Suburban neighbourhoods versus panel housing estates – An ecological footprint-based assessment of different residential areas in Budapest, seeking for improvement opportunities

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Abstract

In this study, the household consumption-related ecological footprint of lifestyles linked to panel housing estates and suburban neighbourhoods were compared in the case of Budapest and its suburbs. Our results show that the biggest parts of the ecological footprint are in both study areas the carbon, the cropland and the forest components, in line with earlier calculations. On the whole, the ecological footprint values are bigger in the suburban study area (2.63 gha/capita) compared to the panel housing estates (2.29 gha/capita), mainly because of the differences between the carbon uptake and the built-up land components. Beyond comparing the ecological footprint values of different residential areas, the study also contributes to the literature by addressing the improvement options of the respective areas through a rough model calculation on the reduction opportunities in both cases, resulting 36 percent in case of panel housing estates, and 47 percent in the suburban areas. Although these values have to be considered cautiously, they show significant opportunities in ecological footprint reduction in both types of residential areas supported by individual motivations, as well as by policy measures.

Keywords: suburbanisation, urban sprawl, sustainability assessment, housing estates, panel buildings, ecological footprint, Budapest

Received February 2024, accepted April 2024.

Introduction

One of the most spectacular processes in the development of post-socialist cities has been the transformation of the inner-city neighbourhoods and the outskirts. Outside the core city, in the agglomeration zone suburbanisation and urban sprawl have determined the development process in the last decades (Kubeš, J. and Nováček, A. 2019; Spórna, T. and Krzysztofik, R. 2020). Within the administrative boundaries of the city, fragmentation has progressed, with different neighbourhoods occupying different position on the housing market. In Hungary, and also in other post-socialist countries, the position of housing estates has been changing recently due to modernisation and upgrading, as evidenced by the rising dwelling prices and a growing demand for such dwellings (Kalm, K. *et al.* 2023).

There is a growing number of suburbanising towns and cities, which is significantly transforming urban land use, but urbanisation also happens at peri-urban areas. The inevitable corollary of decentralisation, on the

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other hand, is urban shrinkage (Champion, T. 2001), which has led to the re-emergence of the compact city concept in the EU's cohesion and social policy. Analysing the trends of the last almost four decades, a reversal towards the compact city in the development of metropolitan regions can be expected and urban sprawl can be seen as an intermediate stage of long-term territorial development (Taubenböck, J. *et al.* 2019). The expected direction of development is therefore not towards further expansion of these areas, but rather towards networking between increasingly compact, highly urbanised areas (Lang, R. and Knox, P.K. 2009). In this respect, the environmental characteristics of residential areas within the city and in the suburban zone are particularly important issues. Last but not least, there is much to be learned from the question of what ecological, architectural and lifestyle changes would be needed for the resident population to increase the sustainability of cities. Based on Ferreira, J.P. *et al.* (2023), different types of urban structure and population are responsible for significantly different levels of ecological impacts. According to Erdeiné Késmárki-Gally, Sz. and Neszmélyi, Gy.I. (2017), this is highly influenced by the significant differences in the level of urbanisation in the world.

Based on previous research, the aim of this study is to compare the ecological impacts of two very different types of urban structures, (1) densely populated panel housing estates in the compact city, and (2) sparsely populated suburban settlements outside the city, but still close the city boundary. This paper compares two types of neighbourhoods through the example of Budapest, using the concept of the ecological footprint (Wackernagel, M. and Rees, W.E. 1996). The research questions are the followings:

– RQ1. How do the ecological footprints of suburban settlements and panel housing estates differ from each other?
– RQ2. Considering their different built-up characteristics, what are the opportunities to decrease the specific ecological footprint of these two different neighbourhoods?

The intended novelty and added value of this study is related to both research questions. In the literature review section, a research gap is detected. In spite there seems to be a consensus among academics that urban sprawl increases ecological footprint compared to compact cities, there is very little empirical research on comparing different types of residential areas, especially when ecological footprint of consumption habits of the respective lifestyles is also considered. Academic literature mainly focuses on the ecological footprint-based comparison of different construction technologies (Li, H.X. *et al.* 2014; Kumar, A. *et al.* 2021; Ottelin, J. *et al.* 2021), or macro-level (national or regional) comparisons (Kovács, Z. *et al.* 2020, 2022; Yang, Y. *et al*. 2022; Kuzyk, L.W. 2023; Zhang, H. *et al*. 2024), while ecological footprint literature lacks convincing studies comparing different residential areas (even Ottelin, J. *et al.* [2015] compares inner and outer urban areas in terms of carbon footprint).

The calculation presented related to RQ1 contributes to fulfil this gap. The results not only help to better understand the differences between the overall ecological footprint values of the two study areas, but also highlight the key components contributing to both the indirect and the direct parts of the overall ecological footprint.

Another novelty value is the addressing and better understanding of the improvement options in panel building estates and suburbs (related to RQ2, in the discussion section). This can contribute to the further development of both public policies and individual strategies aiming at decreasing ecological footprint related to both study areas.

The rest of the study is structured as follows:

a) Literature review section provides a literature review of the major environmental challenges in residential areas, covering both suburban and densely populated prefab neighbourhoods, as well as a short overview of the concept of the ecological footprint with a special focus on the urban level.

b) Methodology section introduces the study areas as well as the method of the ecological footprint calculations mainly based on household consumption.

c) Results section presents the results of comparing the two study areas.

d) Discussion section analyses the opportunities of decreasing the ecological footprint of the different types of neighbourhoods. Finally, the last section concludes the main findings of the research and provides an outlook for further research.

Literature review

Environmental challenges in different residential areas

The environmental challenges of suburban neighbourhoods

Following the recession in the first half of the 1990s, cities of the Central and Eastern European countries have experienced a spectacular development (Enyedi, Gy. 1998). Suburbanisation and urban sprawl became one of the dominant spatial processes in the Budapest urban region, as in other large Central and Eastern European cities (Tammaru, T. *et al.* 2009; Roose, A. *et al.* 2013; Kocsis, J.B. 2015; Csapó, T. and Lenner, T. 2016). Suburbanisation and urban sprawl in the Budapest agglomeration accelerated in the second half of the 1990s triggered by lower land and dwelling prices, lower densities, more attractive environment etc. The target settlements of the accelerating suburbanisation were mainly villages and small towns in the western and northern parts of the urban region, where the hilly and mountainous areas offered an attractive natural environment for the newcomers *(Photo 1).* An uncoordinated and chaotic growth prevailed in the suburban belt of Budapest significantly transforming these areas (Egedy, T. 2012; Kovács, Z. and Tosics, I. 2014). Transport networks have not been developed in line with emerging

Photo 1. Suburban neighbourhood in the Budajenő-Telki area. (Photo taken by the authors.)

needs, typically due to the lack of resources and a focused strategy (Erdeiné Késmárki-Gally, Sz. *et al.* 2020).

Suburbanisation and urban sprawl have led to a dramatic increase in transportation need and the associated car use, and transport problems gradually became the biggest challenge for the city region (Austin, P. and Gregorova, E. 2015). Another major challenge for post-socialist cities is the significant transformation of space and wasteful land use in city regions (Sýkora, L. 2014), as highlighted by *Figure 1.*

The statistics on commuting clearly show that in the post-1990 period, the spatial structure of the metropolitan region of Budapest has gradually transformed towards polycentric development. This process has resulted in an increase in cross-commuting between cities and a sharpening urban-to-rural commuting due to the decentralisation of the economy.

Meanwhile, in terms of land use, the massive conversion of former agricultural land into residential and commercial areas has commenced (Kovács, Z. and Tosics, I. 2014). The consequences of urban sprawl became visible in the region: the share of abandoned land increased, the proportion of agricultural land decreased, and the natural environment became fragmented. The growth of artificial surfaces has significantly accelerated. The post-socialist, post-industrial urban development has increasingly become a victim of ad hoc decisions and development. Investments became often random, making spatial development in the Budapest urban region unpredictable, it became difficult to predict and monitor land use changes. In the last two decades, development has been the result of market processes rather than of well-established development policy interventions (Fazekas, M. *et al.* 2015; Lang, T. 2015). Development has been organised along the lines of weaker resistance and stronger lobbies, reinforced by short-term political interests (Egedy, T. *et al.* 2017). As a consequence of the uncontrolled and unregulated spatial processes, the conflicts and negative environmental and social effects associated with suburbanisation and urban sprawl have intensified (Da Silva Machado, F. 2017).

The most common environmental challenges caused by the rapid development of suburban settlements include transport problems arising from commuting (with the ecological issues arising from car traffic being the main reason), land use problems

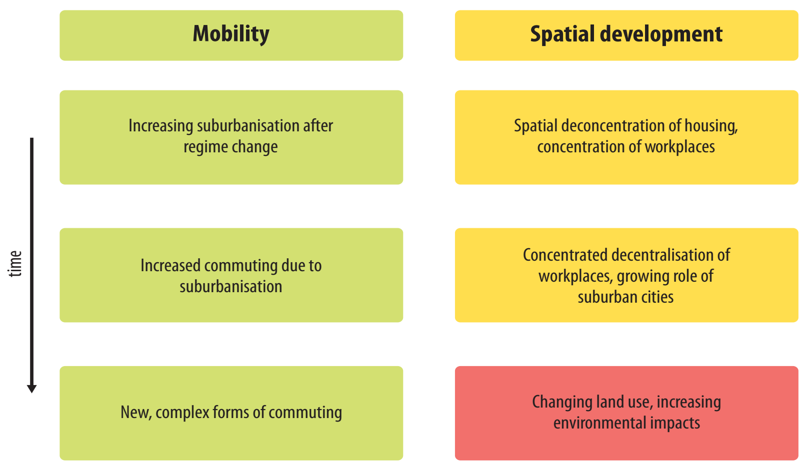

Fig. 1. The interrelationship between mobility and spatial development in the Budapest metropolitan region. *Source:* Authors' own design.

linked to land conversion for housing (encroachment on natural landscapes, growth of artificial surfaces, illegal development and circumvention of regulations).

Challenges of panel housing estates from environmental and social perspectives

The reasons behind the construction of housing estates in both Western and Eastern Europe were similar: on the one hand, they were an attempt to address the quantitative housing shortage by cost-effective means, while on the other hand, it was an attempt to fulfil social equality and/or egalitarian political ideology (communist Eastern Europe) based on the theory of modernist architecture (Benkő, M. 2015; Leetmaa, K. *et al.* 2018). One spectacular and – at the time – effective element of this was the emergence and spread of prefabricated housing estates in Europe and in other parts of the world.

The 1970s was the peak period for the construction of prefab housing estates in East-Central European countries (Ouředníček, M. and Kopecká, Z. 2023), including Hungary (Kovács, Z. *et al.* 2018). Only in Hungary, about 600,000 dwellings were built using prefabricated technology (Benkő, M. and Egedy, T. 2023). Based on the authors, more than half of them has central heating and emerged in the form of greenfield investment. The layout and architectural character of the 1970s housing estates was mainly determined by the Soviet type large-panel technology. Ten-storey high strip houses (slabs) and 15-storey high towers became dominant, mostly with five, sometimes with ten staircases, as illustrated by *Photo 2.* The reduction of costs was only possible with the neglect of the construction of public services, and development of green areas, which became the most serious deficiencies of these housing estates (Kolcsár, R.A. *et al.* 2022). These large-scale, land-intensive, densely built housing estates with medium- and high-rise buildings were usually built on the periphery of large cities, in isolated environments far from the city centre, on open urban land still available for

Photo 2. Typical prefab building built in the 1970s. The "Village House" with 884 dwellings residing 3,000 people built in 1970 in Budapest's 3rd district. (Photo taken by the authors.)

large-scale construction (Petsimeris, P. 2018). The physical characteristics of housing estates: size, design and construction have had a crucial impact on the long-term trajectory and performance of housing estates on the housing market, even if social and housing values have changed over time (Hess, D.B. *et al.* 2018). Monotonous high-rise housing estates located in the periphery with poor accessibility face higher risks for social and physical downgrading than smaller housing estates closer to the city centre (Andersson, R. and Bråmå, Å. 2018).

The 1970s also brought about changes in the social composition of housing estates. Poorer and less educated people got better access to public housing in housing estates, and the average social status of the new estates decreased accordingly. After the change of regime, the wealthier strata who could afford better quality housing moved out of the panel housing estates, and today these neighbourhoods are mainly inhabited by the lower-middle class and the elderly (Egedy, T. *et al.* 2022). At the same time, due to the smaller average dwelling size, prefab housing estates have some potentials as in most European countries (and also in Hungary). They can attract small households composed of young singles, elderly, divorced people, foreign students and temporary workers who seek smaller housing units (Hess, D.B. *et al.* 2018).

The challenges of prefab housing estates can be grouped into three categories: i) challenges caused by the built environment, ii) problems associated with the social environment, and iii) challenges arising from the location (localisation) of the housing estates. The challenges of the built environment include problems of technological origin (problems due to the reinforced concrete construction, poor thermal and acoustic insulation, the single-pipe heating system with its wasteful technology, which did not allow the individual metering and proportional accounting of the energy used per apartment etc.), the lack of services and infrastructure (lack of institutions, shops, public services), the quality of green spaces and parking problems. The social challenges of prefab housing estates include the ageing of the local population, difficulties resulting from the co-existence of different generations (older original population and young newcomers), problems related to segregation, safety and crime. The location and localisation of housing estates (peripheral location in the case of panel estates) and their difficult accessibility often pose significant problems in terms of the lack of proximity and connectivity between the neighbourhood and the rest of the city.

The concept of the ecological footprint in a regionally oriented framework

The ecological footprint indicator measures human demand on nature by showing how much biologically productive land and sea area is needed to sustain a given consumption pattern. The magnitude of the demand, thus, can be compared with the available biocapacity on the supply side. If the demand for land in a certain area (country, region) exceeds the supply of biologically productive land, this results an ecological deficit indicating unsustainability at the longer term.

The concept was originally introduced in the 1990s (Wackernagel, M. and Rees, W.E. 1996), but has since been further developed (Wiedmann, T. *et al.* 2006). The size of the ecological footprint is expropriated through consumption activities is calculated by dividing the amount of resources and services consumed by the yield of the type of land that produces those resources and services. The resulting values are then multiplied by equivalence factors and summed to produce the final ecological footprint values. Meanwhile, biocapacity measures the ecological assets (including forest land, grazing land, cropland, fishing land and built-up land) available within the boundaries of the investigated territory and their capacity to produce renewable resources and ecological services (Galli, A. *et al.* 2020). National footprint calculations are constantly improving as better data become available and new methodologies are developed (Kitzes, J. *et al.* 2009). However, sub-national calculations are still relatively rare.

One direction for improvement in sub-national calculations is to develop a method to disaggregate national ecological footprints by socio-economic groups or certain territories. This is done by combining existing National Footprint Accounts with input-output analysis (Wiedmann, T. *et al.* 2006; Csutora, M. *et al.* 2011; Zhou, X. and Imura, H. 2011). One specific area of application of the ecological footprint indicator is the calculation of the ecological footprint for cities and city regions, which became popular in the literature recently (Galli, A. *et al.* 2020; Kovács, Z. *et al.* 2020; Swiader, M. *et al.* 2020). The results of a recent publication regarding the ecological footprint calculation of Budapest provides the basis for our current research (Kovács, Z. *et al.* 2022). The concept of ecological footprint has been the focus of much criticism (Galli, A. *et al.* 2016; Harangozó, G. *et al.* 2019), but its versatility has made it one of the most popular sustainability assessment indicators, inspiring many creative applications to address spatial aspects (Kocsis, T. 2014).

Despite the popularity and the methodological development of ecological footprint calculations, there are surprisingly few studies aiming at comparing different types of built-up areas beyond the conventional urban-rural approach. Holden, E. (2004) compared different types of residential areas in Norway and found that suburbs had higher footprint than city centres and argued for 'decentralised concentration' as a future development direction of urban areas, meaning smaller and more compact cities instead of urban sprawl. This study, however, mostly focused on the ecological footprint of housing and commuting, while embedded ecological footprint of consumption (this may vary between different residential areas) was disregarded. There are studies comparing the ecological footprint of different built structures, including prefab buildings (e.g., Solís-Guzmán, J. *et al.* 2013; Husain, G. and Prakash, R. 2019), but these still not cover the ecological footprint aspects of the lifestyles related to them.

An interesting perspective is provided by Hurley, R.E. (2009), suggesting that brownfield development of residential areas is preferred to greenfield ones. This sound to be logical (with the addition, that not exactly the ecological footprint is lower, but the need for – further – bio-capacity is less in case of brownfield investment), however, there is no empirical evidence provided for that. Indeed, Zhang, L. *et al.* (2016) could prove such relationship (brownfield investments are better than greenfield ones also from an ecological footprint perspective, in case of Chinese industrial areas), but not in residential areas.

As existing research does not seem to cover the differences between ecological footprint patterns of various types of residential areas (especially considering respective consumption habits), there is a research gap and need for more empirical studies in the field.

Methodology

Delimitation of the study areas

In our study, the household consumption-related ecological footprint of lifestyles linked to panel buildings and suburban neighbourhoods were compared in the case of Budapest. Following the scope of the research, two study areas were defined:

- Prefab panel buildings within the city borders: these neighbourhoods include multistorey, land-intensive buildings with high population density and relatively low apartment sizes, with little or no green surfaces and with district-heating. On one hand, inhabitants of these buildings have limited individual options on energy efficiency improvement (e.g., insulation) or alternative energy sourcing (e.g., solar panels). On the other hand, panel neighbourhoods are close to the compact city centre and supplied by public transportation. Altogether there are 57 housing estates within the city limits of Budapest with partly or fully prefab panel buildings. Based on the authors' estimation, this means about 200,000 dwellings with approximately 460,000 residents.

– Suburban neighbourhoods in the agglomeration of Budapest: these are villages and smaller towns, mostly with single family homes with smaller gardens, the size of dwellings is bigger and they are supplied with individual heating. There are more options regarding individual improvements for energy efficiency or use of alternative energy sources, however, such neighbourhoods have limited access to public transportation. For the research, the following seven municipalities were included in our sample: Budakeszi, Dunakeszi, Halásztelek, Pilisborosjenő, Szentendre, Telki and Vecsés. When compiling the suburban sample, villages, small and medium towns were considered, where relatively new and low-rise family house neighbourhoods are dominant. A further aspect was to include towns from various geographical sectors of the suburbs of Budapest. The total housing stock of the selected settlements is about 48,000 dwellings, with a population of 130,000.

The study areas are overviewed by *Figure 2.*

Fig. 2. Overview and location of the study areas. *Source:* Authors' own compilation.

Data and method

The process of calculating the household-related ecological footprint (associated with both goods and services), was conducted using an input-output model, supplemented with environmental data. Input-output models (based on the seminal work of Leontief, W. in 1936) unveil the interdependence among sectors within an economy and quantify how a unit of output in one sector relies on resources drawn from various other sectors. To illustrate, consider the inputs required for the consumption of a kilogram of potatoes, including the agricultural, energy, transport, and retail sectors etc.

The integration of environmental data into input-output models (environmentally extended input-output analysis – EEIO), it becomes possible to quantify the ecological footprint related to household consumption. This type of ecological footprint calculation is considered as a top-down approach. The input-output model was first used to calculate the ecological footprint by Bicknell, K.B. *et al.* (1998), and Ferng, J.J. (2001). The first application in Hungary was by Csutora, M. *et al.* (2011), who used it to determine the ecological footprint of household consumption. In this study, we extended the application of this methodology to a regional context, following the methodological guidelines set by Wiedmann, T. *et al.* (2006). Similar methodology was used by Córcoles, C. *et al.* (2024), using an environmentally extended multiregional input-output model and the Spanish Households Budget Survey to extract expenditure microdata by municipality size.

The household consumption spending related methodology is highly appropriate to address micro-level differences between the study areas in many aspects. For example, differences in household energy spending address the differences between prefab panel and suburban family house dwellings, spending on transportation and vehicle fuel address the spatial aspects of the study areas, while spending on various goods and services indicate the differences between lifestyles representing the study areas. The ecological footprint embedded in household consumption can be expressed through the formula:

$$EF = EF_{dir} \cdot (I\text{-}A)^{-1} \cdot FD, \qquad (1)$$

where *EF* represents the ecological footprint, EF_{dir} stands for the direct ecological footprint vector of specific sectors (in gha per million HUF). The term $(I\text{-}A)^{-1}$ corresponds to the Leontief-inverse matrix derived from the input-output model, showing the interdependencies among sectors. Finally, *FD* stands for the household-related final demand vector indicating the extent of consumption along the products of various sectors during the study period.

The data for the EF_{dir} vector were obtained from the Global Footprint Network (GFN) database, specific for Hungary, for 2019, the latest dataset provided by GFN. The household *FD* consumption vectors are calculated based on the EU Statistics on Income and Living Conditions (EU-SILC) database, data were obtained from the Hungarian Central Statistical Office (HCSO). Data were available for 2019, the last year before the Covid-19 pandemic. For the first case area (Budapest panel building neighbourhoods) data on households from Budapest with district heating were used as a proxy, while for the agglomeration case area, households from the respective municipalities in the Hungarian SILC database were used. Economy level input-output tables are developed in every five years for Hungary by the HCSO, so we applied the latest version, representing 2020.

Beyond the ecological footprint of the embedded consumption (indirect part), calculated as above based on Wiedmann, T. *et al.* (2006), we also estimated the direct components, originating directly from households. These components have been quantified along two domains of the ecological footprint:

– Carbon related component: This results from carbon emissions directly from residential heating and vehicle fuel usage. Examples include emissions from burning natural gas and gasoline or diesel during private car use. However, it excludes factors like electric heating, as electricity usage generates carbon emissions elsewhere (in power stations and during production and transportation of boilers, already covered by the EEIO-based calculation above). Similarly, the usage of bus transport accounted when acquiring transport services. (The burning of firewood for home heating, relevant for the agglomeration is not quantified in ecological footprint accounts, as it is considered as carbon neutral. However, in practice it is not necessarily the case [Gunn, J.S. *et al.* 2012], not considering other pollution caused by firewood heating.) Quantifying the household's direct carbon footprint involves the following four steps:

a) Identifying expenditure on fuels (piped natural gas, bottled gas, liquid fuels, coal, briquettes, coke) and vehicle fuels (petrol, diesel) based on the HCSO consumption survey data.

b) Determining consumption quantities based on average prices.

c) Calculating annual per capita carbon-dioxide emissions using calorific values (GJ/unit of volume) and specific carbon-dioxide emissions (t CO_2/GJ) of different fuels.

d) Deriving the carbon footprint per capita (gha/person) based on the coefficient of carbon dioxide from the (GFN data).

– Built-up land related component: This is associated with the physical area of residential properties and roads, in proportion to household utilization. As a proxy, properties are estimated to cover 1,000 square metres per households in the agglomeration (accounting for 0.25 gha – 0.12 gha/capita – considering that both built-up land and arable land have an equivalence factor of 2.51 gha/ha). For panel building apartments in multi-storey blocks, this component was neglected. There was no proxy to estimate the household use related part of road surfaces, so this component is somewhat underestimated.

Beyond comparing the per capita ecological footprint values of the study areas, the study goes further. Based on literature and own considerations, specific improvement options are presented and discussed through a model calculation for the study areas.

Results

Table 1 provides an overview of the per capita household-related ecological footprint values for the two study areas, including both indirect (in household consumption embedded) and direct components.

Data show that the biggest components of the ecological footprint are in both study areas the carbon, the cropland, and the forest components, in line with earlier calculations (see Kovács, Z. *et al.* 2020, 2022). Altogether, the ecological footprint values are bigger in the suburban study area (2.63 gha/capita) compared to the panel housing estate neighbourhoods (2.29 gha/capita), mainly because of the differences between the carbon uptake and the built-up land components.

In spite of the clear differences between the two study areas (the overall per capita footprint value in the suburban sample is 15% higher than in the panel housing estate sample), there are major differences, if the direct and indirect parts of the ecological footprint values are considered. The indirect (embedded in the life-cycle of purchased goods and services) part of the household consumption related footprint is 14 percent higher in case of panel housing estates (2.13 gha/capita versus 1.83 gha/capita in the suburbs) and the values of panel housing estates outnumber suburbs related all of the three most influential component (cropland, carbon and forest land). Indeed, the higher overall ecological footprint values of the suburbs emerge based on the major difference between the direct components (0.76 gha/capita in the suburbs), 4.75 times bigger than the 0.16 gha/capita values of the panel housing estate sample. The respective carbon component is much larger in the suburban sample because of heating with natural gas. This component is not relevant in the panel housing sample, because those households use district-heating (and, thus, count into the indirect component), their natural gas consumption is very low (used mainly for heating water and cooking) compared to suburban households. The direct built-up land component is also bigger in the suburban sample (see the details of the respective methodological considerations in the previous section).

*Table 1. Per capita household consumption related and total ecological footprint as well as bio-capacity by land use types**

Land use types	Household-related ecological footprint						Ecological footprint (national, total)	Bio-capacity (national)
	Budapest panel buildings			Suburbs				
	indirect	direct	total	indirect	direct	total		
Cropland	0.93	–	0.93	0.82	–	0.82	1.11	1.68
Grazing land	0.06	–	0.06	0.05	–	0.05	0.11	0.08
Forest	0.35	–	0.35	0.31	–	0.31	0,40	0.67
Fish	0.02	–	0.02	0.01	–	0.01	0.02	0,02
Built-up land	0.04	–	0.04	0.03	0.12	0.15	0.13	0.13
Carbon	0.73	0.04** +0.12***	0.89	0.65	0.48** +0.15***	1.28	2.23	–****
Total	*2.13*	*0.16*	**2.29**	*1.87*	*0.76*	**2.63**	**3.97**	**2.57**

*In gha/person, 2019, household related data. *Source:* Authors' own calculation, national level data: GFN.
**Natural gas related (heating, cooking, hot water; only cooking and hot water in district heated panel buildings.
***Transport related. ****As a fictive land type, not applicable in bio-capacity accounts.

Furthermore, there may be another element to be considered in the carbon component in the suburban study area, the impact of the firewood heating. In the ordinary ecological footprint accounts, biogenic emissions are not considered (based on the assumption that dead wood would decompose anyway), however, Gunn, J.S. *et al.* (2012) debate this approach. It is not the scope of this study to dig deeper in this debate, so a further 0.15 gha/capita carbon uptake land component (based on firewood consumption) was not added to the suburban ecological footprint, but still mentioned as a potential fictive element.

Household consumption-related ecological footprint data for both types of study areas are smaller than the national total values (but this is not very surprising as the latter also involves footprint components beyond the household consumption, such as governmental and third sector activities). If we, however, compare the results to the national bio-capacity (the 'supply' of biologically productive land), it is obvious that the household-related ecological footprint itself approaches (in case of the panel buildings) or even outnumbers (in case of the suburban study area) it, raising serious sustainability concerns.

Table 2 goes further and provides a summary on the ecological footprint data according to consumption (COICOP – Classification of Individual Consumption According to Purpose, United Nations 2011 categories) (UN 2011).

If consumption categories are considered, the most important components are the food, housing (mainly heating) and transportation related ecological footprint components. The food component is somewhat bigger in the panel housing neighbourhoods, that can be the result of higher spendings on food

*Table 2. Household related ecological footprint along COICOP consumption categories**

Budapest and neighbourhoods	Categories	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*
Budapest panel buildings	indirect	0.87	0.19	0.04	0.31	0.05	0.03	0.18	0.01	0.15	0.02	0.22	0.05	*2.13*
	direct	–	–	–	0.04	–	–	0.12	–	–	–	–	–	*0.16*
	total	0.87	0.19	0.04	0.35	0.05	0.03	0.30	0.01	0.15	0.02	0.22	0.05	***2.29***
Suburbs	indirect	0.74	0.16	0.04	0.31	0.07	0.03	0.11	0.01	0.09	0.02	0.25	0.04	*1.87*
	direct	–	–	–	0.61	–	–	0.15	–	–	–	–	–	*0.76*
	total	0.74	0.16	0.04	0.79	0.07	0.03	0.26	0.01	0.09	0.02	0.25	0.04	***2.63***
Difference (suburbs versus Budapest panel buildings in %)	indirect	-14.5	-14.4	3.3	-2.0	30.0	-13.6	-39.8	-15.0	-36.8	4.3	12.4	-14.1	*-11.9*
	direct	–	–	–	142.5	–	–	25.0	–	–	–	–	–	*37.5*
	total	-14.5	-14.4	3.3	122.4	30.0	-13.6	-13.9	-15.0	-36.8	4.3	12.4	-14.1	*15.0*

*In gha/person, 2019. *Source:* Authors' own calculation.

product, which can be further decomposed along product categories using the coefficients of the Global Footprint Network Database *(Table 3).* The most dominant components are bread and cereals (because of their high quantity consumed) and meat products (based on their per unit ecological footprint impacts). The biggest difference between the panel housing and the suburban neighbourhoods are related to the housing component, where the latter has more than double values (0.79 gha/capita versus 0.35 gha/capita), mainly because of the larger average size of appartments and the individual buildings as opposed to panel apartments. The transportation related footprints are relatively similar (higher commuting impacts in the suburban lifestyle may be balanced by more leisure related monility among residents of panel buildings).

If differences between suburbs and panel housing estates are considered, it can be seen that footprint components related to most consumption categories are smaller in case of suburbs, but the large surplus related to housing (mainly related to energy consumption and physical land use) makes the overall value outnumber panel housing estates by 15 percent.

Results comparing the ecological footprint values of different residential areas are not only interesting in themselves, but also serve as the basis of our model calculation on how to reduce them, discussed in the following section.

*Table 3. Household-related food consumption footprint according to main food categories**

Food categories	Panel buildings	Suburbs
Bread and cereals	0.240	0.210
Meat	0.180	0.160
Fish	0.023	0.020
Milk, cheese, eggs	0.064	0.054
Oils/fats (plant-based)	0.100	0.089
Oils/fats (animal-based)	0.037	0.032
Fruit	0.078	0.066
Vegetables	0.077	0.066
Sugar, jam, honey, chocolate	0.039	0.033
Food n.e.c.	0.022	0.018
Total	*0.870*	*0.740*

*In gha/person, 2019. *Source*: Authors' own calculation based on GFN coefficients.

Discussion

Based on the results, it seems that compact, high density, high-rise housing estates are better than low-rise, sprawling, suburban areas, when ecological footprint is considered. It is important to note here, that results emerged as the aggregation of three major influencing factors, covered in the results section: building characteristics (influencing housing related footprint components), spatial aspects (responsible for commuting related footprint) and consumption patterns (influencing a major share of indirect – in the supply chains of products and services consumed).

Although the lack of extensive literature coverage of comparing the ecological footprint of specific residential areas, the results can still be discussed from different angles. If regional urban-rural aspects are considered, the current results are in line with recent calculations (Swiader, M. *et al.* 2020; Kovács, Z. *et al.* 2022), however, the study areas in those calculations are not specified and address only the differences between city and suburban neighbourhoods (disregarding the heterogeneity of those study areas).

Literature focusing on the construction aspects of buildings from an ecological footprint perspective (Solís-Guzmán, J. *et al.* 2013; Husain, G. and Prakash, R. 2019) highlight the benefits of modern apartment blocks. This is partly in line with the results of this study, as panel building neighbourhoods seemed to have lower housing-related footprints, but this is not necessarily because of the modernity of those buildings, but rather related to the lower per capita areas and the detached nature of such dwellings.

The findings of Holden, E. (2004) – an advocate of 'decentralised concentration' based on a Norwegian case study – show similarities with the results of this study, but the current two study areas (panel building estates within a major city and suburbs out of the city, but still linked to it) are far from his ideal settlement, compact and small towns with low travel needs. Very few studies go beyond the aspects mentioned in this section so far and consider general consumption patterns when comparing the ecological footprint values of different residential areas. Gao, X. *et al.* (2024) analysed Chinese households and found that footprint inequality increased both in urban and rural areas. The results are hard to be explicitly compared to this study, but it supports the current finding that footprint related to consumption patterns play a key role in the overall footprint.

Based on the results, it seems that the geographical location of the dwelling, its size, architectural character, the basic communal infrastructure and the consumption patterns of residents are all key determinants of the magnitude of the ecological footprint and the potentials for reducing it. Beyond discussing the results of the two study areas of this paper, maybe an even more important field is to look for options decreasing ecological footprint specific for the different neighbourhoods. In this section, some ideas are presented based on literature, with a special focus on the major footprint components.

Literature differentiates top-down and bottom-up measures to decrease ecological footprint in the different residential areas. The first follows a macroeconomic approach through policies developed and financed by the states or state-level authorities, while the latter, a microeconomic perspective, means locally initiated and realised interventions (Tilov, I. *et al.* 2019; Saunders, H.D. 2000). The measures themselves can cover several fields: energy consumption (housing and transportation), products related to housing and clothing and food consumption (Shinde. R. *et al.* 2022).

Su, B. *et al.* (2022) highlight the significant potential in reducing food-related footprint by consuming less meat or even going vegan. Vávra, J. *et al.* (2018) draw the attention to food self-provisioning, even though such opportunities seem to be limited even in suburban conditions. There is a huge body of literature on how housing-related footprint can be radically decreased. Among them many researchers advocate refurbishing the buildings (Mir, A. *et al.* 2022; Kazemzadeh, E. *et al.* 2023), improving energy efficiency (Li, R. *et al.* 2022), promoting renewable energy in residential use (Shabir, M. *et al.* 2023), developing the electricity grid (Kuzyk, L.W. 2023) or promoting low-carbon technology innovation already at the planning phase of buildings (Gao, X. *et al.* 2024).

Based on these ideas, as a basis of a model calculation, the following measures are quantified here: 1) going totally vegan by avoiding meat, fish and dairy product consumption, 2) giving up totally harmful habits of smoking and alcohol consumption, and 3) transforming household-related energy use totally to renewable energy (and, thus, eliminating the indirect and direct carbon footprint elements) and giving up individual car usage with combustion engines(eliminating the direct carbon component of transportation related footprint). Based on the earlier outcomes of *Table 2* and *3*, this would result in decreased per capita ecological footprint values, as summarised by *Table 4.*

Estimates based on *Table 4* indicate a 0.83 gha/capita (36%) reduction in the panel housing estates and 1.25 gha/capita (47%) in the suburban sample area. An important insight is that suburban neighbourhoods not only have higher potential for reduction, but if the total theoretical potential could be achieved, the remaining per capita ecological footprint would be even lower compared to panel building neighbourhoods (1.38 gha/capita versus 1.46 gha/capita respectively). Additionally, in case the fictive 0.15 gha/capita firewood would also have been accounted, based on Gunn, J.S. *et al.* (2012), as derived in the method section) this could be a further reduction potential.

If our assumption for the number of residents of panel housing estates (450,000) holds true, the overall reduction potential accounts for 373,500 gha for this study area, 8.4 percent of the total footprint value of Budapest based on the most recent related calculation (Kovács, Z. *et al.* 2022). The respective reduction potential for the suburbs may vary between 10.9 and 15.9 percent of the total ecological footprint of the agglomeration of Budapest. Although it is very hard to estimate the population in the suburbs living

Table 4. *Possibly achievable household related ecological footprint along COICOP consumption categories**

Budapest and neighbourhoods	Categories	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*
Budapest panel buildings	indirect	0.87	0.19	0.04	0.31	0.05	0.03	0.18	0.01	0.15	0.02	0.22	0.05	*2.13*
	direct	–	–	–	0.04	–	–	0.12	–	–	–	–	–	*0.16*
	theoretical reduction potential	*0.27*	*0.19*	–	*0.25*	–	–	*0.12*	–	–	–	–	–	*0.83*
	total (potential)	0.70	–	0.04	0.10	0.05	0.03	0.18	0.01	0.15	0.02	0.22	0.05	***1.46***
Suburbs	indirect	0.74	0.16	0.04	0.31	0.07	0.03	0.11	0.01	0.09	0.02	0.25	0.04	*1.87*
	direct	–	–	–	0.61	–	–	0.15	–	–	–	–	–	*0.76*
	theoretical reduction potential	*0.23*	*0.16*	–	*0.70*	–	–	*0.15*	–	–	–	–	–	*1.25*
	total (potential)	0.51	–	0.04	0.22	0.07	0.03	0.11	0.01	0.09	0.02	0.25	0.04	***1.38***

*In gha/person, 2019. *Source:* Authors' own model calculation based on considerations in the text.

in similar neighbourhoods as in our respective study area (small towns that are different from urbanised suburbs or rural areas in the suburbs of Budapest), the range estimated here is based on the assumptions that the whole agglomeration has the *same amount* (higher end of the range) or *same ratio* (lower end of the range) of residents falling into our suburban sample. However, as the considerations of the decreasing potential apply also to the whole Budapest or agglomeration population, the numbers estimated in this passage can be understood as underestimation of the total reduction potential.

Although these estimations are very rough (not taking into account the emerging needs for additional vegan food, public transportation etc.), clearly indicate huge opportunities for ecological footprint reduction. While current values are higher in the suburban areas, the outcome of the reduction options also seems to be higher (also proportionally); this can also be considered when limited governmental resources or funding options are allocated for such purposes. The better understanding of the differences between core-periphery patterns (studied also from a different perspective by Péti, M. *et al.* (2024) can enable more case specific reduction actions.

In some cases, ecological footprint reduction does not need financial investment (in case of going vegan or giving up harmful habits. In other cases, however, improving the energy efficiency of buildings or transportation, monetary resources are essential and modernisation funds indeed play a major role. According to Bajomi, A.Z. *et al.* (2022), in countries, like Hungary and others, where the state provides very little funding and support for modernisation and energy efficiency programmes of residential buildings compared to other EU member states, this is clearly a limiting factor. If the benefits of such programmes are highlighted from properly from multiple angles (including the results of this study, as well), more convincing recommendations for policymakers can be formulated. Furthermore, if also at an international context, state subsidies are scarce or limited, even the disposable income and savings of the local residents can be a basis, when investment is needed for ecological footprint reduction measures (Shinde, R. *et al.* 2022). As the authors studied residential areas in Switzerland, the availability of financial resources of local residents can also be a limitation factor if major refurbishment of buildings is considered, even though this would pay back over time.

In case of both top-down and bottom-up measures to decrease ecological footprint, the rebound effect (savings and, thus, ecological footprint reduction achieved in one area can lead to increased spending, an again larger ecological footprint, in other fields) needs to be considered (Chitnis, M. *et al.* 2013). For example, savings on energy bills may be spent on larger distance driven as leisure activity, partly or fully decreasing the achievement in ecological footprint reduction. This phenomenon draws the attention for the need of a complex, environmentally conscious approach, when promoting measures to decrease ecological footprint. Considering the results of this study as a rough model calculation on how ecological footprint could be reduced in different types of residential areas, several limitations need to be mentioned:

Comparing two lifestyles is obviously artificial – in reality, there are many different lifestyles living side by side. The aim was to illustrate that different neighbourhoods with populations following different lifestyles have different potentials to reduce the level of the current ecological footprint.

This research is based on sample-based statistical data, from which individual differences cannot be identified due to the nature of the research.

The research relates to a single point in time, so comparisons over time, which would be the most meaningful application of ecological footprint calculations, are hence not possible.

The model calculation oversimplifies at some points (not considering the increased need for public transportation or vegan food if higher ecological footprint intensive patterns – such as carnivorous diet or individual driving of combustion-engine vehicles – are given up).

The limitations suggest that the results have to be interpreted with caution. However, the results still show, that a more detailed understanding of ecological footprint of different urban neighbourhoods and related lifestyles can enable both individuals and policy makers to find alternative opportunities on how to launch programmes to decrease local ecological footprints.

Conclusions and outlook

Central and Eastern European cities are undergoing concurrent processes of suburbanization and densification, characterized by ongoing urban sprawl alongside efforts to increase compactness, particularly evident in major capital cities. This trend is particularly pronounced in cities experiencing a transition from a period of shrinking in the 1990s to a recent phase of growth, known as reurbanization. In such cities, strategies are needed to address challenges related to vacant properties, brownfield sites, transportation infrastructure, and overall quality of life for new residents (Wolff, M. 2018). Suburbs face various social and environmental issues, including inadequate infrastructure, increasing social polarization, and growing commuting pressures, contributing to congestions, and impeding residents' daily lives (Buzási, A. and Jäger, B.S. 2020; Mobolaji, D. *et al.* 2022). Therefore, it is key to better understand and measure the environmental challenges related to these areas.

This study compares the ecological footprints of two very different residential areas: panel building housing estates and suburban neighbourhoods through the examples of

Budapest. Based on the literature, this study not only contributes to the ecological footprint-based comparison of the study areas (RQ1), but also provides a novel model calculation to address the improvement potential specific to the study areas (RQ2). The findings and the explicit answers to the research questions can be summarised as follows:

Panel housing estates exhibit a slightly lower per capita ecological footprint, attributed to building-related and spatial differences as well as assumably slightly lower per capita income compared to suburban areas, 2.29 gha/capita versus 2.63 gha/capita respectively. Beyond these factors, differences in food and transportation-related footprints were less pronounced (RQ1).

In addition to absolute footprint values, the study suggests a rough model calculation for estimating opportunities to decrease ecological footprint, as well. Findings show a 36 percent reduction potential for panel housing estates and 47 percent for suburban areas, meaning that suburbs may even achieve lower footprint values than panel housing estates (RQ2).

Although these figures have to be interpreted cautiously, the specific details presented in this study indicate that numerous individual initiatives and policy interventions can be suggested that align with both urban development and ecological objectives. As a new insight offered by this study, such measures to decrease ecological footprint may be structured and scaled along the major aspects influencing the ecological footprint of the study areas:

Related to the energy efficiency characteristics improvement of dwellings, suburbs offer a bigger and more flexible opportunity, as not only large-scale, policy driven refurbishment projects can be implemented, but smaller scale, individual, even do-it-yourself ones. However, newly built, or refurbished panel housing estates can provide comfort and high energy efficiency at the same time (Hess, D.B. *et al.* 2018), a major driver of conscious reurbanization.

Regarding the spatial aspects, different pathways can target the idealistic 'decentralised concentration' (Holden, E. 2004). Panel housing estates within the city perform already right well in this perspective, while the compact municipality approach as a future development stream could contribute to the reduction of ecological footprint in suburbs, as well.

The consumption patterns related to both study areas are important, also from an ecological footprint perspective. To avoid the rebound effect (Shinde, R. *et al.* 2022), environmental education and consciousness should be fostered, so that ecological and financial savings related to the previous aspects are not spent on further ecological footprint intensive goods and services.

Beyond these measures, the limitations of this study presented before also highlight new research directions:

As there are very few research and comparison of the ecological footprint of different residential areas available at this time, further studies are needed to go beyond the urban-rural comparison and assess and compare specific neighbourhoods.

Beyond input-output modelling-based studies, bottom-up ecological footprint assessment and comparisons would be very useful, considering local conditions even more specifically.

This study is based on a single point in time, but temporal comparisons, quantifying the possible differences over time of different residential areas would also add new insights to the better understanding of the ecological footprint aspects of territorial development.

To overcome the simplifications used in this model calculation on the ecological footprint reduction potential of different residential areas, more research is needed to specify and quantify the trade-offs related to specific measures (e.g., switching between transportation modes, diets, habits), also from an ecological footprint perspective.

Acknowledgement: The research was supported by the National Research, Development, and Innovation Fund of Hungary under Grant Nr. K-135546 and K-143542.

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