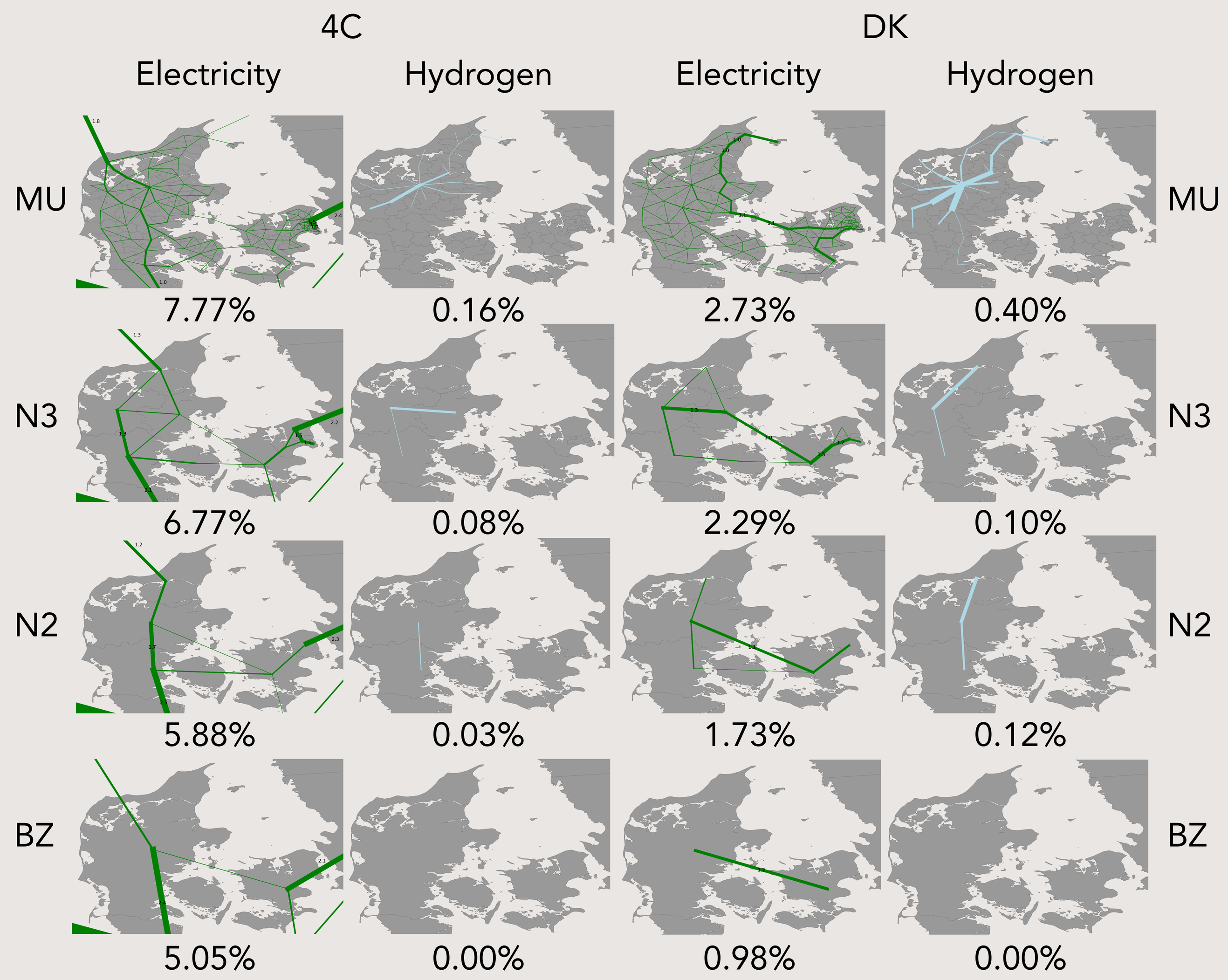


Figure 2: Resulting transmission capacities (in GW) from all scenarios. Lines above 1 GW are labelled, and the transmission share of total system costs reported below each subfigure.

NB: Individual power and H_2 lines cannot be compared below as H_2 lines are displayed ~7 times larger than power due to smaller capacities



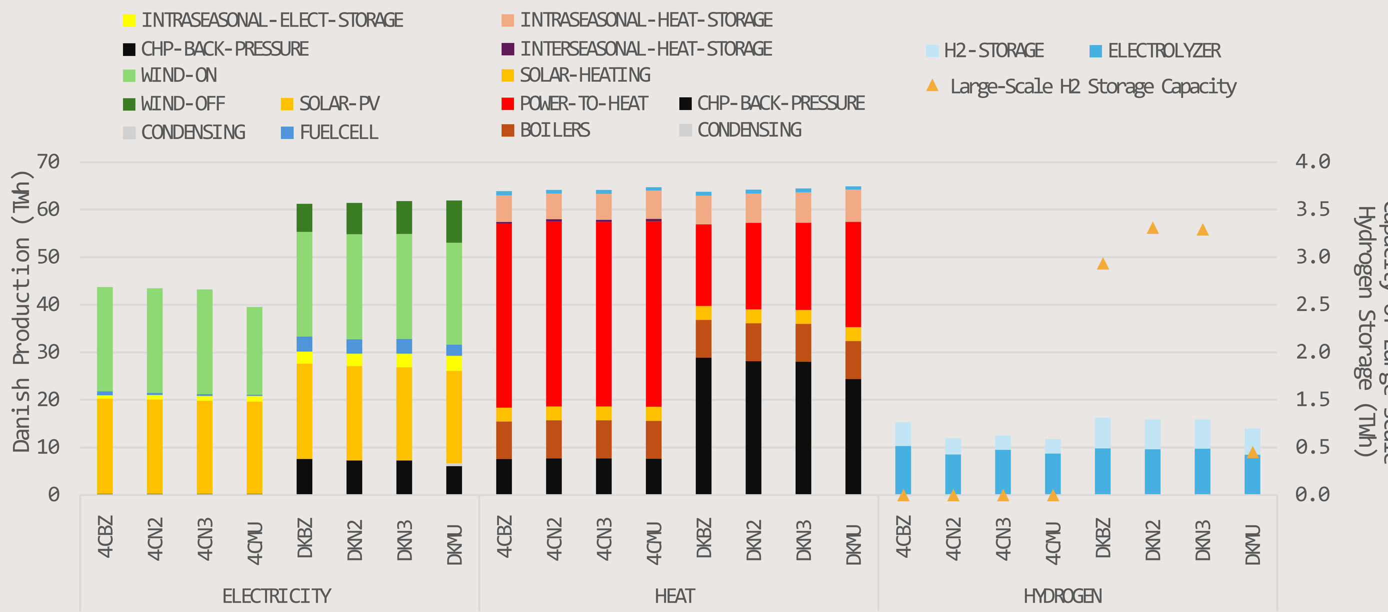
Results

Figure 3 illustrates the impact of increasing spatial resolution, which is seen to be insignificant compared to other uncertainties in energy system modelling. This is especially true in 4C scenarios, despite an increase in electricity imports in 4CMU. However, interesting changes are observed in the isolated Danish cases DKBZ-DKMU:

- Wind and power-to-heat production increases with higher resolution. This can be explained by larger hydrogen grid costs, making hydrogen for power more expensive

Total system costs are generally similar, as electricity and, especially, hydrogen transmission costs are a smaller component (details in Figure 2). Capital and operational costs of transmitting both carriers comprise 1-8% of total system costs.

Figure 3: Annual production of energy commodities and energy capacity of large-scale hydrogen storage



Limitations

- No modelling of individual heating
- Offshore wind modelled with profiles from onshore wind
- Hydrogen consumption for renewable fuel production assumed fully flexible
- Not accounting for retrofitting options

Conclusion and Outlook

The investigation revealed small differences in results when increasing spatial resolution. Most notably a decrease in hydrogen for power balancing.

However, the considerable heat consumption related to individual users should be taken into account in future research, which could further exacerbate differences in power-to-heat penetration at different spatial resolutions

A similar investigation on a European scale could be challenging due to the significant computational time of sector-coupled systems with many investment options. The computation time increased from 0.05-1h at the lowest resolution to 18-31h at the highest.

References

[1] Kountouris, Ioannis. "A Unified European Hydrogen Infrastructure Planning to Support the Rapid Scale-up of Hydrogen Production," August 1, 2023. https://doi.org/10.21203/rs.3.rs-3185467/v1 (Pre-print).

[2] Manz, Pia, Tobias Fleiter, and Wolfgang Eichhammer. "The Effect of Low-Carbon Processes on Industrial Excess Heat Potentials for District Heating in the EU: A GIS-Based Analysis." Smart Energy 10 (May 1, 2023): 100103. https://doi.org/10.1016/j.segy.2023.100103.

[3] Abad Hernando, Diana, Mason Scott Lester, Ida Græsted Jensen, Rasmus Bo Bramstoft Pedersen, Stefanie Buchholz, and Ebbe Münster. "FutureGas System Analysis: Final Report." Report. FutureGas System Analysis, 2020.

[4] Stamdataregister for vindkraftanlæg & data om el- og varmeforsyningen. Accessed: 2022-11-25, URL: https://ens.dk/service/statistik-data-noegletal-og-kort/data-oversigt-over-energisektoren

[5] Hofmann, Fabian, Johannes Hampp, Fabian Neumann, Tom Brown, and Jonas Hörsch. "Atlite: A Lightweight Python Package for Calculating Renewable Power Potentials and Time Series." Journal of Open Source Software 6, no. 62 (June 24, 2021): 3294. https://doi.org/10.21105/joss.03294.

Code & Data Availability

The codes are available at github.com/Mathias157

Python scripts for preprocessing can be downloaded in the balmorel-preprocessing repository (master branch, commit id 3710bf2), while the Balmorel repository contains the model at mbr-spatial-aggregation branch, commit id a22934e.