Sustainable Cities and Society 32 (2017) 669–681

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Integrating the energy costs of urban transport and buildings

Bruno Osório[a,*], Nick McCullen[a], Ian Walker[b], David Coley[a]

[a] Department of Architecture & Civil Engineering of the University of Bath, UK
[b] Department of Psychology of the University of Bath, UK

ARTICLE INFO

Keywords:
Energy consumption
Buildings
Transport
GIS
Urban spaces

ABSTRACT

We cannot effectively reduce the carbon-related urban energy use without first having a good method for measuring it at an effective scale. Most prior research has usually considered the energy consumption of buildings and transport separately, but urban energy use is better understood when both uses of energy are considered together. This paper introduces a new energy use metric that combines the energy consumption of both buildings and transport. Estimates are calculated from readily available data and the simplicity of the methodology enables its replicability. This is attractive for policy-makers and planners by delivering them tools of more direct control of local-level policies. Using a LSOA geographic level and mapping the results produces helpful insights into energy consumption patterns and how the two uses of energy can be combined to support mitigation measures. When applying the methodology to a case study in the United Kingdom, maps produced show, amongst other things, how rural commuter belts are disproportionately energy-hungry when assessed per capita. Urban living is revealed as most energy efficient at this level. The integrated modelling approach demonstrated here improves the understanding of consumption patterns to enable better planning of strategies to reduce energy demand and its negative impact.

1. Introduction, scope and purpose

Industrialisation and subsequent urbanisation has resulted in a continuous growth in the number of people living in cities, and this increase is expected to continue (Fassmann, B & hr, & Jürgens, 2005; Madlener & Sunak, 2011; Reinhart & Davila, 2016). This growth is leading to ever increasing global energy demand (Creutzig, Baiocchi, Bierkandt, Pichler, & Seto, 2015; Komal & Abbas, 2015), with a large fraction of final energy being used in cities and other urban areas. Considering that energy supply is largely obtained from fossil fuels (Anderson, Wulfhorst, & Lang, 2015), cities and overall urban areas are a major source of CO_2 and other greenhouse gas (GHG) emissions (Anderson et al., 2015; Dhakal, 2009; Pacione, 2005). As a result of this, urban mitigation policies are urgently needed (Davis & Caldeira, 2010; Hoornweg, Sugar, & Gomez, 2011; Pacione, 2005) to reduce the negative consequences of those emissions, such as climate change and air pollution. To design and implement such mitigation strategies and reduce carbon-based energy dependency of cities, an accurate understanding of urban energy consumption is required. Identifying patterns of energy consumption will allow the analysis and modelling of urban energy demand, in order to devise better energy planning and management strategies (Akimoto et al., 2008; Feng, Chen, & Zhang, 2013; Vera & Langlois, 2007).

Buildings and transportation are the leading contributors to energy demand (Banister, Watson, & Wood, 1997; Hickman & Banister, 2014; Steemers, 2003) and associated carbon emissions. For example, in the European Union of 27 members (EU-27), transport and buildings represented more than 50% and 33% of the total energy consumption, respectively, in 2011 (European Commission, 2013). Given the impracticality of quantifying actual energy consumption values of every urban component (i.e. each building and vehicle), estimates are produced. At present, different approaches are employed to estimate energy consumption, but no definitive solution has yet been found, particularly when looking at large regions. A common approach to estimate urban energy consumption is using models, for both buildings and transport (Brand, Tran, & Anable, 2012; Crawley, Lawrie, Pedersen, & Winkelmann, 2000; Feng et al., 2013; Fumo, 2014; Gerber, 2014; Heiple & Sailor, 2008; Howard et al., 2012; Travesset-Baro, Gallachóir, Jover, & Rosas-Casals, 2016; Yin et al., 2015), representing the complex dynamics of the real world. However, although they theoretically allow very detailed estimates to be made, these models are usually very complex and require large bulks of input data that are not generally available for the majority of cities or urban areas, limiting the large-scale application of the modelling procedure to other geographic areas.

This paper introduces a unified methodology to estimate the total

* Corresponding author.
E-mail addresses: b.osorio@bath.ac.uk (B. Osório), n.j.mccullen@bath.ac.uk (N. McCullen), i.walker@bath.ac.uk (I. Walker), d.coley@bath.ac.uk (D. Coley).

http://dx.doi.org/10.1016/j.scs.2017.04.020
Received 31 August 2016; Received in revised form 31 March 2017; Accepted 29 April 2017
Available online 10 May 2017

energy consumption costs in urban spaces. Therefore, the methodology combines the operational energy consumption of both buildings and transport into an energy use metric, considering that both are significantly interdependent given that the mobility of the buildings' users and respective travel distances are influenced by the urban spatial layout, i.e. the arrangement of the built environment, affecting, for example, the transport carbon footprint (Stephan, Crawford, & De Myttenaere, 2012). At the same time, transport networks also have an effect on the operational energy consumption of both buildings and transport (Hillier & Vaughan, 2007) by moving individuals and goods between places (Barthelemy, Bordin, Berestycki, & Gribaudi, 2013). Since mitigation strategies are primarily interested in reducing carbon-based energy consumption and its negative impacts, the simultaneous study of the operational energy consumption of both buildings and transport can help planners to avoid unintended outcomes of one-sided strategies.

The introduced methodology seeks also to prevent another major difficulty when estimating urban energy consumption: defining city boundaries. The use of distinct urban/rural boundaries result in different energy estimates. For example, the administrative boundaries of many cities, especially large cities, generally do not encompass the whole urbanised area of a city, since administrative definitions are slow to follow the change over time of urban boundaries (Marcotullio et al., 2014; Steinberger & Weisz, 2013; Tayyebi, Pijanowski, & Tayyebi, 2011). The resulting energy consumption estimates may lead planners and policy-makers to develop biased and ineffective actions to reduce and mitigate carbon-related energy demand (Steinberger & Weisz, 2013). For that reason, in this paper a large scale geographical unit – Lower layer Super Output Area (LSOA) – is used so that the boundaries of cities and urban areas are not predefined and a bias is not added to the analysis. At the same time, the use of the fine-grain detail LSOA units enables to have a better understanding of the energy internal dynamics of cities and urbanised areas, in addition to the regional dynamics and between cities.

The work presented here focuses on urban areas and seeks to feed into policy concerning working and living patterns (rather than global commerce), and so the analysis on the example data was restricted to the operational energy of buildings and commute transport by road and rail. However, the proposed methodology easily allows the inclusion of other factors such as the transport of goods to urban areas and leisure travel. This flexibility of the procedure will prove advantageous to many of the models and approaches used to estimate energy consumption found in the literature. Furthermore, the use of readily available official government data sources and the straightforward simplicity of the methodology makes it easy to replicate to other regions. It can therefore be employed by planners and policy-makers (and even other users) aiming to design effective mitigation strategies to reduce carbon-related energy consumption by buildings and transport. On this account, the benefits of the introduced energy use metric are (but not restricted to): (i) integration of both buildings and transport energy consumption; (ii) use of large scale geographic units, LSOAs, to avert defining city boundaries; (iii) simplicity and replicability of the procedure; (iv) use of official available information, thus considered reliable sources. Overall, the methodology outlined here demonstrates a new, simple alternative approach to estimate energy that uses relevant available data, combines buildings and transport and has the prospect of being replicable, providing additional tools to planners and policy-makers. The energy use metric is aimed to the end-user and local councils and so it is assumed that the operational energy of buildings and commute transport energy are the main variables over which authorities and urban planners have more direct control through policies.

The paper is structured in the following way: Section 2 introduces the methodological approach by presenting data sources and calculation methods. Section 3 deals with the application of the methodology to a case study, discussing results and causes. Finally, Section 4 is a summary of the previous discussions, and identifies the methodology's limitations and suggests paths for future developments.

2. Methodology

The approach introduced here combines data from both buildings and transport to estimate total energy consumption, thereby developing a new, simple energy use metric. The unfeasibility of estimating the energy consumption of every building and vehicle of a neighbourhood or a large area led to the use of readily available official data to produce a non-detailed energy estimate at large scale. The energy use metric is user-friendly and may be used by policy-makers and planners as an initial estimate to outline strategies to reduce or mitigate carbon-related energy consumption, since the approach combines data from the operational energy consumption of both buildings and commute transport. The proposed methodology is based (and was partly introduced) on previous work (Osório, McCullen, & Walker, 2015; Osório, McCullen, Walker, & Coley, 2017), and consists of: (i) data selection and aggregation at appropriate scale; (ii) the theoretical energy use metric framework; (iii) data output and presentation. An explanation of each step follows. Additionally, a detailed explanation of the downscaling procedure is presented in Section 2.4.

2.1. Data aggregation, scaling and units

2.1.1. Data selection and aggregation

Urban energy consumption is primarily due to both buildings (here split into residential and non-residential buildings) and transport (including road and rail transport) (Anderson et al., 2015). The approach followed here to estimate the energy consumption of those two vectors includes only the operational energy of buildings, as this is immediately related to short-term urban characteristics that can interact with transport, and commute transport carbon footprint, converted to energy use. The use of only buildings' operational energy and commute transport is further justified here as these are urban components over which it is expected for local authorities and planners to have more control to prompt change at short–medium-term. Yet, the flexibility of the approach allows the future inclusion of other urban energy factors, such as the embodied energy of buildings or the transport of goods.

To produce a simple energy metric enabling replication, only available official data is used here. The use of information published by official governing bodies in the UK is perceived as being both reliable and accessible data sources for end users of the research. However, the methodology is robust enough to allow the use of other data sources of varying resolution, if available. Energy consumption values for buildings is derived from sub-regional energy utility data, a procedure found in some previous studies (Baynes & Bai, 2009; Baynes, Lenzen, Steinberger, & Bai, 2011; Lenzen & Peters, 2010). The Department of Energy & Climate Change (DECC) is the main government institution in the UK publishing energy-related data. Consequently, energy consumption estimates for buildings are based on DECC's tables of sub-regional energy use. This is split by type of building (residential and non-residential) and form of energy (electricity, gas, etc.).

The analysis of transport energy consumption is restricted here to commute transport mainly because of: (i) the availability of reliable data; (ii) the significant proportion of energy consumption this commute transport represents (Boussauw & Witlox, 2009; Muñiz & Galindo, 2005) in urban areas – about 4.1% of total energy use and about 14.4% of transport energy use in the UK (Lovelace, 2014); (iii) the greater influence (and control) that local governing bodies and planners have to produce actual changes in the system. Commute transport carbon footprint (then converted to energy use) values are derived from the Origin-Destination (OD) matrix table of work commute journeys published by the Office for National Statistics (ONS) and mapped by the DataShine web platform (O'Brien & UCL CASA, 2014). The information of the OD table allows the calculation of estimates for each mode of transport (car, bus, etc.).