Z. Kovács, G. Harangozó, C. Szigeti, K. Koppány, A. Cs. Kondor, B. Szabó: Measuring the impacts of suburbanization with ecological footprint calculations. Cities, Volume 101, 2020, 102715
Published version: https://doi.org/10.1016/j.cities.2020.102715

Measuring the impacts of suburbanization with ecological footprint calculations

Abstract

In this paper we present a complex Ecological Footprint (EF) analysis of one of the largest metropolitan regions in post-socialist East Central Europe, the Budapest Metropolitan Region. Our overall goal is to use both top-down and bottom-up approaches and measure the changes of footprint at a metropolitan scale between 2003 and 2013. Our specific objective is to explore how the spatial rearrangements of wealth, density and consumption influence the spatiotemporal changes of EF. The top-down (compound) calculations indicate growing footprint values both in Hungary and in the Budapest Metropolitan Region in the investigated period. However, household-level hybrid (component-based) calculations revealed decreasing footprint values for Hungary both in absolute and relative terms, and a growth for the metropolitan region. This finding suggests growing income disparities within the country. The indirect (consumption embedded) components of EF findings show that in the core city footprint values are higher due to higher disposable income. However, there is a gradual catching up in the suburban zone as younger and more affluent households arrive. On the other hand, direct per capita footprint values decreased in Budapest and grew in the suburbs between 2003 and 2013, mainly due to a higher heating footprint.

Keywords: Ecological Footprint, sustainability, local consumption, EEIO analysis, suburbanization, Budapest Metropolitan Region

1. Introduction

As cities are hotspots of human activities and main drivers of greenhouse gas (GHG) emissions, the sustainability of contemporary urbanization is increasingly on the agenda (Zhang, 2016). Cities cannot survive without their wider hinterlands for resources and emissions sequestration (Kissinger & Haim, 2008). The location of jobs, residences and other facilities within city regions strongly affects the spatial pattern of mobility and consumption (Poom & Ahas, 2016). However, this pattern is continuously reconfigured by suburbanization and urban sprawl, which often cause harmful ecological consequences such as the fragmentation of land use, the loss of biodiversity, or the increasing use of personal vehicle and higher fossil fuel consumption (Mustard et al., 2004; Dietz et al., 2007; Bohnet & Pert, 2010; Piña-Martinez, 2014). The decentralization of production and consumption destroys exactly cities' hinterlands. As suburbanization and urban sprawl continuously transform the spatial pattern of urban regions, the social and environmental demands of these processes must be considered.

Cities of East Central Europe were characterized by a predominantly compact urban form before 1990. There were few features which resembled Western type suburbanization (Hirt, 2013; Kovács et al. 2019). Besides planning interventions, the growth of suburban areas was prevented by poorly-organized public services, low levels of car ownership and limited infrastructural networks. After 1990, in line with the advent of a free market system and privatization of land, suburbanization suddenly intensified. The process of suburbanization, i.e. the decentralization of people and urban functions (housing, jobs) is among the most studied phenomena of post-socialist urban transition (Hirt, 2007; Stanilov & Hirt, 2014; Kok & Kovács, 1999; Kovács & Tosics, 2014; Kubeš & Nováček, 2019; Leetmaa & Tammaru, 2007, Leetmaa et al., 2009, 2014; Ouředníček, 2007; Pichler-Milanović, 2014; Slaev et al., 2018). However, studies in the field have focused so far primarily on the socio-economic contexts of suburbanization, the newly evolving patterns of social segregation around cities, whereas, the environmental demand of suburbanization, the sustainability of post-socialist urban transformation have been insufficiently explored.

The concept of Ecological Footprint (EF) provides a valuable holistic tool in assessing the sustainability of urban areas (Rees, 1992). Since its first application at the city level (Wackernagel, 1998) sustainability analyses of urbanization via footprint assessments have proliferated over the past decades (Minx et al., 2013; Baabou et al. 2017; Isman et al. 2017) contributing to the spread of this indicator. Research presented in this paper sets out to assess the spatial and temporal changes of a supporting hinterland for post-socialist Budapest and its urban region by using the Ecological Footprint Analysis (EFA). The primary aim here is to explore how different consumer lifestyles influence the EF of a major European metropolitan region (Budapest) and how it has been changed by suburbanization and urban sprawl between 2003 and 2013, when better off people shifted from the core city to the suburbs changing the consumption pattern and environmental demand at the urban region level (Kovács & Tosics, 2014).

The novelty of this study is threefold. First, the territorial focus of investigation is on a metropolitan region where the core-city and its agglomeration are handled separately. Previous studies considered metropolitan regions as single units. Second, the research uses both top-down and bottom-up approaches in measuring ecological footprint. Only a few case studies exist, to our knowledge, in which both methods have been used to assess the Footprint of the same city. Third, the temporal change of footprint between 2003 and 2013 is also covered. The specific objective of the study is to explore how the spatial rearrangements of wealth, density and consumption influence the spatiotemporal changes of ecological footprint at the metropolitan scale.

The rest of this paper is organized as follows. First, we review the literature on EF as a tool for measuring the environmental pressure of urbanization. We then discuss the methodology, including the delimitation of the case-study area, the collection and analysis of data. A section then follows with main findings of the research, and evaluation of the results derived by compound and component-based methods, and the temporal and spatial change of EF in the urban region of Budapest. Finally, we discuss the main findings, formulate policy recommendations, outline the limitations of the methodology, and present our conclusions.

2. Ecological footprint as a tool for measuring sustainability: a literature review

Human demand on ecosystem services has been steadily growing, as has the need for adequate metrics to capture it. A widely recognized composite indicator of sustainability, the Ecological

Footprint measures human demand on nature by assessing how much biologically productive land and sea area is necessary to maintain a given consumption pattern (Rees, 1992; Wackernagel & Rees, 1996, Wiedmann et al., 2006a). The purpose of the concept is to determine the size of land used by humans to meet the needs of a certain population group. In the most common approach (see for example Wackernagel et al., 1999), EF is composed of six different land-use components (cropland, grazing land, forest land, fishing grounds, carbon footprint/carbon uptake land and built-up land) and measured in bioproductivity-weighted hectares or global hectares (gha). Ecological footprint calculations first focused on national-scale assessments (Lin et al. 2018; Borucke et al. 2013). Later, approaches calculating the EF at the regional, individual and even organizational level have proliferated (GFN, 2018, Baabou et al. 2017; Harangozo et al., 2015), adding new insights to the sustainability debate (Chen & Chen, 2007). Among the regional level footprint calculations, those focusing on the environmental impacts of urbanization has become especially popular (Jones & Kammen, 2014; Moore, et al., 2013). Although data for urbanized areas are not as consistently collected and calculated as for nation states and are therefore, less comparable, footprint calculations at urban level have become widespread in North America, Western Europe and China (Wackernagel et al., 2006; Minx et al., 2013). Baabou et al. (2017) documented 63 city EF assessments in the literature across 20 countries. In addition to case studies, comparative ecological footprint assessments of groups of cities have also appeared in the literature. For instance, Isman et al. (2017) analysed the carbon footprint subcomponent of EF for 15 Canadian cities according to census metropolitan areas (CMA), while Baabou et al. (2017) calculated the footprint of 19 Mediterranean cities based on a multi-regional input-output analysis using data on average household expenditures.

To calculate a city's, EF one of two approaches is generally followed: the top-down or the bottom-up method. The top-down or *compound approach* is based on national ecological footprint data disaggregated by smaller geographical areas (Wiedmann et al., 2006a). The crudest way is to use per capita national footprint values multiplied by the size of population of a certain area (Moore et al., 2013). More refined versions of these calculations also consider local characteristics, most often wealth indicators (e.g. Wackernagel, 1998; Ewing et al., 2010). On the one hand, the major benefit of this approach is the relatively easy availability of data that can be obtained with low cost/effort. Another advantage is that missing data does not prevent the calculation of a rough estimate. With very few additional datasets results quickly improve in accuracy while still being low cost, and easily comparable among cities. On the other hand, without using local data specific to the urban region, information loss may occur and the evaluation of local policies can also be more difficult (Aall & Norland, 2005; Wilson & Grant, 2009).

The bottom-up or *component-based approach* uses local data for a sub-national geographical unit to quantify the consumption of local population, on some (e.g. commuting, energy use etc., see Muñiz et al., 2013) or all components of the ecological footprint (Barrett, 2001). The basis is usually a material flow analysis (Wiedmann et al., 2006a; Simmons et al., 2000), but it may be integrated with an urban metabolism framework (Curry et al., 2011) to collect and structure the data, as attempted by Moore et al. (2013) for Vancouver and Piña and Martinez (2014) for Bogota. Main advantage of this approach is that it enables policy makers to better understand the exact flow of materials and energy in a given region, providing better opportunities to influence them (Collins & Flynn, 2006). However, this bottom-up approach is resource and data intensive (Hengrasmee, 2013; Xu & San Martin, 2010) and often requires longer execution time due to data unavailability. It does not easily allow comparison of cities across different countries due to different data sources and assumptions within the calculation.

An alternative is the combination of the top-down and bottom-up approaches, i.e. hybridization. The application of an input-output model extended with environmental data (environmentally extended input-output analysis, EEIO) can be adapted to a subnational unit by integrating it with local production or consumption data (labelled as sub-national input output analysis, SNIO, by Moore et al., 2013). Input-output models (based on Leontief, 1936) aim at calculating the interrelationships between different economic sectors by quantifying the resource need from one sector per unit of output in another. EEIOs were first applied for EF calculations by Bicknell et al. (1998) and Ferng (2001). The pioneering paper by Barrett et al. (2005) using this approach in the EF calculation for Wales and Cardiff has been followed by many others like Gu et al. (2015). The advantage of the SNIO model is the relatively easy access to data (regarding national level input-output data), whereas, data of production or consumption at the local level may be problematic. Peters and Hertwich (2008) and Vetone Mozner (2012) argue that the consumption-based perspective better reflects the responsibility principle (meaning that , to use an example, the environmental impacts of a car's supply chain are accounted for in the EF of the city or region where they occur, independently of the place of manufacturing). The methodology of the consumption-based perspective at the sub-national level has been further developed by Wiedmann et al. (2006b) and Collins et al. (2006).

Despite the growing number of footprint calculations for cities, empirical evidence on differences of EF at the metropolitan level remains scarce (Burgalassi & Luzzati, 2015; Heinonen et al., 2011). Comparison of metropolitan regions in this respect is hampered by the fact that the administrative system and legal definition of "urban region" differs by country. There are also substantial differences regarding the delimitation of the "core" and "suburbia" within urban regions. Studies in the field tend to focus on whether a compact or sprawling urban morphology is more favourable for sustainable urban development (e.g. Kahn, 2000; Høyer & Holden, 2003; Roberts, 2007; Gaigné, et al., 2012; Muniz et al., 2013; Legras & Cavailhès, 2016; Ogle et al., 2017; Thomson & Newman, 2018). Answering this question is a complex task. Therefore, papers primarily aim to compare the ecological footprint of certain activities or economic sectors, for example commuting (Muñiz & Galindo, 2005; Aguiléra & Voisin, 2014; Jones & Kammen, 2014), energy efficiency (Ewing & Rong, 2008; Conticelli et al., 2017) or logistics (Dablanc & Rakotonarivo, 2010). Papers concentrating on the spatial form of urban regions generally agree that increasing commuting can dramatically increase the carbon footprint. From this point of view, the compact city can ecologically be considered more favourable (Muñiz & Sánchez, 2018). However, increased urban density may not necessarily reduce EF, as the beneficial effects of reduced commuting can easily be eroded by rising consumption and carbon emissions. If the footprint is calculated at the household level, the position of core cities may be even worse, as suburbs can generally be characterized by larger household size (Ala-Mantila et al., 2013; Poom & Ahas, 2016). This phenomenon was described in detail in the case of Helsinki Metropolitan Area by Heinonen et al. 2011, and Heinonen and Junilla 2011. The role of residential location and position in the settlement hierarchy in the environmental load of households was also emphasized by Poom et al. (2014) in Estonia, who found that the ecological footprint of residents of Tallinn and other major cities was significantly higher than those of rural peripheries. The suburban belt is not homogeneous either, as the EF of suburban gated communities and residential parks where affluent inhabitants live is significantly higher due to intense commuting and high level of consumption (Rashid et al., 2018). In other parts of the suburban zone like the rural-urban fringe or peripheral rural communities, the ecological footprint is generally lower. All these factors suggest that future research should examine income, demographic conditions and lifestyle in the interpretation of the footprint within urban regions.

Temporal change of the EF also seems to be important. Nevertheless, it is rarely dealt with in the literature (Van der Bergh & Verbruggen, 1999). Papers consider temporality usually in a model-like manner (Mostafa, 2010; Lu & Chen, 2017), in most cases sprawl or suburbanization is shown as a constant background process or endowment. Research results are based mostly on data collection at a given time (e.g. census, questionnaire surveys see e.g. Poom et al. 2014). The combination of space and time approaches in the analysis of urban sprawl and suburbanization is by and large missing. Therefore, in this paper we focus on the spatiotemporal changes of the ecological footprint in the Budapest Metropolitan Region (BMR). We seek to answer the question how the spatiotemporal transformation of the urban region has affected the region's ecological footprint. We apply two methods simultaneously in order to quantify changes of EF in the Budapest Metropolitan Region. The first follows a compound approach based on the correlation of the GDP and EF and uses the GDP data specific for the investigated area (estimated through an own-model). The second method is a combined component-based approach, where a national input-output model is integrated with area specific household consumption data (thus, it is a hybrid model combining top-down and bottom-up elements). Direct comparison of the calculations is not the scope of this study as the logic of the two approaches differ considerably, however, these calculations can inform us about the spatial shifts of ecological footprint from different perspectives.

3. Research design

3.1. Study area

The boundaries of the Budapest Metropolitan Region (BMR) were defined by using the threshold of 15% of commuters to the core city in the 2001 census. According to our delimitation the BMR includes the City of Budapest and 185 surrounding municipalities of various size with 2.9 million inhabitants covering 6,077 sq. km with a maximum radius of 70 km (Fig. 1).

[Fig. 1: Budapest Metropolitan Region – The study area]

BMR occupies 6.5% of the territory of Hungary and is home to 29% of the country's population. This is a monocentric spatial organization, with strong functional relationship between the core city and the suburban zone. On the eve of the 2011 census nearly 60% of commuters living in the suburban zone worked in Budapest, and 52% of commuters residing in Budapest worked in the suburban ring. Since 1990 the socio-economic weight of the BMR has increased within the country as Budapest and its suburbs have absorbed a large share of new business and housing developments (Kovács et al., 2019). As a consequence, by 2011 more than one-third of Hungary's jobs concentrated in the BMR. Due to intense suburbanization (i.e. the relocation of people and jobs from the core city to the suburbs) the share of Budapest within the population of the metropolitan region has decreased from 70% in 1990 to 60% in 2011.

3.2. A compound method based on estimated regional GDP data

One method for calculating the ecological footprint of the Budapest Metropolitan Region is based on a linear regression model, originally developed to estimate historical EF values for the world (Tóth & Szigeti, 2016; Szigeti et al., 2017). In this model regression functions are estimated by using national GDP and Global Footprint Network (GFN) EF data between 1961 and 2008 for 113-119 countries (depending on data availability). Based on that, a regression function emerged for each year. In this model, the two extreme functions are considered to estimate a range for the national EF values (including one constant or 'autonomous' and one GDP-dependent part):

$$EF = 0.0004*GDP + 1.02 \quad [1]$$

$$EF = 0.0002*GDP + 1.26 \quad [2]$$

The model shows around (+/-3-9%) inconsistency with the GFN-based EF data, which, when compared to the large, differences (up to 100%) among different EF calculation methods in the literature (Haberl et al., 2001), can be accepted. When using this model for the current calculation, it is assumed that the EF in Hungarian cities has a linear relationship with GDP, and the variation can be described by the variation in ecological footprint and GDP observed across various countries of the world (the limitations of the basic models are described in the cited papers). For simplicity, we will use the (arithmetic) mean of [1] and [2] in the following.

The main reason to use this model is the opportunity to estimate the BMR-level GDP data at basic prices (gross value added, GVA). Since GVA data are available only at county (NUTS3) level in Hungary, a model has been developed that allows a relatively accurate estimation of value added for smaller territorial units. This applies a top-down method of regional GDP calculation (Kahoun & Sixta, 2013), by which value added data provided by the Hungarian Central Statistical Office (HCSO) at the NUTS3 level is split into finer territorial resolution, based on the indirect variables that show high correlations with official county GDP-shares and available at the municipal level in the TeIR (National Spatial Planning and Regional Planning Information System, www.teir.hu) database. For a detailed mathematical presentation of the model see Koppány et al. (2019). Using an optimal weight vector, the national GVA share of each municipality and then finally the GVA data for each municipality (and thus also for the BMR) could be estimated.

3.3. A component-based method integrating national input-output data with regional level consumption data

The calculation of the household-consumption-based ecological footprint of the Budapest Metropolitan Region covers two fields. First, we calculated the indirect EF of household consumption, embedded in the supply chains of the goods and services consumed. Second, we added an indirect EF part generated by household consumption (covering heating and transport related carbon emissions).

The embedded part of the household consumption related EF is based on an environmentally extended input-output analysis (EEIO) developed for a subnational area, the Budapest Metropolitan Region. The calculation was based on the model of Wiedmann et al. (2006b) developing a framework for allocating ecological footprints to final consumption categories with IO analysis, adjusted to the BMR and Hungarian circumstances. The basic idea of the model is to combine national footprint data with the IO structure of a national economy and then disaggregate it by final demand categories. The original publication focuses on the UK economy as a whole, but – depending on the data in final demand function – it is possible to use the model for sub-national level, for different socio-economic groups or specific industries. In this paper, a sub-national level application is performed comparing two different years (2003 and 2013). The logic for calculating the embedded EF of the household consumption was based on the following equation:

$$EF = EF_{dir} * (I-A)^{-1} * FD \qquad [3]$$

where EF_{dir} stands for the direct intensity matrix, covering EF that are directly related to the production activities of different sectors per million units of national currency. The basic, 64*64 IO model for Hungary is published by the Hungarian Central Statistical Office (HCSO) in every five years, so we could use the 2005 model for 2003 and the 2010 model for 2013 (assuming that there were only minor changes in the economic structure in between). The $(I-A)^{-1}$ is the Leontief-inverse matrix derived from the national input-output model and the EF_{dir} vector is calculated by using the Hungarian dataset of the Global Footprint Network (GFN, 2011, 2014). FD, the household level final demand vector (final demand by sectors), however is covering the study area, BMR. Thus, it is also assumed, that the structure of the BMR's economy is equivalent of the national structure (as there is no area specific IO model available and considering that BMR accounts for nearly 50% of the Hungarian GDP).

In our study, final demand of household consumption for the BMR was approached according to the 12 COICOP (Classification of Individual Consumption by Purpose) consumption categories (UN, 2011). Data from the Hungarian Central Statistical Office's annual household budget and living conditions survey (2003, 2013) were used for the input-output modeling. Similar household consumption surveys conducted by HCSO before 2003 did not follow EUROSTAT methodology. Thus, data from the 1990s could not be compared with the most recent ones. The sample size is high with nearly 9500 households for Hungary and 2200 for the BMR. The level of detail in the survey is very high according to COICOP 12.XXXX classification, thus the HCSO collects 358 categories altogether. We then aggregated the data to the COICOP 12.X level, still keeping 47 categories. We then integrated the data into the national EEIO model, but first we needed to translate the 47 COICOP categories to the matching 64 sector FD vector, as it was not directly available for the BMR area. There is no explicit key to correspond the two vectors (even if there are similar categories, in some cases the correspondence is not mutually identical and there can be differences over time and between countries), we used an iterative, RAS based approach. The RAS is a well-known method for data reconciliation, aiming at achieving consistency between the entries of nonnegative matrices and pre-specified row and column totals (Miller & Blair, 1985). The RAS method applied by Owen et al. (2017) proved to be the most accurate tool to link COICOP-based consumption data with sector level final demand. In our calculation, we used the RAS method with 500 iterative steps to build the correspondence matrix between the national level COICOP and FD vectors. Then we used the correspondence matrix to transform the BMR-level COICOP vector to gain the BMR-level, 64-sector FD vector. Finally, we again used the correspondence matrix to disaggregate the EF by FD categories to EF by COICOP categories as it is used in the results section.

Beyond the embedded, indirect part of the household consumption related EF, there are also direct elements of it (emerging directly at the households):

- Carbon footprint as a result of household heating and transportation fuel related carbon-dioxide emissions. This element covers releases of firewood based heating or own passenger car related releases, but do not contains emissions related to electric heating or transportation services, as these are already covered by the embedded EF calculation of the EEIO-model presented earlier.

- Built-in land footprint related to residential properties and other infrastructure (roads for example) for residential use.

The direct element of the household related EF was calculated along the following steps:

- quantifying the household and individual level expenditures on different heating (natural gas, bottled gas, liquid fuels, coal, briquette, coke, firewood) and transportation (gasoline, diesel) fuels by using HCSO data for the different geographical areas and periods;
- calculating quantities based on average prices (HCSO);
- specifying per capita carbon-dioxide emissions (t CO_2/capita) based on the heating values (GJ/measurement unit) and the specific carbon-dioxide emission values (t CO_2/GJ);
- calculating per capita carbon footprints (gha/capita) based on the carbon-dioxide area coefficients (GFN-database).

The quantification of the built-in land footprint element (properties possessed by households and the part of roads serving residential use) was beyond the possibilities of this study, which means that the calculated EF values can be considered as an underestimation.

4. Results

Here we present the results of the Footprint analysis with compound method (section 4.1) and the component-based method (section 4.2) highlighting the main factors affecting the changes of these values over time.

4.1. Compound method

As a first step, EF values for different spatial units for the years 2003 and 2013 were calculated based on the compound method. Research results show that per capita EF values have increased at all spatial levels during the investigated period (Table 1).

[Table 1: Per capita ecological footprint in Hungary at different spatial level in 2003 and 2013, (gha/capita) based on the compound method]

The share of the Budapest Metropolitan Region in Hungary's GDP increased from 44.4% to 48.0% between 2003 and 2013, which is in line with the strengthening position of the urban region within the country's economy, especially in the field of services and knowledge intensive activities (Egedy et al., 2018). After recovering from the financial crisis of 2008, GDP began to rise again in Hungary. This resulted in the growth of ecological footprint. However, there are significant differences among the different spatial levels. In 2003, there was already a gap between the national and the BMR EF values (1.63 gha and 1.94 gha per person respectively). Moreover, the BMR EF hid great differences, as the value of the core area (Budapest) well exceeded the national average (with 2.15 gha per capita) while the suburban belt had a value (1.59 gha per capita) even below the national average, more similar to the rest of the country (1.51 gha per capita). By 2013 GDP levels had exceeded the values before the crisis, which resulted in a growth of the EF values. The gap between different spatial units (BMR vs. country; Budapest vs. agglomeration) kept on rising (2.41 gha per capita vs. 1.91 gha per capita; and 2.80 gha per capita vs. 1.82 gha per capita respectively), while the rest of the country lagged behind (1.70 gha per capita). As mentioned before, the compound method is based on the regional GDP value, so the trends are in line with the sharpening core-periphery relations within the country (even though they are smoothened by the 'autonomous' EF component).

4.2. Component-based method

As a second step, a more refined, consumption-based method was applied for the calculation of the household level EF, combining an indirect (in consumption embedded) and a direct (direct CO_2 emissions related to heating and transportation of households) component. Through this methodology, not only could the overall impacts of economic growth on EF be analyzed, but also changes in the composition of EF caused by changing consumer behavior and lifestyle (some components of the consumption, like exotic food or oversea holidays are responsible for higher EF values, while others, like teleconferencing instead of physical oversea trips can even decrease the EF).

Based on the indirect – in the household consumption embedded – EF calculation, the values and their temporal changes show clear differences form the compound method (Table 2). The per capita values of EF decreased by 9.3% at the national level, due to the restructuring of consumption and improvements in eco-efficiency, whereas the value of the BMR, and especially the core-city Budapest increased (by 1.6% and 3.8% respectively). Data confirm an increasing gap between the BMR and the rest of Hungary, which is the result of changing wealth and consumption pattern within the country. Also within the BMR the per capita EF value of Budapest exceeded the value of the agglomeration between 2003 and 2013, as latter slightly shrunk (-1.7%) in the investigated period.

[Table 2: Per capita – in household consumption embedded – ecological footprint by land use categories, 2003 and 2013 (gha/capita)]

If we consider different sub-categories of EF by land use, the three most important categories are cropland, carbon and forest footprint (in this order, for all spatial categories in both years). These three sub-categories are responsible for around 95% of the total ecological footprint. If we also consider changes of the population number between 2003 and 2013 (2% decrease at the national level accompanied by a 2.2% increase in Budapest and 9.6% increase in its agglomeration), it seems that the absolute footprint value for Budapest increased (by 6% to 3.85 million gha in 2013) due to both population growth and increasing consumption, whereas in the agglomeration the increase of absolute EF value (by 8% to 2.48 million gha in 2013) was the result of population growth caused by migration.

So far differences in the overall values and changes of relative ecological footprint values by different spatial units have been analyzed., However, the composition of EF caused by differences in affluence and consumption is also important factor. Table 3. provides an overview of the different footprint components based on consumption categories for different spatial units in the investigated period.

(Table 3: Ecological footprint of household consumption by consumption (COICOP) categories at different spatial level in 2013 and related to the changes between 2003 and 2013 (in gha and in gha per capita]

Analysis of the consumption based EF values according to the 12 COICOP categories shows that the most important components are food and beverages, housing and household energy followed by alcohol and tobacco products and transportation. These four components account for approximately 80% of the national household consumption EF. In addition, the role of restaurant and hotel services, as well as recreation and culture is also important. Considering the extremely low footprint values of education and health care, it is important to note that in this study only household consumption is covered, and the expenditures of the state and the civil sector have not been considered.

Regarding the Budapest Metropolitan Region, the absolute EF value of the core city Budapest exceeds by more than 50% of the agglomeration, which is in line with the difference in population size between the core city and its suburban belt (1.5:1). The relative footprint values are roughly the same for Budapest and its agglomeration (2.21 versus 2.15 gha per person), however, their composition differs significantly. In 2013, the agglomeration had higher per-capita food consumption, energy consumption and transport EF. In the agglomeration, the larger average size of dwellings and the higher share of single-family houses with higher energy demand explains higher values associated with housing and household energy consumption, while a higher EF for transport stems from higher mobility caused by commuting. In this case, however, it should be emphasized that it is not the direct EF component (the area of buildings or roads as a built-up land component or the carbon emissions of heating or transport as carbon footprint), but is linked to the embedded footprint components along the supply chain (e.g. related to the manufacture and maintenance of a passenger car).

In contrast, the relative footprint values related to restaurants and hotels, health, education, clothing and other services (e.g. telecommunications, entertainment and culture) was higher in Budapest in 2013. This is probably the result of higher consumption levels due to higher per capita income. At the same time transport and household energy expenditures remained significantly lower in the city compared to the agglomeration zone.

Looking at temporal changes of EF values between 2003 and 2013 it can be noticed that four categories of the embedded footprint grew both in the core city and the agglomeration (in order): 1.) transportation, 2.) alcohol and tobacco products, 3.) health, and 4.) housing and energy consumption. Except for transportation, in all categories the growth rate of the agglomeration exceeded the value of Budapest. Regarding the indirect EF value related to food, growth (both in absolute and relative terms) could be observed in the core city, whereas in the agglomeration the per capita value declined. In contrast, the sub-footprint of alcohol and tobacco increased in the agglomeration at a higher rate than in the city. In the case of leisure activities, (tourism, restaurant, accommodation etc.), the footprint of Budapest grew dynamically, as the higher income and the relatively smaller transport and energy expenditures enabled Budapest's citizens to spend more for restaurant and hotel services.

Beyond the indirect (embedded) EF, the direct component of footprint was also considered during the research. The direct per capita ecological footprint in the agglomeration was double the value of the core city in 2013. Results show 10% decrease in the core city and 18% growth in the agglomeration zone between 2003 and 2013, whereas the relative EF of the countryside decreased by 6.5% (Table 4). The heating (and total direct) footprint per capita in Budapest was already much lower in 2003 than the national or even the suburban value. This was mainly due to the lower carbon emissions linked to the more efficient heating system of the city. This gap widened between 2003 and 2013. By the end of this period, the direct heating footprint of Budapest was less than half of the agglomeration (and ca. half of the countryside). Remarkable is a sharp increase in the use of firewood in the agglomeration, which is mainly responsible for the growing footprint. Vehicle fuels did not make a big difference related to the direct part of the footprint. Residents of the agglomeration (and the countryside) may commute more, however, due to their higher income levels the residents of Budapest may travel more for leasure and/or they ride bigger cars with higher fuel consumption.

Considering population data, the absolute direct ecological footprint value for Budapest decreased by 8% (to 0.54 million gha in 2013) between 2003 and 2013, while in the agglomeration skyrocketed by 29.6% (to 0.74 million gha in 2013). The opening gap can be explained by differences in population dynamics and lifestyles (especially housing and heating) between the core city and the agglomeration.

[Table 4: Direct ecological footprint at different spatial level in 2003 and 2013]

Thus far, results show that the overall (indirect and direct) absolute ecological footprint increased both in Budapest and in the agglomeration between 2003 and 2013. However, in Budapest it was driven mainly by the increasing disposable income (and consumption), while in the agglomeration the major factors were the population growth and the increased use of firewood.

If we calculate relative (per capita) ecological footprint values based on total household consumption (i.e. indirect and direct together) it can be seen that the EF of Budapest and the agglomeration increased at similar rates, while the national footprint decreased between 2003 and 2013 (Table 5). In the case of Budapest, the growth of the footprint was primarily the result of the growing per capita income and the increasing consumption of the population (growth of indirect EF). Between 2003 and 2013, the gross domestic product per capita in Budapest remained double the value of the national average, especially during the crisis and the post-crisis years. While all the regions of Hungary suffered from the economic crisis, the economy did not fall significantly in Budapest. The consumption strengthened, and its EF increased. In the agglomeration, however, the per capita ecological footprint of household consumption decreased by 2%, but the direct carbon footprint of the heating increased very fast which resulted in a growth of the aggregated per capita EF value.

[Table 5: Consumption based per capita ecological footprint values from a sustainability perspective for different spatial units in 2003 and 2013]

If, as a further step, ecological footprint values are compared to the biocapacity of the different spatial units, they can be evaluated from a sustainability perspective. In a dynamic approach, the state of unsustainability is indicated when EF exceeds biocapacity for a certain area (labelled as 'overshoot' by Costanza, 2000). It is calculated globally each year, by when humanity 'consumes' the available biocapacity for that year. In 2018 the Earth Overshoot Day was 1st August, in 2019 29th July, the earliest ever.

Results shown in Table 5 indicate that the rate of overshoot has slightly decreased between 2003 and 2013 compared to Hungary's biocapacity value. However, the reason behind is that the biocapacity in 2013 was higher than in 2003, due to better climatic conditions for agriculture. However, the gap between the Budapest Metropolitan Region and the rest of the country has significantly increased. Furthermore, the component-based analysis only considered household consumption as the basis for the EF calculation. If the entire Hungarian EF is considered (including government and civil sector activities – as it can be seen in the last row of the table), the overshoot is clear. Thus, from a global perspective, none of the Hungarian spatial units analyzed can be considered as sustainable, nor is the direction hopeful.

The overshoot was also analyzed on a per capita basis. From an absolute perspective (by comparing EF values with biocapacity in a region) the values are even more extreme (with for example a 37- and 32-fold overshoot for Budapest for 2003 and 2013). However, one has to consider that a significant share of the population and the economy of the country is concentrated in the capital city and its agglomeration. In return for the extreme high EF, it offers economic added value and other services for the whole country.

5. Discussion and conclusions

Cities represent both opportunities and challenges to the increasing concentration of people, wealth and consumption (Baabou et al. 2017; Zhang, 2016). This study showed the changing environmental load of urban transformations with ecological footprint calculations in a major European metropolitan region, Budapest. The novelty of the study is that it covers both the spatial and the temporal dimensions of environmental pressure. As it was shown, after 1990 robust suburbanization rearranged the socio-demographic conditions and the spatial configuration of affluence and consumer behavior in the studied urban region. Considering the aggregated household ecological footprint values, which were 2.52 gha per capita in Budapest and 2.79 gha per capita in the suburban zone in 2013, it seems that the EF of the metropolitan region dynamically increased within the country after 2003, despite improving eco-efficiency. At the same time, the value of the EF of the countryside decreased from 2.43 to 2.11 gha per capita. Thus, there is a growing disequilibrium of wealth and consumption within the country, Budapest and its metropolitan region attains an ever growing share within the environmental pressure of urbanization in Hungary.

The study also illustrates the benefits of using a hybrid methodology to calculate EF in a rapidly transforming urban region. The two methods used in this study differ in scope, accuracy and the process of calculation. Using GDP as a basis, the compound method is based on production, which means that it covers domestic production and export, but does not include imports. On the other hand, the component-based method is based on consumption and thus includes imports but ignores exports. In this sense, the two approaches differ in their focus (see Vetone Mozner, 2012), but each provides valuable information on the spatiotemporal changes of EF.

Results of the production-based compound method suggest that after the recovery from the financial crisis, the EF also increased in Hungary and the gap between core and periphery widened, both at the national and the metropolitan level. However, the consumption-based calculation captured divergent trajectories. From a consumption-based perspective, the indirect, total embedded household footprint decreased by 11% in Hungary between 2003 and 2013, and increased by 6% in Budapest and by 8% in its suburban zone. In the suburban belt the growing EF was mainly the outcome of population growth, while the major driver of growth in Budapest was increasing consumption. The per capita indirect EF values increased in Budapest and slightly decreased in the suburban zone, due to differences in economic prosperity and per capita disposable income. However, temporal changes of different categories of the embedded EF values reflect a gradual catching up in the suburban zone, due to the arrival of younger and more affluent households (suburbanization) with higher consumption level. On the other hand, per capita direct EF values decreased in Budapest and grew in the suburban zone between 2003 and 2013, and in 2013 the figure was already more than double that of Budapest in the suburban zone. This is mainly due to the higher heating footprint (caused mainly by the spread of wood combustion), whereas, there was no significant difference regarding the relative carbon footprint values of the fuels used for vehicles, despite longer travel distances in the suburbs.

In spite of the differences, the combination of the compound and component-based methods revealed relevant findings regarding the sustainability of urbanization in Hungary. First, the BMR has a higher per capita EF compared to the rest of the country and the gap tends to increase over time. Therefore, policymakers should pay particular attention to the BMR in formulating long-term sustainability policies with adaptation to climate change and reduction of greenhouse gas emissions. Second, within the BMR the compound method showed higher growth of EF values for Budapest than for the agglomeration as a consequence of differences in GDP growth.

Third, the consumption-based calculation showed a decrease of indirect – household-level – per capita EF values in the agglomeration, suggesting that certain elements of consumption are responsible for different per unit EF values and the potential improvements in eco-efficiency, thus achieving a certain level of decoupling (UNEP, 2011). Indeed, the GDP-based method overestimated the Budapest-level EF compared to the consumption-based method (differently from the other spatial units) suggesting that decoupling can really be detected here. Furthermore, the component-based method also highlighted that beyond the indirect EF (embedded in the total supply chains of products consumed), the direct component (related to heating and transportation) was also significant and its increase played an important role in the growth of the agglomeration-level EF. Thus, local and regional policies aimed at reducing the environmental load of inhabitants in the suburban belt should focus in the future on improving public transport connectivity, supporting car-sharing services (Tóth & Szigeti, 2019) and reducing wood combustion. The main problem here, however, is that despite intensifying cooperation and physical infrastructural linkages between Budapest and its agglomeration, the BMR has remained until now only a statistical but not an administrative or a planning unit. The administrative and political fragmentation significantly undermine any efforts for sustainability policy in the region of Budapest.

Comprehensive city level EF calculations for other East Central European capitals are very scarce, especially with using an input-output approach. Thus, comparison of the Budapest results is difficult. Shmelev and Shmeleva (2019) provides a review of different indices assessing city level sustainability with covering also Vienna and Prague. However, in those accounts EF is usually understood as carbon emissions or water consumption. These only contribute a minor weight to the value of the specific indices, thus making comparison impossible. Swiader et al. (2018) analyze the EF of Wroclaw (a major city in Poland) using a comparable input-output model, supplemented by COICOP consumption data. However, authors only focused on the EF of food consumption. Their results for 2013 accounted 0.974 gha/person, in line with our 0.92 gha (BMR core area) and 0.97 gha (BMR agglomeration) values for the EF of food consumption (Table 3), which highlight the similarities between the consumption patterns of Hungary and Poland, two post-socialist countries. The Hungarian case indicates that despite policies on regional levelling-out, differences in income and consumption sharply increased after 2000. The fast-development of the metropolitan region of Budapest, as opposed to the rest of the country, resulted in sharp gradients in the environmental loads of inhabitants. This is probably symptomatic for other transitional societies and their major urban agglomerations in East Central Europe, however, future research should test this assumption.

The limitation of the methods used in this study is set by i) the calculation method and ii) the data used. Regarding the compound method, it cannot reveal the potential improvements in eco-efficiency, if the GDP and EF values are decoupled. Related to the data, subnational GDP data had to be estimated, as there is no data available for regions below the NUTS3 level.

The assumptions and limitations of the consumption-based model are similar to those of the input-output models (see Wiedmann et al., 2006a). First, imported products are assumed to be produced as domestic ones. Second, the complex input-output model cannot be used for further forecasting, as coefficients are unlikely to stay unchanged. Third, when calculating the direct EF component, only the carbon footprint part has been quantified. The built-up component (properties, roads) were not considered as there was no proper method how to quantify the share of these that is related to household consumption. This can be a future direction of research.

Last, but not least, this method is based on the GFN database, so it assumes indirectly that the method and data used there are valid.

References

1. Aall, C., & Norland, I., (2005). The use of the ecological footprint in local politics and administration: results and implications from Norway. *Local Environment*, 10(2), 159–172.
2. Aguiléra, A., & Voisin, M. (2014). Urban form, commuting patterns and CO2 emissions: Whatdifferences between the municipality's residents and its jobs? *Transportation Research Part A*, 69, 243–251.
3. Ala-Mantila, S., Heinonen, J., & Junnila, S. (2013). Greenhouse Gas Implications of Urban Sprawl in the Helsinki Metropolitan Area. *Sustainability*, 5, 4461–4478.
4. Baabou, W., Grunewald, N., Ouellet-Plamondon, C., Gressot, M., & Galli, A. (2017). The Ecological Footprint of Mediterranean cities: Awareness creation and policy implications. *Environmental Science & Policy*, 69, 94–104.
5. Barrett, J., Birch, R., Cherrett, N., & Wiedmann, T. (2005). Reducing Wales' Ecological Footprint—Main Report. Stockholm Environment Institute, University of York; published by WWF Cymru, Cardiff, UK; March 2005.
6. Barrett, J. (2001). Component ecological footprint: developing sustainable scenarios. *Impact Assessment and Project Appraisal*, 19(2), 107–118.
7. Bicknell, K. B., Ball, R. J., Cullen, R., & Bigsby, H. R. (1998). New methodology for the ecological footprint with an application to the New Zealand economy. *Ecological Economics*, 27(2), 149–160.
8. Bohnet, I. C., & Pert, P. L. (2010). Patterns, drivers and impacts of urban growth – A study from Cairns, Queensland, Australia from 1952 to 2031. *Landscape and Urban* 97, 239–248.
9. Borucke, M., Moore, D., Cranston, G., Gracey, K., Iha, K., Larson, J., Lazarus, E., Morales, J. C., Wackernagel, M., & Galli, A. (2013). Accounting for demand and supply of the biosphere's regenerative capacity: The National Footprint Accounts' underlying methodology and framework. *Ecological Indicators*, 24, 518–533.
10. Burgalassi, D., & Luzzati, T. (2015). Urban spatial structure and environmental emissions: A survey of the literature and some empirical evidence for Italian NUTS 3 regions. *Cities*, 49, 134–148.
11. Chen, B., & Chen, G. Q. (2007). Modified ecological footprint accounting and analysis based on embodied exergy – a case study of the Chinese society 1981–2001. *Ecological Economics*, 61(2-3), 355–376.
12. Collins, A., Flynn, A., Wiedmann, T., & Barrett, J. (2006). The environmental impacts of consumption at a subnational level. *Journal of Industrial Ecology*, 10(3), 9–24
13. Collins, A., & Flynn, A. (2006). Engaging with the ecological footprint as a decisionmaking tool: process and responses. *Local Environment*, 12(3), 295–312.
14. Conticelli, E., Proli, S., & Tondelli, S. (2017). Integrating energy efficiency and urban densification policies: Two Italian case studies. *Energy and Buildings*, 155, 308–323.

15. Curry, R., Maguire, C., Simmons, C., & Lewis, K., (2011). The use of material flow analysis and the ecological footprint in regional policy-making: application and insights from Northern Ireland. *Local Environment,* 16(2), 165–179.

16. Dablanc, L., & Rakotonarivo, D. (2010). The impacts of logistics sprawl: How does the location of parcel transport terminals affect the energy efficiency of goods' movements in Paris and what can we do about it? *Procedia Social and Behavioral Sciences*, 2, 6087–6096.

17. Dietz, Th., Rosa, E. A., & York, R. (2007). Driving the human ecological footprint. *Frontiers in Ecology and Environment,* 5(1), 13–18.

18. Egedy, T., Kovács, Z., & Szabó, B. (2018). Changing geography of the creative economy in Hungary at the beginning of the 21st century. *Hungarian Geographical Bulletin*, 67(3), 275–291.

19. Ewing, B., Reed, A., Galli, A., Kitzes, J., & Wackernagel, M. (2010). Calculation Methodology for the National Footprint Accounts, 2010 Edition. Global Footprint Network, Oakland.

20. Ewing, R., & Rong, F. (2008). The impact of urban form on U.S. residential energy use. *Housing Policy Debate,* 19(1), 1–30.

21. Ferng, J. J. (2001). Using composition of land multiplier to estimate ecological footprints associated with production activity. *Ecological Economics*, 37(2), 159–172.

22. Gaigné, C., Riou, S., & Thisse, J.-F. (2012). Are compact cities environmentally friendly? *Journal of Urban Economy,* 72(2–3), 123–136.

23. GFN (2018). *Ecological footprint. The Share Guide: The Holistic Health Magazine and Resource Directory.*

24. GFN (2011,2014): *National Footprint Accounts and Hungarian dataset*, 2011 and 2014 Editions.

25. Gu, Q., Wang, H., Zheng, Y., Zhu, J., & Li, X. (2015). Ecological footprint analysis for urban agglomeration sustainability in the middle stream of the Yangtze River. *Ecological Modelling*, 318, 86–99.

26. Haberl, H., Erb, K.-H., & Kraussmann, F. (2001). How to calculate and interpret ecological footprints for long periods of time: the case of Austria 1926–1995. *Ecological Economics,* 38, 25–45.

27. Harangozó, G., Széchy, A., & Zilahy, G. (2015). Corporate Sustainability Footprints—A Review of Current Practices. In Corporate Carbon and Climate Accounting (pp. 45-76). Springer, Cham.

28. Heinonen, J., & Junilla, S. (2011). Implications of urban structure on carbon consumption in metropolitan areas. *Environmental Research Letters,* 6(1), 1–9.

29. Heinonen, J., Kyrö, R., & Junnila, S. (2011). Dense downtown living more carbon intense due to higher consumption: a case study of Helsinki. *Environmental Research Letters,* 6(3), 1–9.

30. Hengrasmee, S. (2013). A study of suburban Thailand. In R. Vale, & B. Vale (Eds.) *Living within a fair share ecological footprint* (pp. 201–214). Routledge.
31. Hirt, S. (2007). Suburbanizing Sofia: Characteristics of post-socialist peri-urban change. *Urban Geography*, 28(8), 755–780.
32. Hirt, S. (2013). Whatever happened to the (post)socialist city? *Cities*, 32, 529–538.
33. Høyer, K., & Holden, E. (2003). Household consumption and ecological footprints in Norway: Does urban form matter? *Journal of Consumer Policy*, 26, 327–349.
34. Isman, M., Archambault, M., Konga, C., Lin, D., Iha, K., & Ouellet-Plamandon, C. (2018). Ecological Footprint assessment for targeting climate change mitigation in cities: A case study of 15 Canadian cities according to census metropolitan areas (CMA). *Journal of Cleaner Production*, 174, 1032–1043.
35. Jones, Ch., & Kammen, D. M. (2014). Spatial Distribution of U.S. Household Carbon Footprints Reveals Suburbanization Undermines Greenhouse Gas Benefits of Urban Population Density. *Environmental Science and Technology*, 48(2), 895−902.
36. Kahn, M. E. (2000). The environmental impact of suburbanization *Journal of Policy Analysis and Management*, 19(4), 569–586.
37. Kahoun, J., & Sixta, J. (2013). Regional GDP Compilation: Production, Income and Expenditure Approach. *Statistika*, 93(4), pp. 24–36
38. Kissinger, M. & Haim, A. (2008). Urban hinterlands – the case of an Israeli town ecological footprint. *Environment Development and Sustainability*, 10(4), 391–405.
39. Kok, H., & Kovács, Z. (1999). The process of suburbanization in the agglomeration of Budapest. *Netherlands Journal of Housing and the Built Environment*, 14(2), 119–141.
40. Koppány, K., Kovács Z., & Dusek, T. (2019). A gazdasági teljesítmény területi eloszlása és koncentrációja Magyarországon. (Spatial Distribution and Concentration of Economic Performance in Hungary). Kautz Gyula Memorial Conference, 5th June 2018, Győr, Hungary.
41. Kovács, Z., & Tosics, I. (2014). Urban sprawl on the Danube: the impacts of suburbanization in Budapest. In K. Stanilov, & L. Sýkora (Eds.), *Confronting suburbanization: Urban decentralization in postsocialist Central and Eastern Europe* (pp. 33–64). Oxford: Wiley-Blackwell.
42. Kovács, Z., Farkas, J. Z., Egedy, T., Kondor, A. C., Szabó, B., Lennert, J., Baka, D., & Kohán, B. (2019). Urban sprawl and land conversion in post-socialist cities: The case of metropolitan Budapest. *Cities*, 92, 71–81.
43. Kubeš, J., & Nováček, A. (2019). Suburbs around the Czech provincial city of České Budějovice – territorial arrangement and problems. *Hungarian Geographical Bulletin*, 68(1), 65–78.
44. Leetmaa, K., & Tammaru, T. (2007). Suburbanization in countries in transition: destination of suburbanizers in the Tallinn metropolitan area. *Geografiska Annaler, Series B: Human Geography*, 89(2), 127–146.
45. Leetmaa, K., Tammaru, T., & Anniste, K. (2009). From priority-led to market-led suburbanization in a post-communist metropolis. *Tijdschrift voor Economische an Sociale Geografie*, 100(4), 436–453.

46. Leetmaa, K., Kährik, A., Nuga, M., & Tammaru, T. (2014). Suburbanization in the Tallinn Metropolitan Area. In K. Stanilov, & L. Sýkora (Eds.), *Confronting suburbanization: Urban decentralization in postsocialist Central and Eastern Europe* (pp. 192–224). Oxford: Wiley-Blackwell.

47. Legras, S. & Cavailhès, J. (2016). Environmental performance of the urban form. *Regional Science and Urban Economics* 59. 1–11.

48. Leontief, W. (1936). Quantitative input and output relations in the economic system of the United States. *Review of Economics and Statistics*, 18(3), 105–125.

49. Lin, D., Hanscom, L., Murthy, A., Galli, A., Evans, M., Neill, E., Mancini, M.S., Martindill, J., Medouar, F.-Z., Huang, S. & Wackernagel, M. (2018). Ecological Footprint accounting for countries: Updates and results of the Nationa Footprint Accounts, 2012-2018. *Resources*, 7(3), 58.

50. Lu, Y. & Chen, B. (2017). Urban ecological footprint prediction based on the Markov chain. *Journal of Cleaner Production*, 163, 146–153.

51. Miller, R. E. & Blair, P.D. (1985). *Input–output analysis: Foundations and Extensions*. Prentice-Hall, Englewood Cliffs, New Jersey.

52. Minx, J., Baiocchi, G., Wiedmann, T., Barrett, J., Creutzing, F., Feng, K., Förster, M., Pichler, P-P. Weisz, H. & Hubacek, K. (2013). Carbon footprints of cities and other human settlements in the UK. *Environmental Research Letters*, 8(3), 1–10.

53. Moore, J., Kissinger, M., & Rees, W. E. (2013). An urban metabolism and ecological footprint assessment of Metro Vancouver. *Journal of environmental management*, 124, 51–61.

54. Mostafa, M.M. (2010). A Bayesian approach to analysing the ecological footprint of 140 nations. *Ecological Indicators* 10, 808–817.

55. Muñiz, I., Catalayud, D. & Dobano, R. (2013). The compensation hypothesis in Barcelona measured through the ecological footprint of mobility and housing. *Landscape and Urban Planning* 113, 113–119.

56. Muñiz, I., & Galindo, A. (2005). Urban form and the ecological footprint of commuting. The case of Barcelona. *Ecological Economics*, 55, 499–514.

57. Muñiz, I., & Sánchez, V. (2018). Urban Spatial Form and Structure and Greenhouse-gas Emissions From Commuting in the Metropolitan Zone of Mexico Valley. *Ecological Economics*, 147, 353–364.

58. Mustard, J. F., Defries, R. F., Fisher, T. & Moran, E. (2004). Land-Use and Land-Cover Change Pathways and Impacts. In G. Gutman, A. C. Janetos, C. O. Justice, E. F. Moran, J. F. Mustard, R. R. Rindfuss, D. Skole, B. L. Turner II & M. A. Cochrane (Eds.). *Land Change Science: Observing, Monitoring, and Understanding Trajectories of Change on Earth's Surface* (pp. 411–429). Kluwer.

59. Ogle, J., Delparte, D., & Sanger, H. (2017). Quantifying the sustainability of urban growth and form through time: An algorithmic analysis of a city's development. *Applied Geography*, 88, 1–14.

60. Ouředníček, M. (2007). Differential suburban development in the Prague urban region. *Geografiska Annaler, Series B: Human geography* 89(2), 111–126.

61. Owen, A., Wiedmann, T., Chen, G., Lumsden, C., Hurst, T., & Barrett, J. (2017). *Global city-level household demand: data, derivation and deviation*. Working Paper.

62. Peters, G. P., & Hertwich, E.G. (2008). CO2 embodied in international trade with implications for global climate policy. *Environmental Science and Technology*, 42(5), 1401–1407.

63. Pichler-Milanović, N. (2014). Confronting Suburbanization in Ljubljana: From “Urbanization of the Countryside” to Urban Sprawl. In K. Stanilov & L. Sýkora (Eds.). *Confronting suburbanization: Urban decentralization in postsocialist Central and Eastern Europe* (pp. 65–96). Oxford: Wiley-Blackwell.

64. Piña, W. H. A., & Martinez, C. I. P. (2014). Urban material flow analysis: An approach for Bogotá, Colombia. *Ecological Indicators*, 42, 32–42.

65. Poom, A., Ahas, R., & Orru, K. (2014). The impact of residential location and settlement hierarchy on ecological footprint. *Environment and Planning A*, 46, 2369–2384.

66. Poom, A., & Ahas, R. (2016). How does the environmental load of household consumption depend on residential location? *Sustainability*, 8(9), 799.

67. Rashid, A., Irum, A., Ali Malik, I., Ashraf, A., Rongqiong, L., Liu, G., Ullah, H., Ali, M. U., & Yousaf, B. (2018). Ecological footprint of Rawalpindi; Pakistan's first footprint analysis from urbanization perspective. *Journal of Cleaner Production*, 170, 362–368.

68. Rees, W. E. (1992). Ecological footprints and appropriated carrying capacity: What urban economics leave out. *Environment and Urbanization*, 4, 120–130.

69. Roberts, B. H. (2007). Changes in Urban Density: Its Implications on the Sustainable Development of Australian Cities Proceedings of the State of Australian Cities National Conference 2007. Adelaide. pp. 720–739.

70. Shmelev, S. E., & Shmeleva, I. A. (2019). Multidimensional sustainability benchmarking for smart megacities. *Cities*, 92, 134–163.

71. Simmons, C., Lewis K., & Barrett, J. (2000). Two feet — two approaches: a component-based model of ecological footprinting. *Ecological Economics*, 32(3), 375–380.

72. Slaev, A. D., Nedović-Budić, Z., Krunić, N. Petrić, J., & Daskalova, D. (2018). Suburbanization and sprawl in post-socialist Belgrade and Sofia. *European Planning Studies*, 26(7), 1389–1412.

73. Stanilov, K., & Hirt, S. (2014). Sprawling Sofia: Postsocialist suburban growth in the Bulgarian capital. In K. Stanilov, & L. Sýkora (Eds.), *Confronting suburbanization: Urban decentralization in postsocialist Central and Eastern Europe* (pp. 163–191). Oxford: Wiley-Blackwell.

74. Świąder, M., Szewrański, S., Kazak, J., van Hoof, J., Lin, D., Wackernagel, M., & Alves, A. (2018). Application of ecological footprint accounting as a part of an integrated assessment of environmental carrying capacity: A case study of the footprint of food of a large city. *Resources*, 7(3), 52.

75. Szigeti, C., Tóth, G., & Szabó, D. R. (2017). Decoupling – shifts in ecological footprint intensity of nations in the last decade. *Ecological Indicators*, 72, 111–117.

76. Thomson, G., & Newman, P. (2018). Urban fabrics and urban metabolism – from sustainable to regenerative cities. *Resources, Conservation and Recycling*, 132, 218–229.

77. Tóth, G., & Szigeti, C. (2016). The historical ecological footprint: From over-population to over-consumption. *Ecological Indicators*, 60, 283–291.

78. Tóth, Á., & Szigeti, C. (2019). Example of a German Free-Float Car-Sharing Company Expansion in East-Central Europe. *Resources*, 8(4), 172.

79. UN, United Nations, (2011). *Classification of Individual Consumption According to Purpose (COICOP).* https://unstats.un.org/unsd/iiss/Classification-of-Individual-Consumption-According-to-Purpose-COICOP.ashx Accessed. 2018.11.13

80. UNEP, United Nations Environment Programme. International Resource Panel, United Nations Environment Programme. Sustainable Consumption, & Production Branch (2011). *Decoupling natural resource use and environmental impacts from economic growth.* UNEP/Earthprint.

81. Van der Bergh, J. C. J. M., & Verbruggen, H. (1999). Spatial sustainability, trade and indicators: an evaluation of the ecological footprint. *Ecological Economics,* 29, 61–72.

82. Vetoné Mozner, Z. (2012). A fogyasztási szemlélet jelentősége a természeti erőforrások és a CO2-kibocsátások elszámolásában. (The relevance of consumtion-based perspective in carbon emission accounting). Budapesti Corvinus Egyetem. *Fenntartható Életmód Műhelytanulmányok,* 1, 1–31.

83. Wackernagel, M., Kitzes, J., Moran, D., Goldfinger, S., & Thomas, M. (2006). The Ecological Footprint of cities and regions: comparing resource availability th resource demand. *Environment & Urbanization*, 18(1), 103–112.

84. Wackernagel, M. (1998). The ecological footprint of Santiago de Chile. *Local Environment*, 3(1), 7–25.

85. Wackernagel, M., Onisto, L., Bello, P., Linares, A. C., Falfán, I. S. L., Garcıa, J. M., Guerrero, A. I. S., & Guerrero, M. G. S. (1999). National natural capital accounting with the ecological footprint concept. *Ecological Economics*, 29(3), 375–390.

86. Wackernagel, M., & Rees, W. E. (1996). Our ecological footprint: Reducing human impact on the Earth, Gabriola Island, BC, New Society Publishers.

87. Wiedmann, T., Minx, J., Barrett, J., & Wackernagel, M. (2006a). Allocating ecological footprints to final consumption categories with input–output analysis. *Ecological Economics,* 56(1), 28–48.

88. Wiedmann, T., Minx, J., Barrett, J., Vanner, R., & Ekins, P. (2006b). Sustainable Consumption and Production e Development of an Evidence Base. Project Reference SCP001-Resource Flows. Project Code CTX0505/SCP1.1. Department of Environment, Food and Rural Affairs (DEFRA).

89. Wilson, J.. & Grant, J. (2009). Calculating ecological footprints at the municipal level: what is a reasonable approach for Canada? *Local Environment*, 14(10), 963–979.

90. Xu, S., & San Martin, I., (2010). Ecological Footprint for the Twin Cities: Impacts of Consumption in the 7-county Metro Area. Metropolitan Design Centre, College of Design, University of Minnesota, Minnesota.

91. Zhang, X. Q. (2016). The trends, promises and challenges of urbanisation in the world. *Habitat International,* 54, 241–252.

Table 1. Per capita ecological footprint in Hungary at different spatial level in 2003 and 2013, (gha/capita) based on the compound method

	2003	2013	Change
BMR Core (Budapest)	2,30	2,99	30,4%
BMR Periphery (Agglomeration)	1,70	1,94	14,2%
BMR total	2,07	2,57	24,4%
Rest of Hungary	1,61	1,81	12,6%
Hungary total	1,74	2,04	17,2%

Table 2. Per capita – in household consumption embedded – ecological footprint by land use categories, 2003 and 2013 (gha/capita)

	BMR Core (Budapest)			**BMR Periphery (Agglomeration)**			**BMR total**			**Rest of Hungary**			**Hungary total**		
	2003	**2013**	**Change**	**2003**	**2013**	**Change**	**2003**	**2013**	**Change**	**2003**	**2013**	**Change**	**2003**	**2013**	**Change**
Crop	0,89	0,93	*4,0%*	0,95	0,90	*-5,1%*	0,92	0,92	*0,3%*	0,82	0,61	*-25,4%*	0,84	0,70	*-17,1%*
Grazing	0,06	0,06	*4,0%*	0,06	0,06	*-5,1%*	0,06	0,06	*0,3%*	0,05	0,04	*-25,4%*	0,06	0,05	*-17,1%*
Forest	0,24	0,35	*46,8%*	0,26	0,36	*42,0%*	0,25	0,36	*45,0%*	0,21	0,29	*35,7%*	0,22	0,31	*39,0%*
Fish	0,02	0,02	*18,0%*	0,02	0,01	*-16,1%*	0,02	0,02	*4,6%*	0,01	0,01	*0,8%*	0,01	0,01	*2,8%*
Built-up	0,04	0,04	*2,0%*	0,04	0,03	*-6,8%*	0,04	0,04	*-1,5%*	0,03	0,03	*-7,9%*	0,03	0,03	*-5,4%*
Carbon	0,88	0,80	*-8,3%*	0,86	0,77	*-10,2%*	0,87	0,79	*-9,1%*	0,74	0,61	*-17,5%*	0,77	0,66	*-14,5%*
TOTAL	**2,13**	**2,21**	***3,8%***	**2,19**	**2,15**	***-1,7%***	**2,15**	**2,18**	***1,6%***	**1,87**	**1,59**	***-14,8%***	**1,94**	**1,76**	***-9,3%***

Table 3. Ecological footprint of household consumption by consumption (COICOP) categories at different spatial level in 2013 and related to the changes between 2003 and 2013 (in gha and in gha/capita)

			01 - Food and beverages	02 – Alcohol. tobacco and narcotics	03 - Clothing and footwear	04 - Housing, water, electricity, gas, fuels	05 - Furnishings, household equipment	06 - Health	07 - Transport	08 - Communication	09 - Recreation and culture	10 - Education	11 - Restaurants and hotels	12 - Miscellaneous goods/services	TOTAL
BMR Core (Budapest)	**gha**	**2013**	1 606 815	385 590	59 550	456 092	115 962	77 726	491 083	34 597	187 703	8 894	336 786	93 497	**3 854 294**
		2013/2003	*1,05*	*1,23*	*0,67*	*1,12*	*0,69*	*1,19*	*1,53*	*0,79*	*0,62*	*0,66*	*1,27*	*0,94*	***1,06***
	gha/cap	**2013**	0,92	0,22	0,03	0,26	0,07	0,04	0,28	0,02	0,11	0,01	0,19	0,05	**2,21**
		2013/2003	*1,02*	*1,20*	*0,65*	*1,10*	*0,67*	*1,17*	*1,50*	*0,77*	*0,60*	*0,64*	*1,24*	*0,92*	***1,04***
BMR Periphery (Agglomeration)	**gha**	**2013**	1 125 568	267 438	28 851	323 513	57 703	39 417	363 970	17 502	97 420	5 008	110 927	44 594	**2 481 911**
		2013/2003	*1,01*	*1,45*	*0,57*	*1,26*	*0,55*	*1,30*	*1,59*	*0,72*	*0,66*	*0,77*	*1,05*	*0,86*	***1,08***
	gha/cap	**2013**	0,97	0,23	0,02	0,28	0,05	0,03	0,32	0,02	0,08	0,00	0,10	0,04	**2,15**
		2013/2003	*0,92*	*1,32*	*0,52*	*1,15*	*0,51*	*1,19*	*1,45*	*0,66*	*0,60*	*0,70*	*0,96*	*0,78*	***0,98***
BMR total	**gha**	**2013**	2 732 383	653 028	88 401	779 604	173 666	117 143	855 053	52 099	285 123	13 902	447 713	138 090	**6 336 205**
		2013/2003	*1,03*	*1,31*	*0,63*	*1,18*	*0,64*	*1,23*	*1,55*	*0,77*	*0,63*	*0,69*	*1,21*	*0,91*	***1,07***
	gha/cap	**2013**	0,94	0,23	0,03	0,27	0,06	0,04	0,29	0,02	0,10	0,00	0,15	0,05	**2,18**
		2013/2003	*0,98*	*1,25*	*0,60*	*1,12*	*0,61*	*1,17*	*1,48*	*0,73*	*0,60*	*0,66*	*1,15*	*0,87*	***1,02***
Rest of Hungary	**gha**	**2013**	5 077 798	1 052 817	169 890	2 228 844	261 671	168 805	608 303	101 750	510 402	46 935	676 434	362 964	**11 266 614**
		2013/2003	*0,91*	*0,76*	*0,67*	*0,91*	*0,72*	*0,71*	*0,34*	*0,65*	*0,79*	*1,65*	*1,29*	*0,98*	***0,82***
	gha/cap	**2013**	0,72	0,15	0,02	0,31	0,04	0,02	0,09	0,01	0,07	0,01	0,10	0,05	**1,59**
		2013/2003	*0,95*	*0,79*	*0,70*	*0,95*	*0,75*	*0,74*	*0,36*	*0,67*	*0,82*	*1,72*	*1,34*	*1,02*	***0,85***
Hungary total	**gha**	**2013**	7 810 181	1 705 845	258 291	3 008 449	435 337	285 949	1 463 356	153 849	795 525	60 838	1 124 147	501 054	**17 602 820**
		2013/2003	*0,95*	*0,91*	*0,66*	*0,97*	*0,68*	*0,86*	*0,63*	*0,68*	*0,72*	*1,26*	*1,26*	*0,96*	***0,89***
	gha/cap	**2013**	0,78	0,17	0,03	0,30	0,04	0,03	0,15	0,02	0,08	0,01	0,11	0,05	**1,76**
		2013/2003	*0,96*	*0,92*	*0,67*	*0,98*	*0,69*	*0,87*	*0,64*	*0,69*	*0,73*	*1,28*	*1,28*	*0,97*	***0,91***

Table 4. Direct ecological footprint at different spatial level in 2003 and 2013

	BMR Core (Budapest)			**BMR Periphery (Agglomeration)**			**BMR total**			**Rest of Hungary**			**Hungary total**		
	2003	**2013**	**Change**	**2003**	**2013**	**Change**	**2003**	**2013**	**Change**	**2003**	**2013**	**Change**	**2003**	**2013**	**Change**
Natural gas	0,25	0,22	*-11,3%*	0,37	0,31	*-18,2%*	0,29	0,25	*-14,2%*	0,16	0,15	*-9,7%*	0,20	0,18	*-10,5%*
Firewood	0,01	0,01	*-20,5%*	0,06	0,23	*273,0%*	0,03	0,10	*224,6%*	0,29	0,28	*-4,5%*	0,22	0,22	*2,6%*
Heating total	**0,26**	**0,23**	***-11,5%***	**0,45**	**0,55**	***22,2%***	**0,33**	**0,36**	***7,5%***	**0,47**	**0,44**	***-5,6%***	**0,43**	**0,42**	***-3,2%***
Gasoline	0,06	0,06	*0,0%*	0,07	0,07	*7,6%*	0,06	0,06	*3,3%*	0,07	0,06	*-13,6%*	0,07	0,06	*-9,2%*
Diesel	0,02	0,02	*-18,9%*	0,03	0,02	*-25,2%*	0,03	0,02	*-21,4%*	0,02	0,02	*-4,1%*	0,02	0,02	*-9,2%*
Vehicle fuel total	**0,08**	**0,08**	***-5,5%***	**0,09**	**0,09**	***-1,9%***	**0,09**	**0,08**	***-3,9%***	**0,09**	**0,08**	***-11,2%***	**0,09**	**0,08**	***-9,2%***
Direct EF total	**0,34**	**0,31**	***-10,0%***	**0,54**	**0,64**	***18,1%***	**0,42**	**0,44**	***5,1%***	**0,56**	**0,52**	***-6,5%***	**0,52**	**0,50**	***-4,3%***

*Natural gas (bottled), coal, briquette/coke and liquid fuels were considered here also, but because of the insignificant values they are not included in the table (but included in the total values.

Table 5. Consumption based per capita ecological footprint values from a sustainability perspective for different spatial units in 2003 and 2013

	EF (gha/capita)		**Biocapacity - Hungary (gha/capita)**		**Biocapacity - Global (gha/fő)**		**Overshoot - Hungary**		**Overshoot - Global**	
	2003	**2013**	**2003**	**2013**	**2003**	**2013**	**2003**	**2013**	**2003**	**2013**
BMR Core (Budapest)	2,47	2,52					1,23	1,04	1,37	1,49
BMR Periphery (Agglomeration)	2,73	2,79					1,36	1,15	1,51	1,65
BMR total	2,57	2,63	2,01	2,42	1,81	1,69	1,28	1,09	1,42	1,55
Rest of Hungary	2,43	2,11					1,21	0,87	1,34	1,25
Hungary total	2,47	2,26					1,23	0,94	1,36	1,34
Hungary grand total	*3,79*	*3,27*					*1,89*	*1,35*	*2,09*	*1,93*

** EF values relate to household consumption (indirect – embedded – and direct together), except ’Hungary grand total’ that relates to the total national final consumption (including also governmental and civil sector as well, but not including exports. Source of the ’Hungarian grand total’ EF data and the biocapacity data is the GFN database, the rest is based on own calculation).*