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# The effect of spatial resolution on outcomes from energy systems modelling of heat decarbonisation

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A B S T R A C T

Spatial resolution is often cited as a crucial determinant of results from energy systems models. However, there is no study that comprehensively analyses the effect of spatial resolution. This paper addresses this gap by applying the Heat Infrastructure and Technology heat decarbonisation optimisation model in six UK Local Authorities representing a range of rural/urban areas, at three levels of spatial resolution, in order to systematically compare results. Results show the importance of spatial resolution for optimal allocation of heat supply technologies and infrastructure across different urban/rural areas. Firstly, for the studied cases, differences of up to 30% in heat network uptake were observed when comparing results between different resolutions for a given area. Secondly, for areas that generally exhibit the high and low extremes of linear heat density, results are less dependent on spatial resolution. Also, spatial resolution effects are more significant when there is higher variability of linear heat density throughout zones. Finally, results show that it is important to use finer resolutions when using optimisation models to inform detailed network planning and expansion. Higher spatial resolutions provide more detailed information on zones that act as anchors that can seed network growth and on location of network supply technologies.

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## 1. Introduction

Spatial resolution has emerged as an important challenge for modelling energy system transitions [1]. While many studies exist at different spatial resolutions, for example modelling a group of consumers, districts or cities, or regions/nations, there are yet no comprehensive studies that compare how results from energy systems models differ when modelling at different spatial resolution levels. This paper applies the Heat Infrastructure and Technology (HIT) model [2] in six Local Authorities in the UK representing a range of rural/urban areas, at three levels of spatial resolution, in order to systematically compare results for heat decarbonisation energy system pathways for different resolution levels.

Heat decarbonisation is an apposite topic for a study comparing spatial resolutions. This is because the system that meets heat demand is inherently integrated across the energy system, with potential trade-offs between many energy carriers, infrastructures and end-use options. Therefore, it represents well the typical characteristics of broader energy systems, while still remaining relatively tractable given the challenges of collecting data and implementing models at multiple spatial resolutions. Finally, it is also a key challenge in overall heat decarbonisation: As stated by the Committee on Climate Change [3], heating for buildings in the UK constitutes around 40% of the total energy consumption and generates around 20% of greenhouse gas emissions. A deep reduction in emissions from heat in buildings is necessary to meet the Climate Change Act targets and the UK's contribution to the Paris Agreement.

This article is structured as follows. The next section reviews how some national/regional system models have been used for heat, and how urban scale models have been applied for systems that include heat and distribution networks, together with the spatial resolution levels they have used. This concludes in a discussion on the importance of spatial resolution for heat modelling and the gap identified in the literature on the comparison of results for different spatial resolution levels. The methodology section describes the model used in this research and presents the areas and spatial resolution levels modelled, together with the input assumptions. Results and then presented and discussed, leading to

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the conclusions summarising the main findings of this work.

## 2. Background

In order to place this article in context, this section shows how a selection of system models have been applied for heat-focused applications in the existing literature, their spatial resolution levels, and how infrastructure is modelled within them. Based on this, the potential importance of spatial resolution is highlighted.

### 2.1. National optimisation system models that include heat

National and larger-scope models typically have very coarse spatial resolution. For example, Dodds and Mc Dowall [4] use the UK MARKAL model and characterise the UK into a single region, in order to assess the cost-effective future of the UK gas network. Dodds and Demoullin [5] adapt the UK MARKAL model and also describe the UK as one aggregated region, to examine the economic feasibility and benefits of converting the UK gas grid to transport hydrogen. Pye et al. [6] implement the ESME model which uses a coarse disaggregation of the country into sub-regions to investigate the influence of uncertainty in techno-economic parameters, in cost-effective energy transition pathways. Another example is the EnergyPLAN [7] model, which simulates and optimises the operation of user-defined systems with a coarse disaggregation of a country into sub-regions. Several studies form the Heat Roadmap Europe project use this tool, such as [8], in which the potential of district heating and heat savings to decarbonise heat are analysed.[1]

This, however, does not mean that these models are unable to reflect spatial constraints or opportunities. For example, while each energy service demand is typically characterised as a time series for each region, it is possible to constrain end-use technologies to serve a limited portion of that demand, or to disaggregate the demand into different types (e.g. urban vs rural) based on the spatial (or other) characteristics of that demand. Similarly, while infrastructure in these models is often characterised via simple linear processes, those processes can be disaggregated and/or constrained to better represent a spatial aspect of that infrastructure (e.g. in UK TIMES, high and low pressure gas infrastructure is disaggregated [9]). Furthermore, the energy supply sources in these models are often represented via stepped supply curves, which can be used to characterise the spatial aspects of supply (e.g. location-based renewable potentials [10]).

Therefore, while coarsely resolved models such as most national models are certainly capable of indirectly representing spatial issues, it is clear that results become dependent on the assumptions in the studies that generated the related input data. Shortcomings of these models are not mainly in their formulations per se, but rather on the data base that is used to spatially describe heat demands and their location relatively to prospective heat supply. The aggregation of demand and supply over large areas is what can potentially cause variations in outputs.

### 2.2. Urban optimisation system models for heat

At the urban scale, a group of models exist in the literature in which the modelled area is more explicitly spatially resolved, either via “top-down” subdivision of geographical areas into zones, or via “bottom up” representation of a network of nodes based on individual buildings, consumers or other entities. Selected publications that can be categorised as such are described below.

In the category of models that take the approach of subdividing a geographical zone, there are several relevant publications. Girardin et al. [11] develop a geographical information system to model energy systems in urban areas. They argue that modelling advanced integrated energy systems requires a detailed definition of energy service demands, and illustrate this with spatially resolved case studies. Binary variables are used to represent networks between zones and networks within zones. Resolution is not stated, but the model is a disaggregation of the Geneva district.

Keirstead et al. [12] study the impact of combined heat and power (CHP) planning restrictions on the efficiency of an urban energy system using the TURN mixed integer linear optimisation model. The studied city is divided into grids of $400\,m \times 400\,m$ square cells. TURN is applied again in Keirstead and Calderon [13] to study spatial effects, technology interactions, and uncertainty in policy input parameters, using the city of Newcastle as a case study. They disaggregate the city into middle layer super output areas [14] and find the optimal technology mix and demand side measures in dwellings for supplying heat and electricity. A Monte Carlo analysis is then performed to understand the impact of uncertainty of certain parameters in the optimal solution. Finally, the model is applied to one neighbourhood using a finer resolution. This is the only example in the literature identified where different spatial resolutions were used in one model, and is discussed further in the section below. In Pantaleo et al. [15] the RTN model is adapted to consider biomass in urban energy systems. They divide a generic city into 16 cells and specify which cells have road connections between them for biomass transportation, and which cell connections are available for gas and heat networks.

In Ref. [2], Jalil-Vega and Hawkes use the HIT optimisation model to study decarbonisation pathways for heat, including heat supply, infrastructure, and end-use technology trade-offs. The model is applied to case studies in the City of Bristol, subdivided into 55 middle layer super output areas [14] (described further in Section 3.2.). Distribution networks are modelled between and within zones.

The other group of models, in which representative consumers/buildings/entities are modelled as nodes and connections between them represent distribution networks, usually (but not always) use a finer spatial resolution. Table 1 shows a selection of these models, the purpose of the research, and the number of nodes or spatial resolution used in the respective case study.

### 2.3. Importance of spatial resolution

As discussed by Pfenninger et al. [1], national and international energy systems models are being challenged by new emerging concerns such as distributed energy generation or renewable potentials. This translates into the need of more spatial detail than what the current established national scale models require or provide. On the other hand, maintaining coarser spatial resolutions is required to maintain practical solving times. Analysing the revised urban models, it is observed that the first group of models which divide areas into sub-zones, generally study areas such as districts or cities. The second group of models which assign each consumer to a node are able to model networks in higher detail, but in return have limited spatial coverage. There is a trade-off between capturing complexity and maintaining model tractability.

Specifically regarding heat networks, Morvaj et al. [22] highlights the importance of models providing information on location of technologies, heat network layouts, and de-centralisation level, and argues that bottom-up models can address these requirements, as opposed to top-down models. Nielsen and Möller [28] describe

[1] It is noted that any of the modelling frameworks used in these studies, TIMES/MARKAL, ESME and EnergyPLAN can and have also be applied at finer spatial resolutions. However, this is rarely done for national level studies due to tractability issues.

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