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# Spatial dynamics of household energy consumption and local drivers in Randstad, Netherlands

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ABSTRACT

This study is an attempt to bridge an eminent knowledge gap in the empirical studies on Household Energy Consumption (HEC): the previous studies implicitly presumed that the relationships between HEC and the geographic drivers is uniform in different locations of a given study-area, and thus have tried to disclose such everywhere-true relationships. However, the possible spatially varying relationships between the two remain unexplored. By studying the performance of a conventional OLS model and a GWR model -adjusted $R^2$, randomness of distribution of residual (tested by Moran's I), AIC and spatial stationary index of the geographic drivers, ANOVA test of residuals-this study demonstrates that the GWR model substantially provides a better understanding of HEC in the Randstad. In this respect, the core conclusion of this study is: the relationships between HEC and geographic drivers are spatially varying and therefore needed to be studied by means of geographically weighted models. Additionally, this study shows that considering spatially varying relationships between HEC and geographic drivers, by application of hierarchical clustering, the areas of the Randstad can be classified in four clusters: building age and income impact areas, building density impact areas, population density and built-up impact areas, household size and income impact areas.

## 1. Introduction

Curbing level of energy consumption has been matter of policy makers' interest since 1970s subsequent to geopolitical turmoil in 1973 and 1979. The interest has been widened into the environmental impact of energy consumption, particularly greenhouses gases (GHG) emission and global warming, following United Nations Framework Convention on Climate Change (UNFCC) in 1992, and preparation of Kyoto treaty in 1997, and United Nations Climate Change Conference held in Paris, 2015. However, despite the effort spend on international treaties, between 1990 and 2012, final energy consumption in EEA countries (the European Economic Area) increased by 6.5% (European Environment Agency, 2015a). In EU-15 countries between 1990 and 2011, the GHG emission decreased for 14.9% (European Environment Agency, 2013), which is still short of the target set by 2020 climate & energy package: 20% cut from 1990 level (Climate Action 2020 European commission, 2009). The share of Households energy consumption (HEC) in total energy use is substantial. In EU-27 countries in 2010, HEC accounts for some 27% of the total final energy consumption (European Environment Agency, 2015b) and creates 25% of GHG emissions (European Environment Agency, 2012). In the Netherlands, in order to reduce HEC, Third National Energy Efficiency Action Plan for the Netherlands (Ministry of Economic Affairs, 2014) introduces set of incentives and regulations, applicable for all the locations of the country, which mainly aim for improving quality of buildings e.g. low interest loans for building insulation, low-interest loans for building renovation, stricter energy standards for new construction, and compulsory measures to ensure efficiency of buildings' heating and ventilation appliances.

Many previous studies explored the impact of variety of geographic drivers on the HEC. Plenty of the previous studies have established links between level of the income of the inhabitants and the level of HEC (for instance Yun & Steemers, 2011; Druckman & Jackson, 2008; Joyeux & Ripple, 2007). Several previous studies found associations between family type and HEC, mainly concluding that consumption per head drops as the size of family grow (for instance Fong, Matsumoto, Lun, & Kimura, 2007; Lenzen et al., 2006; Tso & Yau, 2003). The age of the inhabitants is also introduced as one of the significant drivers of HEC, particularly the portion of children and senior citizens from total population (York, 2007; Yun & Steemers, 2011; Yust, Guerin, & Coopet, 2002). Moreover, the higher percentage of economically inactive inhabitants –for instance inhabitants with disability or retired-has been seen as sources of higher HEC (for instance Fong et al., 2007). The HEC of the inhabitants of different housing tenure also found to be meaningfully different due to varying level of investment in insulation and different methods of payment for energy cost (for instance Druckman &

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Jackson, 2008; Tso & Yau, 2003; Aydinalp, Ugursal, & Fung, 2004). Several studies highlighted significant variation of HEC between different types of dwellings, for instance between single-family and multi-family houses, and also between dwellings of different age (for instance Yun & Steemers, 2011; Druckman & Jackson, 2008; Aydinalp et al., 2004). Moreover, land-cover has been found to be effective on HEC due to its links with formation of urban heat islands (for instance Madlener & Sunak, 2011; Georgakis & Santamouris, 2006; Hui, 2001). Wind intensity is found to impact HEC by affecting the thermal exchange between buildings and outside space by affecting infiltration and exfiltration of the buildings (for instance Sanaieian, Tenpierik, van den Linden, Seraj, & Shemrani, 2014; Van Moeseke, Gratia, Reiter, & De Herde, 2005). Ewing and Rong (2008) suggest that higher building density could decrease the energy used for heating, and increase that for cooling. Several studies suggest that the surface-to-volume ratio of the building affects the heat loss of buildings and HEC (for instance Steemers & Yun, 2009; Druckman & Jackson, 2008; Lenzen et al., 2006). Population density is also considered as an effective determinant of HEC (for instance York, 2007; Lenzen et al., 2006).

A knowledge gap is eminent in the current body of literature on HEC: all of previous studies implicitly presumed that geographic drivers have an unvarying impact on HEC across a given area, and therefore attempted to disclose such everywhere-true impacts. Consequently, the policies-recommendation brought forward by previous study are uniform and generic for all areas in question instead of location-specific and spatially varying. The core objective of this research is to tackle such knowledge gap chasing answers to the following questions: (a) Are the relationships between HEC and the geographic drivers spatially varying across the areas of the Randstad region, the Netherlands? (b) If yes, how such relationships differ across the areas of the Randstad region?

To do so, this study aim to conduct geographically weighted regression (GWR) for studying HEC. The method has been successfully deployed in several geographic studies of different disciplines such as afforestation (Clement, Orange, Williams, Mulley, & Epprecht, 2009), regional wealth and land cover (Ogneva-Himmelberger, Pearsall, & Rakshit, 2009), urban landscape fragmentation (Gao & Li, 2011), agriculture and urbanization (Su, Xiao, & Zhang, 2012), land use and water quality (Tu, 2011), residential land price (Hu, Yang, Li, Zhang, & Xu, 2016), late-stage prostate cancer diagnosis (Goovaerts et al., 2015), urban heat island (Ivajnšič, Kaligarič, & Žiberna, 2014), and fire density (Oliveira, Pereira, San-Miguel-Ayanz, & Lourenço, 2014). However, surprisingly, HEC studies are lagging behind in application of GWR. To bridge this gap, this study investigates the location-specific effect of variety of socioeconomic, housing, urban morphology, solar radiation and wind-intensity related indicators on HEC in the neighborhoods of the Randstad region, the Netherlands.

## 2. Material and methods

### 2.1. Case study

The study-area is consisted of *buurten*, a spatial division defined by the Dutch central bureau of statistics (CBS), roughly could be translated as neighborhoods, in the Randstad region in 2013 (account for 2413 neighborhoods). The Randstad is a conglomeration of highly urbanized areas located in the south west of the Netherlands comprising the four major Dutch cities of Amsterdam, Rotterdam, the Hague and Utrecht, as well as the relatively less urbanized areas between them – the so-called "green heart". In order to avoid the boundary-effect problem in GWR models, we also defined "analysis areas" which is consist of the study-area plus a 20 km buffer around it (3514 neighborhoods in total). All the calculations are conducted on the analysis area, however at the end only the results obtained for areas within the study-areas are reported (Fig. 1).

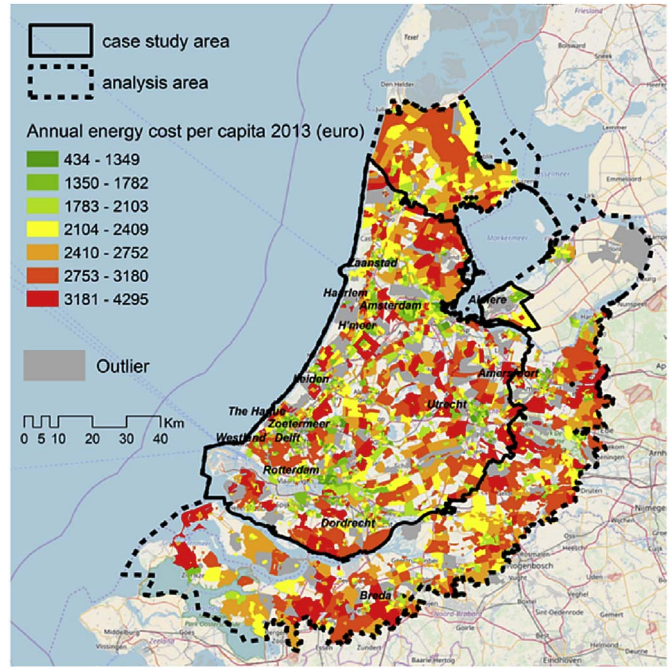


**Fig. 1.** Annual energy expenditure per capita (dependent variable of this study), the study-area and the analysis area.

### 2.2. Data collection and processing

#### 2.2.1. Dependent variable

The dependent variable of this study is average annual energy expenditure per head within the dwellings on gas and electricity, in 2013 (Fig. 1). The data on consumption of gas and electricity are extracted from *wijk-en-buurtkaart 2013* (Centraal Bureau voor de Statistiek, 2013). As the available data does not indicate the neighborhoods with solar energy supply or district heating, the abnormal values of gas and electricity use needed to be filtered out thus univariate outliers of gas and electricity use (incidents with z-value $<=-2.5$ or z-value $>=+2.5$) are identified as outlier and excluded. The average cost of gas and electricity for domestic consumption in 2013 in Netherlands, is taken from Eurostat (Eurostat, 2015).

#### 2.2.2. Independent variables

This study is conducted on 21 independent variables (Table 1). The first two variables indicate the portion of the population aged 14 or younger and aged 65 or older. One variable show population density per square kilometer. One variables specify the household structure by demonstrating average household size. Three variables show economic status of the residents: average annual disposable income per head (in euros), Percentage of population aged 15–64 receiving disability benefits, and Percentage of population aged 15–64 receiving unemployment benefits. Four variables are deployed in order to describe the status of housing tenure in the areas: Property-value (WOZ in Dutch), shows the average value of residential real estate in the areas; percentage of housing tenure owned by public associations (not necessarily social housing); median age of residential buildings; and percentage of residential floor area constructed after the introduction of building energy-efficiency standards in 1988. Land-cover of the areas is further explained by means of two variables including the portion of built-up areas, semi built-up areas and portion of green land covers (consisted of recreational, agricultural and natural areas).

The status of urban morphology (properties related to geometrical distribution of the building masses within space) is described using five variables: floor area ratio (FAR); building coverage ratio (BCR); buildings' surface to volume ratio; frontal area index ($\lambda_f$) - the ratio of total