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Urban form, resource intensity & renewable energy potential of cities

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Introduction

Due to a rapidly growing global urban population, the resource consumption of cities has become increasingly important. According to the United Nations, more than half of the global population live in urban areas [1]. As a result, a significant part of the world's resources is consumed in cities. However, calculating urban resource consumption has proven to be challenging. One of the few exceptions is a prediction for urban energy consumption made by the International Energy Agency. According to this, the share of the world's energy consumed in urban areas – an estimated 7900 Mtoe in 2006 – will grow from two thirds to almost three quarters in 2030. Furthermore, energy related CO_2 emissions in urban areas were estimated to be 71% of the world's total in 2006; this is predicted to rise to 76% by 2030 [2]. Therefore, cities need to be the focus of attention when addressing the issues related to climate change, which are directly linked to urban economies. This paper summarises a research effort to develop a standardised way of empirically analysing urban areas. The main goal of this research is to produce a spatially explicit, consistent and replicable methodology to analyse cities from a material and energy consumption perspective. A new method was developed for this analysis and the results are illustrated using data from London. This method uses geo-referenced data that can be found for other cities throughout the world and the objective of this study is to apply this method to other cities using the same types of data.

Methodology

This analysis consists of an approach to examine the relationship between urban form and resource performance of cities. For this, urban resource performance is considered from complementary perspectives, integrating neighbourhood characterisation with the assessment of energy consumption, while also considering the potential for implementing renewable energy technologies. The combination of these three dimensions will lead to a holistic analysis of the city, from an urban sustainability perspective. The specific methods of each part are described in the following subsections.

Neighbourhood characterisation

The first step is to analyse the urban form using information about the physical layout of an urban area. The characterisation of distinct types of urban form helps to improve the understanding of the city's complexity by identifying homogenous neighbourhood types and their dominant characteristics. For achieving this goal, four variables are used to describe the urban fabric, as described in Table 1. This analysis is applied to the greater London area at the *Lower Layer Super Output Area* (LLSOA) scale, a spatial unit defined by the UK census bureau. In the greater London area there are approximately 5600 LLSOA units, each containing a population of approximately 1500 inhabitants.

Based on these four descriptors, an unsupervised classification of the urban form is performed using the k-means clustering algorithm, which works by iteratively partitioning the data until it reaches a maximum in a Euclidian distance metric in the multidimensional space of the input parameters. The clustering is performed using the open-source statistical software R (using the 'stats' package). The k-means algorithm is applied with the default McQueen implementation. A similar approach of characterising the urban form was used to estimate the material required for buildings and road infrastructure [3].

Category	Description
Plot ratio	Total floor space / LLSOA area
Average building height	Average height of buildings in LLSOA
Fraction built area	Total built area / LLSOA area
Fraction green space	Total green space / LLSOA area

Table 1: Variables used for characterisation of urban form

Statistical analysis of energy consumption

In the second step, multivariate regression modelling of the drivers of energy consumption was used to relate resource consumption measures with the urban form parameters previously used to determine urban clusters. This modelling technique examines the parameters used for clustering and tests for their statistical significance in relation to energy consumption.

When using spatially aggregated data, observations may be biased due to spatial autocorrelation. To address this problem, a spatial error modelling approach can be used [4]. In spatial error regression models, the error structure is related to the spatial distribution of the observations to avoid the possible bias from the existing spatial autocorrelation. As spatially auto-correlated errors are present in this analysis, spatial error regression modelling was used.

Estimation of renewable energy potential

The third and final step in this methodology consisted of an assessment of the renewable energy potential (REP) of cities. This step was carried out using a top-down approach for calculating simple REP indexes, and considered the spatial requirements of different renewable energy technologies (RET). Using spatial and land use descriptors, the potential for each RET (solar, wind, geothermal, biomass, etc.) was independently evaluated and expressed in nine different REP indexes. Finally, the total REP was expressed by the sum of all indexes analysed.

For each sample, all the REP indexes produced were linked with the results of the spatial clustering analysis, which allowed to analyse the relationships between the spatial characteristics of neighbourhoods and their corresponding REP.

Preliminary results and discussion

This section summarises the results obtained from the analysis, illustrated using data from the greater London area. The data sources used were: the UK 2001 census, energy data from the UK Department of Energy and Climate Change (DECC), land use statistics from the Generalised Land Use Database (GLUD), and building footprint data (including building heights), obtained from the University of Edinburgh's Digimap collections.

Cluster observations

The patterns observed in London are generally distributed in radial bands, following the gradient in building density that decreases from the centre of the city towards the suburbs. Although the results of this unsupervised clustering process are still general and do not reflect the high level of complexity in the urban fabric, they show that the structure of the city can be identified using only four general descriptors of urban form. Figure 1 illustrates the distribution of each of the four variables per cluster typology, while Map 1 shows the spatial distribution of the three typologies for London.

Energy consumption analysis

To test the influence of the clustering descriptors on resource consumption, spatial error regression models were applied to the study area. These models include the same four variables that were used to determine the cluster typologies. The resulting output of the regression models is shown in Table 2.

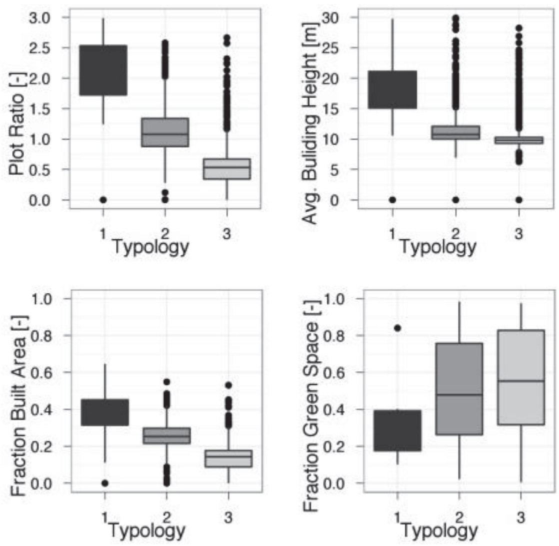
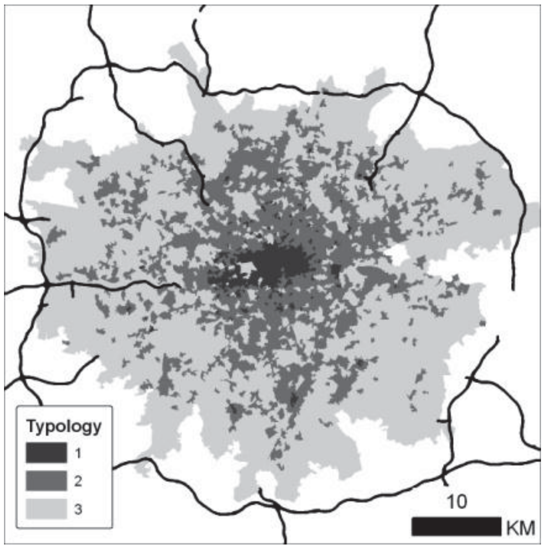


Figure 1: Cluster typologies and their variables for London at the LLSOA level



Map 1: Map of London showing the distribution of three cluster typologies

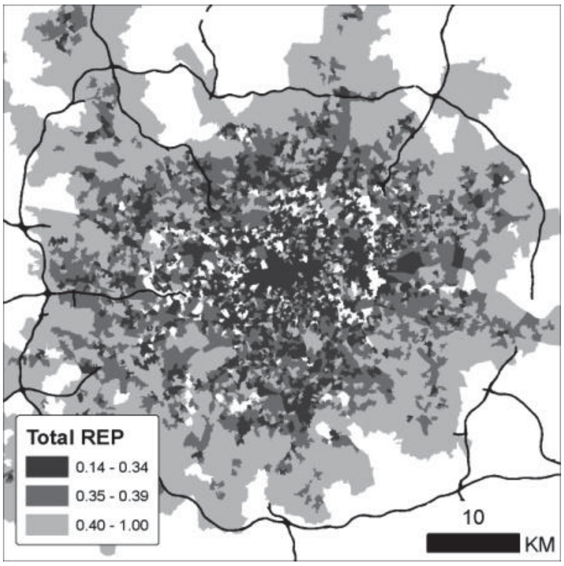
Variable	**Estimate**	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	9594.1	152.54	62.8958	< 2.2e-16
Plot ratio	0.80138	0.094259	8.5018	< 2.2e-16
Average building height	-200.03	12.729	-15.7142	< 2.2e-16
Fraction built area	-4029.9	561.88	-7.1721	7.385e-13
Fraction green space	-7.1453	0.42338	-16.8766	< 2.2e-16

Lambda: 0.4145, LR test value: 490.06, p-value: < 2.22e-16, Observations: 5514, Nagelkerke pseudo-R-squared: 0.23, AIC: 97754, Log likelihood: -48869.8, Nr. Of parameters estimated: 7

Table 2: Regression table from the spatial error model. The dependent variable is residential consumption of gas and electricity per capita in kWh

Renewable energy potential

Preliminary results of this analysis are below. Map 2 illustrates the distribution of the REP index for London, while Figure 2 shows the total REP per cluster typology. The results suggest that total REP for low-density areas, such as London's suburbia (typology 3), is 1.7 times higher than in the case of high-density areas, such as the city centre (typology 1).



Map 2: Total REP distribution for London at the LLSOA level

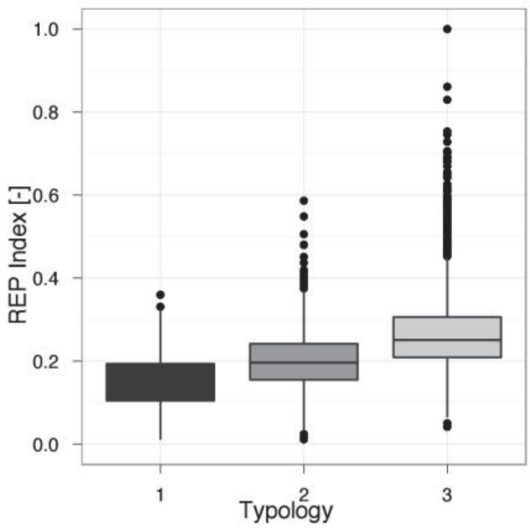


Figure 2: Total REP index per cluster typology for London at the LLSOA level

Conclusions

The work presented here focuses on combining different measures of urban form to develop a holistic assessment of urban resource performance. This is done through the development of a methodology to characterise urban form, and illustrated using data from the greater London area. The preliminary results for neighbourhood characterisation show a clear distinction between three different urban cluster typologies, mainly driven by descriptors of building density. The results of the analysis for residential energy consumption and renewable energy potential show that urban form also has a significant relationship to resource performance. In the next phases of this work, more case studies will be analysed, combining other measures of urban resource performance, such as material and water intensity.

References

[1] **United Nations** (2007), World Population Prospects: The 2006 Revision and World Urbanisation Prospects: The 2007 Revision. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat

[2] **International Energy Agency** (2008), World energy outlook

[3] **Quinn D., Wiesmann D., and Sarralde J.J.** (Forthcoming, Sept. 2011), Estimating Resource Consumption Using Urban Typologies, CISBAT

[4] **Anselin, L.** (1988)**,** Spatial econometrics: methods and models, Springer