Spatial-Temporal Dynamics of Gas Consumption in England and Wales: Assessing the Residential Sector Using Sequence Analysis.

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Summary

The UK's residential sector has not decarbonised due to an inefficient housing stock with a reliance on natural gas.

This paper uses sequence and clustering algorithms to identify four consumption trajectory groups within English and Welsh neighbourhoods between 2010-2020. These are labelled "Very High to High Consumption"; "High to Medium Consumption"; "Medium to Low Consumption" and "Low to Very Low Consumption".

The results help for the location of electrification and retrofitting policies. Targeting areas of continual-high consumption will accelerate decarbonisation. Whereas targeting areas who under consume and may be in fuel poverty will enhance the occupants well-being and finances.

KEYWORDS: Spatial-temporal analysis, Uneven residential gas consumption, Fuel poverty, Climate Change

1.0- Research Context

Since 1990 the UK residential sector has only seen a 18.97% reduction in carbon due to an inefficient housing stock reliant on gas (Broad, Hawker and Dodds, 2020; DLUHC, 2020). Providing retrofits and electrifying properties via renewably generated electricity will reverse this trend and limit climate damage, as well as enhance the occupants well-being and finances (Holmes et al., 2019 and DLUHC, 2022).

However, higher household energy consumptions have been associated with greater affluence- a group who are both a strain on the climate and energy system (Chatterton et al., 2019; Karatasou and Santamouris, 2019). Targeting such groups will cause the biggest drop in emissions and have limited consequences for their well-being (Garcia et al., 2021)/ Furthermore, targeting policy towards those who are under-consuming and likely to be in fuel poverty will improve their finances and well-being, potentially relieving them of such poverty.

Research has focussed on household's energy consumption, but has done at an isolated period of time (Chatterton et al., 2016; Karatasou and Santamouris, 2019; Buchs and Schnepf, 2013), something which limits understanding towards progress of low carbon transitions. This paper addresses such issues via sequence and clustering analysis to identify common consumption trajectories within English and Welsh neighbourhoods between 2010-2020.

2.0- Methodology

This paper uses annual weather corrected domestic median gas consumption per meter at the MSOA level between 2010-2020, and also socio-economic and housing data.

Sequence analysis requires categorical data to operate, hence the consumption data was converted into 10 equal intervals from "1" for lowest consumers, and "10" for the highest consumers. Figure 1 outlines the same breaks used in 2010 were used for every year to ensure sufficient change in consumption states across the analysis period.

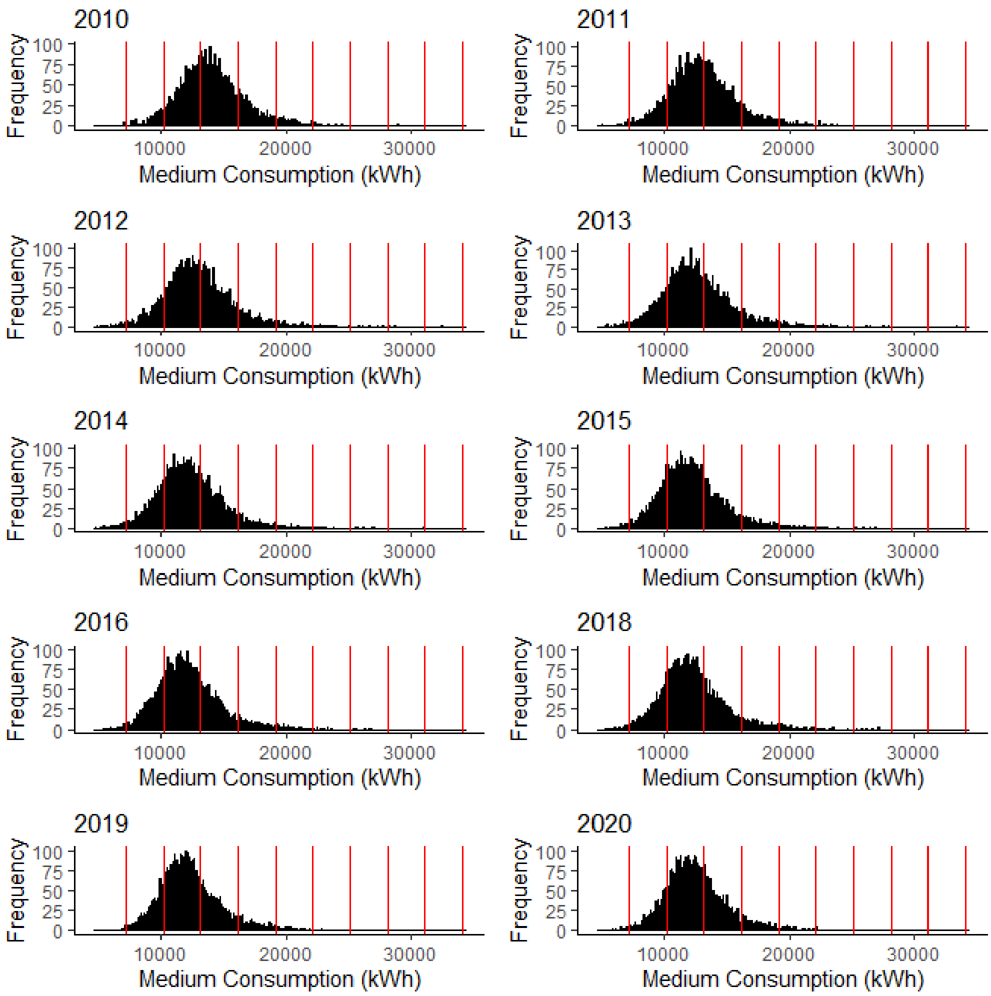

Figure 1- Median gas consumption MSOA 2010-2020

Sequence analysis was developed using the TraMineR package (Gabadinho et al., 2011) to identify similar transitions between areas by measuring their dis/similarity to others. A distance matrix was developed to calculate the distance between sequence trajectories as the number of transitions required for such sequences to be identical. Ward Hierarchical clustering is then used to group the sequence trajectories and an elbow and silhouette plot (Figure 2 and 3) was initiated to find the optimum number of clusters, which was decided at 4.

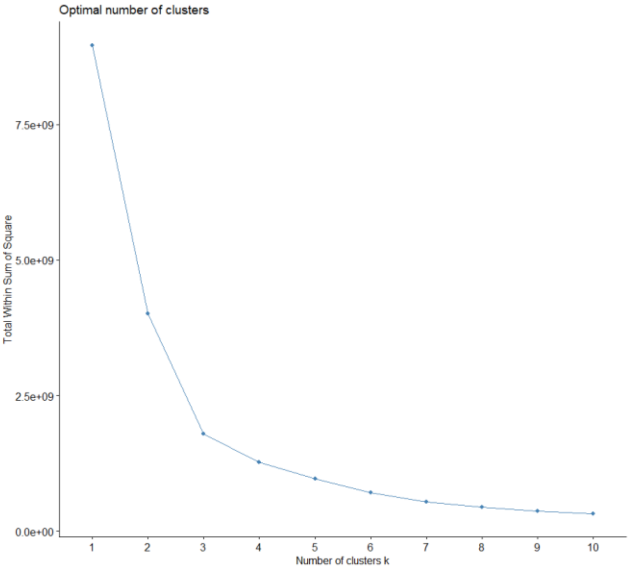

Figure 2- Elbow Plot

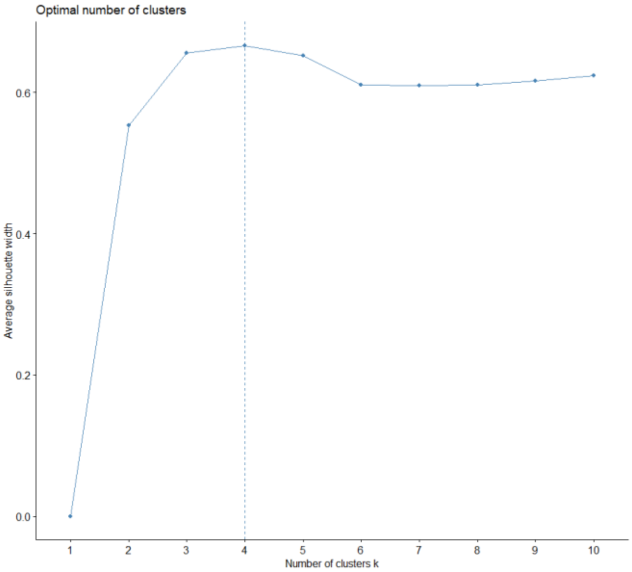

Figure 3- Silhouette Plot

3.0- <u>Results and Discussion</u>

3.1- Overall Trends in Gas Consumption

Figure 4 outlines the median gas consumption at 2010 (left) and 2020 (right). Figure 5 outlines the number of consuming meters at 2010 (left) and 2020 (right), with figure 6 highlighting the difference in gas meters across the decade. The results show an overall decrease in gas consumption in MSOA, but an increase in the number of meters. This indicates greater portions of properties are reliant on gas, but each property is using less. The highest consumption is in South East England and the outskirts of London, with the lowest in the center of London. The Capital is the only major area reducing its reliance on gas, as shown by a decrease in meters.

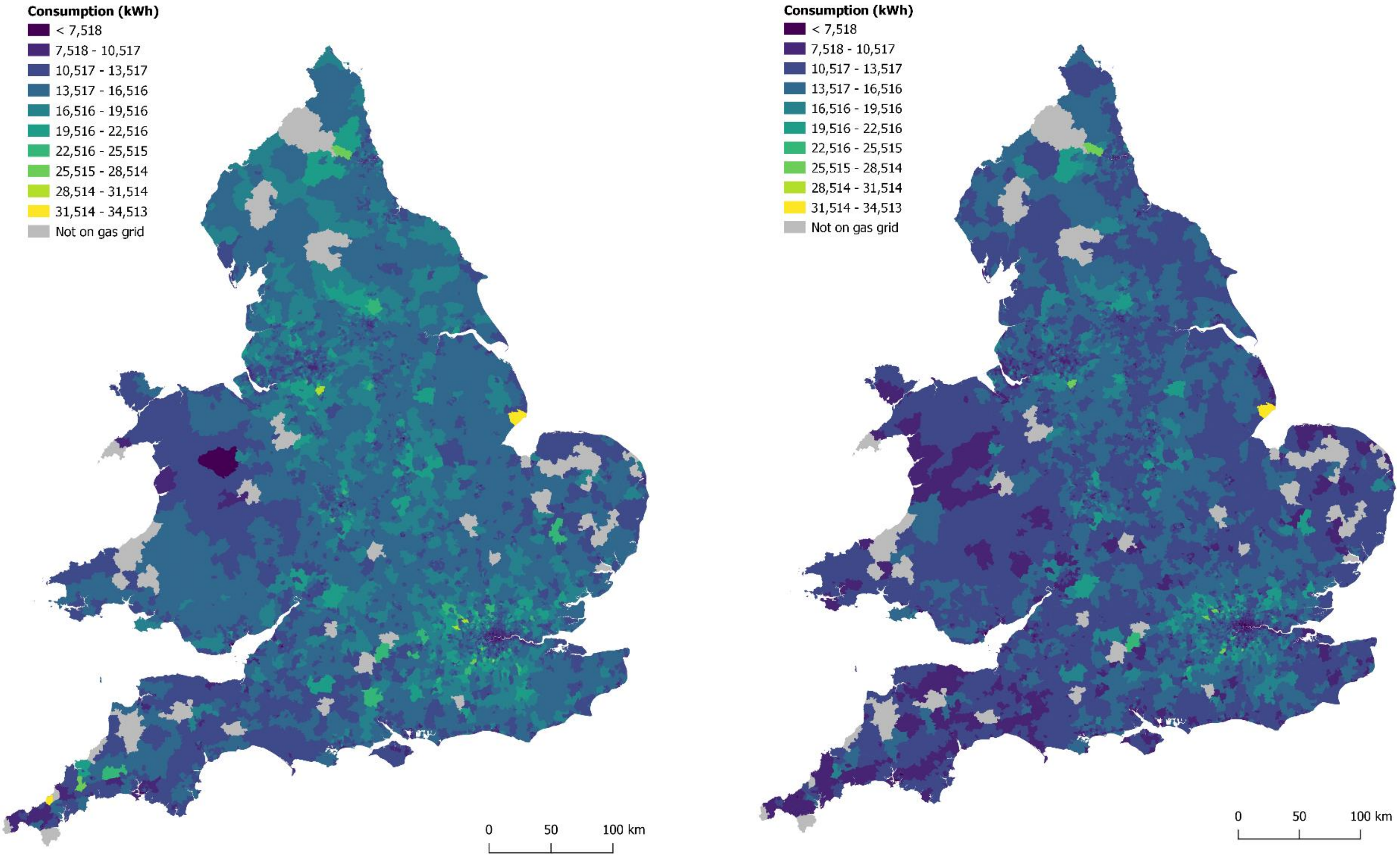

Figure 4- 2010 median gas consumption (left) 2020 median gas consumption (right)

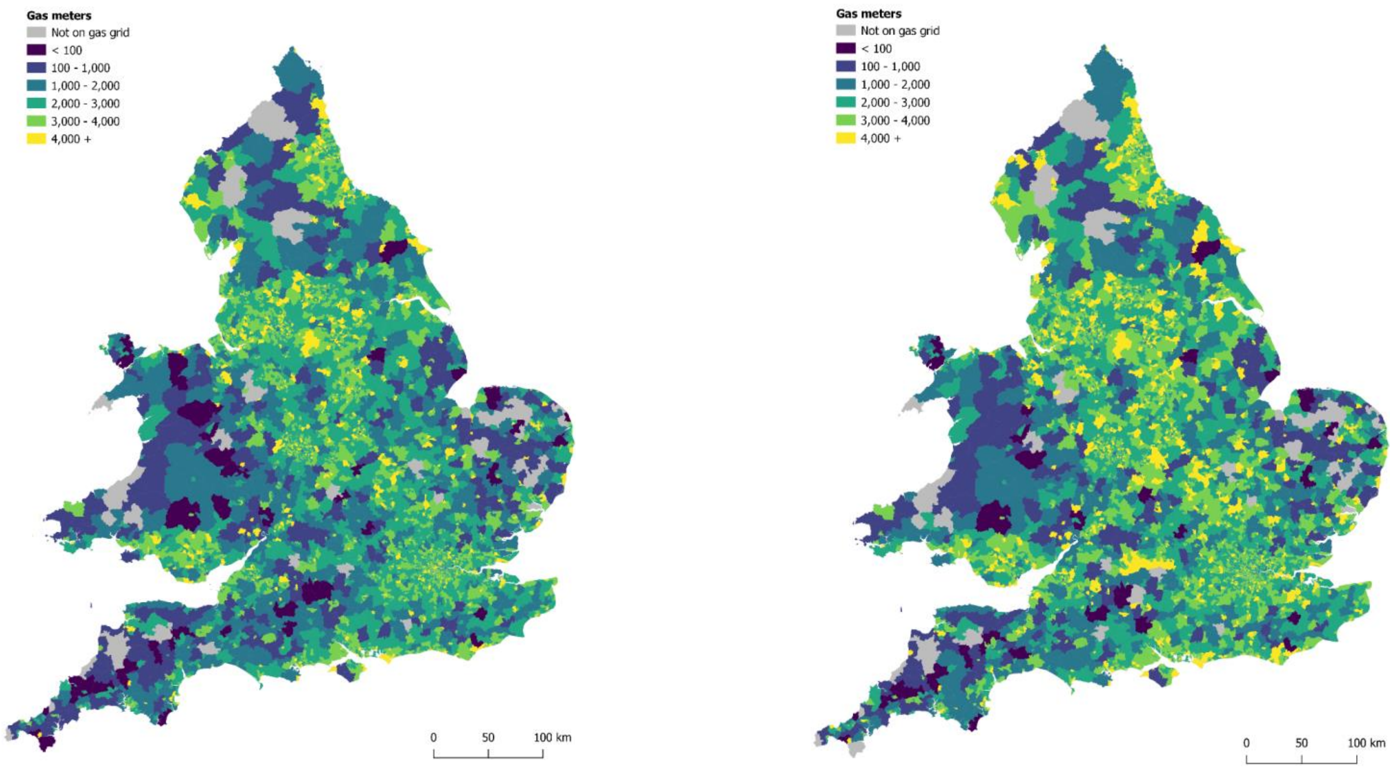

Figure 5- 2010 number of gas meters (left) 2020 number of gas meters (right)

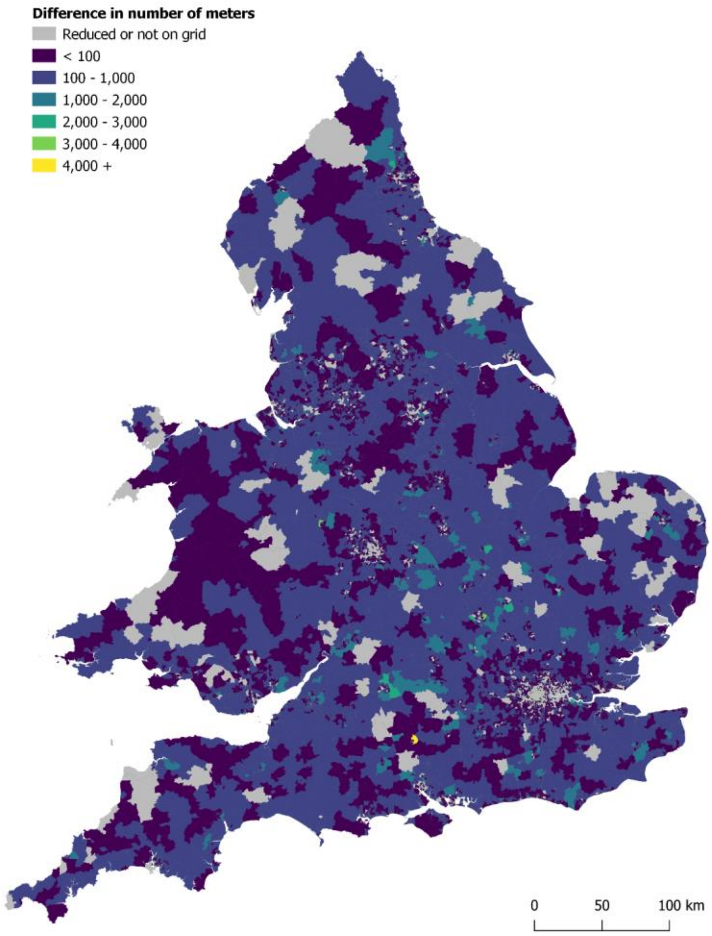

Figure 6- Difference in number of gas meters between 2010-2020

Smaller properties in urban areas, specifically an increase in the portions of flats and terraces are a reliable explanation for lower gas usage in London. The average floor space of these properties is $58m^2$, which is smaller than the $149m^2$ of floor space for detached properties which dominate the rural and peripheral areas (MHCLG, 2020).

The downward gas usage can be explained by enhanced efficiencies of properties. Between 1996-2019 the average Standard Assessment Procedure (environmental and energy performance of dwellings) increased from 45/100 to 65/100 thanks to enhanced insulation and double/triple glazed windows (MHCLG, 2020). The introduction of smart meters enable better control over energy usage and finances. They are estimated to save between 1-3% and with over 22 million installed, it's a reliable explanation for the reduced gas usage. The analysis period also includes the aftermath of the 2008 Financial Crisis, where many households restricted energy usage due to financial challenge (Petrova, 2018; Eisfeld and Seebauer, 2022)

3.2- Sequence and Clustering Analysis

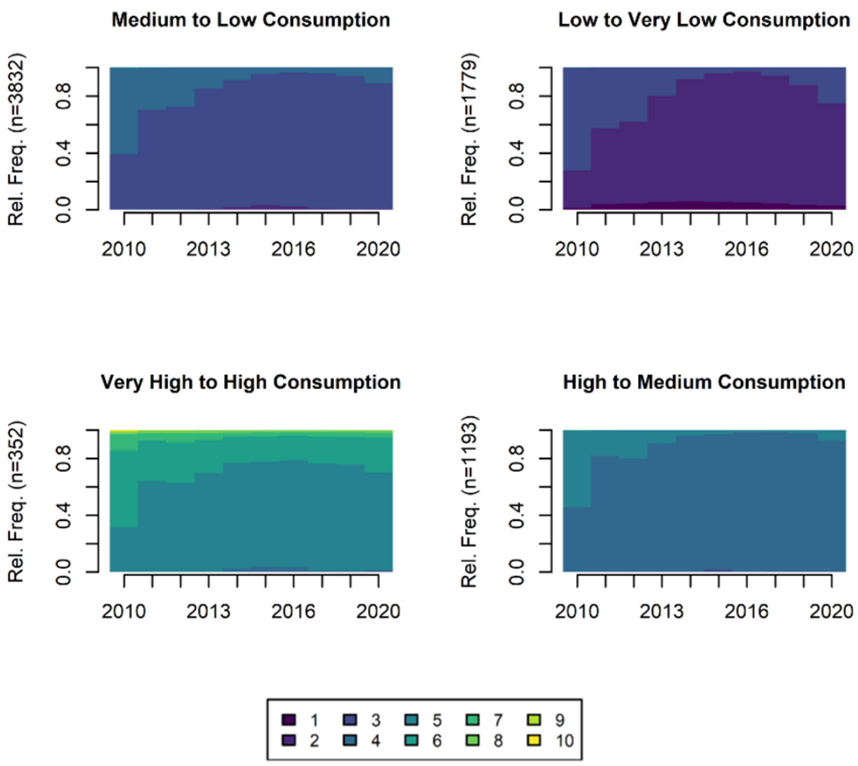

Figure 7- Clustering analysis of gas consumption in MSOA from 2010-2020

Figure 7 shows that gas consumption has decreased across all clusters, but there are variations within the clusters. The "Very High to High" cluster has 19 MSOA that consistently have the highest consumption states of 7-10 (145,550 individuals from population estimates (ONS, 2021)), while the 43 MSOA in the "Low to Very Low Consumption" cluster consistently have the lowest consumption states of 1-2 (444,516 individuals from population estimates (ONS, 2021)). The large gulfs in consumption leads onto why this could be.

3.3- Temporal Consumption is not uniform

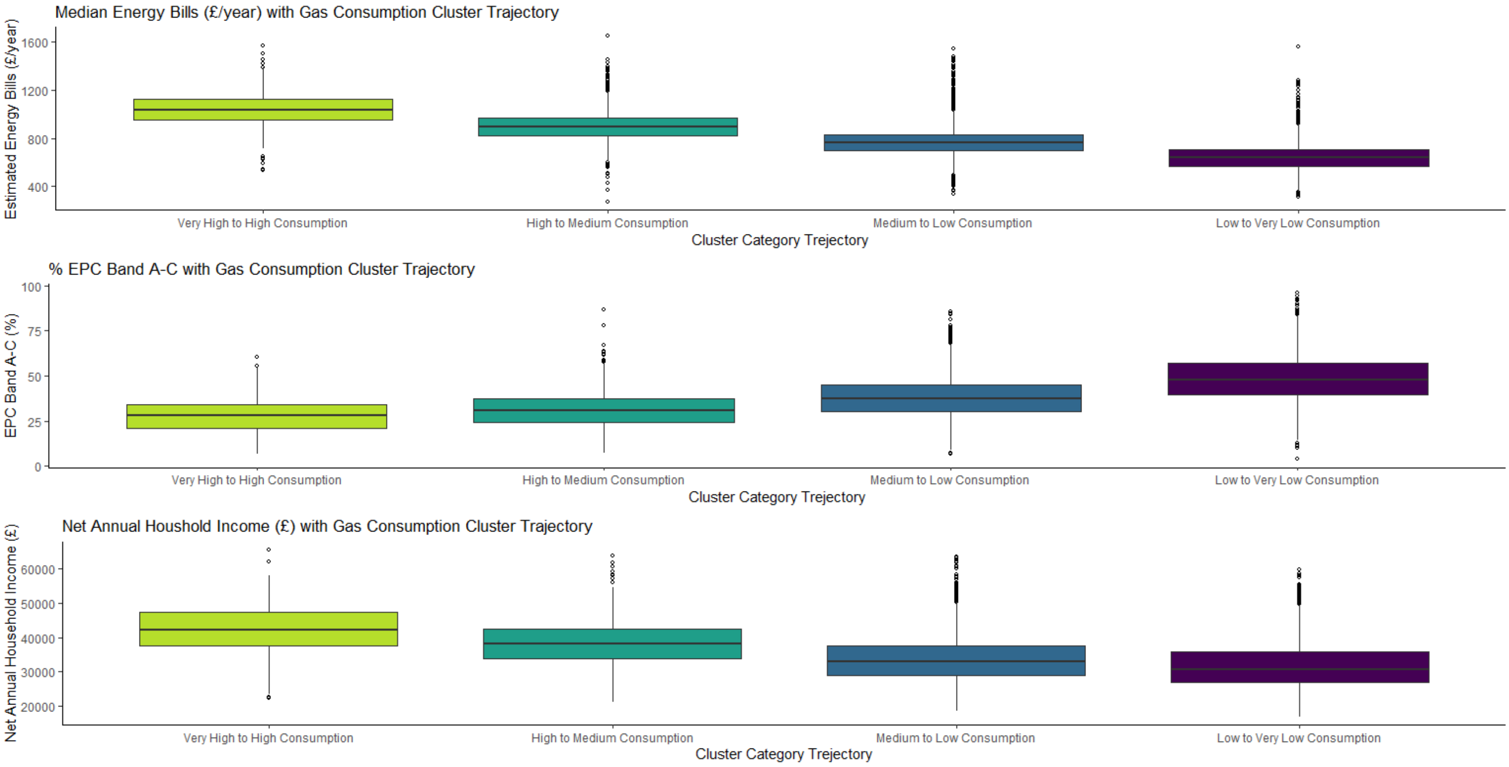

Figure 8- Contextualised clusters

Figure 8 shows that the higher consumption groups are shown to have smaller proportions of efficient properties, impacting their energy costs as shown via the “Very High to High Consumption” group seeing bills over £1,000, in comparison to around £800 or less for other groups. However, the “Very High to High Consumption” group has the highest incomes. As this cluster consumes heavily and has 19 MSOA who haven’t reduced, it supports the idea that the sector has a select few who overconsume, having a drastic impact on the energy system and climate.

The "Low to Very Low Consumption" cluster should be noted, as 43 MSOA within this cluster consistently have the lowest consumption levels. This cluster has the smallest incomes and 50% of properties within the MSOA of this cluster have an inefficient EPC band of D-G. These are significant drivers of fuel poverty, which can lead to households under-consuming which can develop numerous health issues for doing so.

3.3- Spatial-Temporal Variations in Gas Consumptions

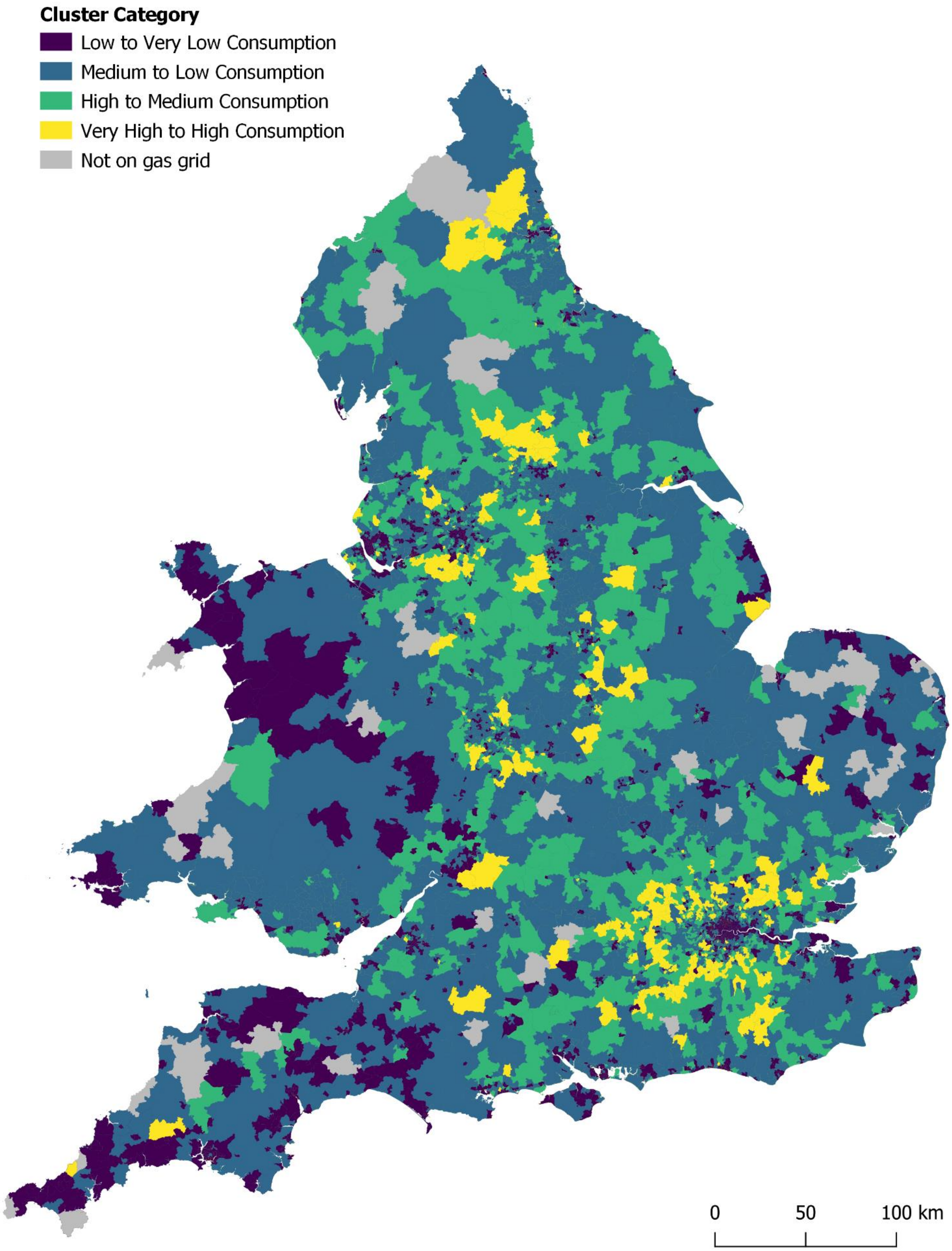

Figure 9- Spatial-temporal variation of has consumption within England and Wales

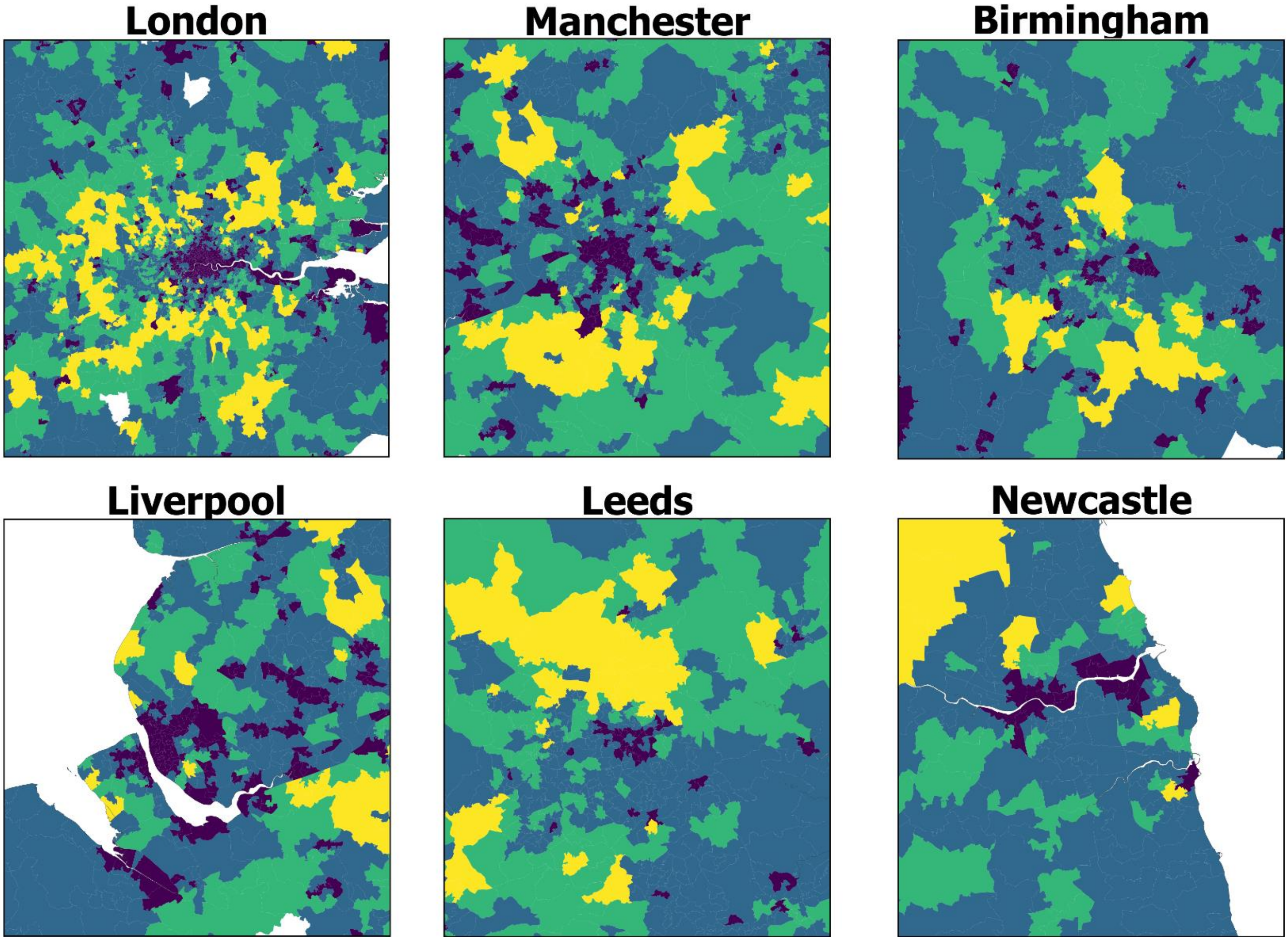

Figure 10- Spatial-temporal variation of gas consumption in urban centres

Figure 9 observes the spatial-temporal variations of gas consumption, with Figure 10 zooming into major urban centres. These centres are highly populated with lower consumption clusters, likely to be explained by these areas housing smaller properties rich require less energy. South West England and North Wales have particularly low consumption levels. The low consumptions in north Wales can be attributed to high levels of rural poverty due to significant economic fragility, where many cut back on fuel usage due to high portions of income taken up by rent and mortgages (Williams and Doyle, 2016). Furthermore, both of these areas have high concentrations of second addresses, which are often vacant during the colder months when gas consumption is higher (Kulakiewicz, Garton-Grimwood and Cromarty, 2022).

4.0- Biography

Cameron Ward completed a BA Geography degree at the University of Liverpool. Later moving onto an integrated Masters/PhD at the Geographic Data Science Lab within Liverpool as part of the Data Analytics and Society CDT. Key research interests involve fuel poverty, spatial inequality and climate change.

Caitlin Robinson is a Research Fellow and Proleptic Lecturer in the School of Geographical Science at University of Bristol. Caitlin is currently leading a UKRI Future Leaders Fellowship project mapping ambient vulnerabilities in UK cities.

Alexander Singleton is a Professor of Geographic Information Science at the University of Liverpool**,** Deputy Director of the ESRC Consumer Data Research Centre (CDRC) and Director of the ESRC Data Analytics & Society CDT.

Francisco Rowe is Professor in Population Data Science and the Lead of the Geographic Data Science Lab at the Department of Geography and Planning within the University of Liverpool. His areas of expertise are: internal & international migration; human mobility; and geographic data science.

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