How Can a Household Reduce its Ecological Footprint? - An Example from Hungary

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Abstract: Literature extensively uses ecological footprint accounts to measure the natural resource use of human consumption patterns. Beyond national-level accounts, there is a wide range of literature on calculating ecological footprints at the sub-national, regional, or even micro level. However, there seems to be surprisingly little research on how different urban neighborhoods relate to each other in terms of their ecological footprint. The study employs a literature review and the results of an ecological footprint calculation based on the input-output methodology to investigate what households can do to reduce their ecological footprint in various urban neighborhoods. Furthermore, this study builds on the gap that earlier research has uncovered that different households in different neighborhoods consume in different ways, however, complex estimates of reduction opportunities have not been carried out. The results indicate that the choice of housing is the most important intervention point. This has an impact on available transport options, heating types, and food choices. The research results indicate significant potential for reducing the ecological footprint by promoting individual motivation (e.g., the use of public transport) and developing a policy support system (e.g., incentives for energy-efficient investments). Every household has the potential to reduce its ecological footprint, but the methods to achieve this may differ. The greatest impact is expected from modernizing heating, but using public transport and switching to a plant-based diet can also be effective. The research results indicate that the ecological footprint values of different dwelling types are similar, but the potential for reduction varies. It seems encouraging that sustainability appears to be an important issue for young people, but positive scenarios may be threatened by the fact that they feel less *inclined to make significant changes in their behavior that would reduce their ecological footprint.*

Keywords: ecological-footprint; household; urbanism; lifestyle

1 Introduction

Inner city and suburban transformation have been one of the most spectacular processes in post-socialist city development. Suburbanization and urban sprawl have determined the development process outside the city's administrative boundaries, in the agglomeration zone, and in the more remote areas of the urban region. Suburbanization is a common phenomenon, but urbanization also happens in peri-urban areas. Urban shrinkage accompanies decentralization [1], prompting the resurgence of the compact city concept in EU policy literature. When analyzing the trends of the last almost four decades, we can expect a reversal towards the compact city in the development of metropolitan regions, and we can view urban sprawl as an intermediate stage in long-term territorial development [2].

Due to rising land prices and service and infrastructure problems, instead of a further expansion of built-up suburban areas, one can expect the development of previously less developed areas, which increases the level of compactness. Therefore, the expected direction of development is not towards further expansion of these areas, but rather towards networking between increasingly compact, highly urbanized areas [3]. There is a connection between mobility and spatial development (Figure 1).

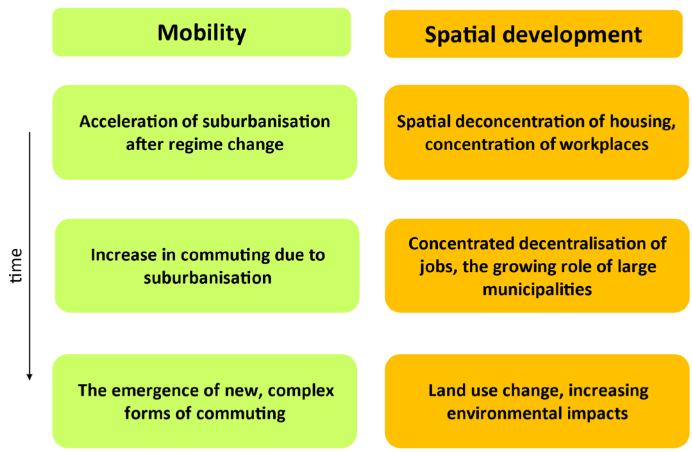

Figure 1

The interrelationship between mobility and the use of space in the Budapest city-region (source: own design)

In this respect, the environmental characteristics of residential areas within urban administrative areas and those in peri-urban or suburban areas of the city, as well as the environmental and economic benefits of population reallocation in the urban region, are particularly important issues. Finally, the question of what ecological, architectural, and lifestyle changes the resident population would need to enhance the sustainability of cities offers valuable insights. This research is unique in that it not only investigates the size of the ecological footprint associated with different habitats and lifestyles, but also identifies the potential for reduction.

Earlier research has shown that significantly different per capita ecological footprint is related to different population groups [4]. The ecological footprint measures the environmental impact of human activity [5]. Any human community, including a household, can use the ecological footprint to measure its ecological footprint, also at the spatial level [6], [7].

Table 1 summarizes the options for reducing the household ecological footprint. The table shows that energy modernization presents the largest opportunities, followed by transport improvements and dietary changes.

Table 1
Reduction options of household-level ecological footprint

Reduction options	Sources
Reduction in fossil fuel sources of the electric grid	[8]
Expansion of renewable energy	[9]
Reducing energy consumption	[10], [11]
Transformation of energy consumption structure, improving energy efficiency	[12]
Low-carbon technology innovation to reduce carbon intensity	[13]
Electric or hydrogen-powered public transportation	[14]
Promoting public transportation	[15]
Less meat consumption Lower per capita food wastage	[16] [17]

Urbanisation and sustainability are complex relationships influenced by many factors [18]. New studies extend beyond the classic urban-rural question and seek deeper causes [19]. Top-down comparisons at different study units are common [8]. The idea that different households consume in different ways [13] is emerging, but no one has yet estimated the reduction potential. The literature primarily links footprint calculations for new urbanization to Chinese consumer behavior and environmental policy, thereby highlighting a research gap. Studies on the household ecological footprint, while numerous, have not considered the unique characteristics of East-Central Europe.

The rest of the study includes the research design and methodology that enables to comparison of ecological footprint values for households with different backgrounds, presents and discusses the results. It also includes an in-depth analysis of factors driving individual motivations and barriers to decrease their ecological footprint, as well as a model scenario analysis as a foundation for future research in the field.

2 Methodology and Data

This study compared the ecological footprint of household consumption in Budapest with that of prefabricated housing and suburban residential lifestyles.

Two study areas were defined for the scope of the study:

- Prefabricated buildings within the city boundaries: these neighbourhoods comprise multi-story buildings with high population density, relatively small dwelling sizes, little or no green space, district heating, and space heating ('Budapest Panel'),
- The suburban neighbourhoods of Budapest's agglomeration are primarily villages and small towns, characterized by single-family houses, small gardens, varying dwelling sizes, and individual heating systems.

We used an environmentally extended input-output model (EEIO) to calculate the household ecological footprint. [20] and [21] first used the input-output model to calculate the ecological footprint. [22] Establish methodological guidelines that can be applied to a regional context. [6] Also, a calculation was applied using a similar methodology, utilizing statistical data from households for the Budapest Metropolitan Area.

The ecological footprint embedded in household consumption can be expressed by the following formula (Eq. 1.):

$$EF = EFdir \times (I - A)^{-1} \times FD \tag{1}$$

where

- EF represents the ecological footprint [23],
- EF_{dir} denotes the direct ecological footprint vector of specific sectors, expressed in gha per million HUF.
- The input-output model derived the Leontief-inverse matrix $(I\text{-}A)^{-1}$, which illustrates the interdependencies among sectors.
- FD stands for the household-related final demand vector, which indicates the extent of consumption across 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, specifically for Hungary in 2022, the latest dataset provided by

GFN. We calculated the household FD consumption vectors using the EU Statistics on Income and Living Conditions (EU-SILC) database, which we obtained from the Hungarian Central Statistical Office (HCSO). Data were available for 2022. We used data on Budapest households with district heating as a proxy for the first case area (Budapest panel building neighbourhoods), while we used households from the respective towns in the Hungarian SILC database for the agglomeration case area. The HCSO develops economy-level input-output tables for Hungary every five years, and we used the latest version, which represents 2020.

We used an input-output model and environmental data to calculate the household-related ecological footprint (associated with both goods and services).

The integration of EEIO (environmentally extended input-output) analysis enables the quantification of the ecological footprint associated with household consumption. This type of ecological footprint calculation is considered a top-down approach. [20] and [21] first used the input-output model to calculate the ecological footprint. The first application in Hungary was by Csutora et al. [24], who used it to determine the ecological footprint of household consumption. This study extended the application of this methodology to a regional context, adhering to the methodological guidelines set by [22].

Kovacs et al. [6] conducted research on the Budapest urban area, while Egedy et al. [25] focused on the ecological footprint of households. The latter study compared the ecological footprints of people living in housing estates and those living in detached houses in the Budapest metropolitan area. The current research focuses on the potential for reduction rather than the actual difference. A basic premise for positive change is that consumers, especially younger generations, are willing to adopt more sustainable consumption patterns. The research focused on whether young people can be expected to shift toward more positive consumption patterns. In other words, how much of the reduction potential can be exploited. In order to add further empirical aspects to the in-depth data analysis, we conducted a survey of a sample of 1,667 university students (88% of whom were born after 2000). In the research, we explored the question of how environmentally conscious they consider themselves to be and whether they are willing to change their consumption habits as a result.

The students surveyed answered questions about their consciousness, attitudes, and actual behaviour in relation to sustainability using an online questionnaire. They could give their answers on a 6-point Likert scale (with 1 = total disagreement and 6 = complete agreement). The survey was conducted in December 2024 at universities in Budapest.

This research has several limitations, including:

- Comparing two lifestyles (which are obviously artificial) reveals a multitude of diverse lifestyles coexisting side by side. The aim was to illustrate that different lifestyles have different ecological footprint reduction potentials.

- Due to the nature of the research, the research solely relies on secondary statistical data, making it impossible to identify individual differences.
- The research pertains to a single point in time, so comparisons over time, which would be the most meaningful application of ecological footprint calculations, are not applicable.

3 Results

The footprint calculation is based on the results of a study by Egedy et al. [25]. Earlier results indicate that panel housing estates have a somewhat reduced per capita ecological footprint compared to suburban regions, primarily due to their distinct architectural features, spatial dynamics, and potentially lower per capita income. The average ecological footprint was found to be 2.29 global hectares (gha) per capita in panel housing estates, in contrast to 2.63 gha per capita in the suburban sample area. Disparities in food and transportation-related footprints were less pronounced. Earlier results not only covered absolute footprint estimates but also presented estimates for future reduction options of the ecological footprint at the sample areas. The results indicated that panel housing estates may decrease their footprint by 36%, whilst suburban regions have a reduction potential of 47%. This suggests that, with certain interventions, suburban regions may achieve a smaller ecological footprint compared to panel housing developments.

While these estimations require careful interpretation, the comprehensive analysis in this study underscored several options for both individual and policy-oriented actions that correspond with urban development and ecological objectives. This study revealed that measures for mitigating ecological footprint can be achieved through addressing factors that influence the size of ecological footprint the most (such as energy efficiency, decentralised urban planning and conscious household consumption).

The results of their calculations show that there is only a 15% difference in the size of the ecological footprint by dwelling type (Table 2).

Table 2
Household related ecological footprint values along COICOP consumption categories (gha/person, 2022, own calculation)

	01	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**Total**
Budapest panel	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
Suburb	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
Budapest panel %	38	8	2	15	2	1	13	0	7	1%	10	2	100
Suburb %	28	6	2	30	3	1	10	0	3	1	10	2	100

COICOP categories cover: 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 (global hectares (gha) are the accounting unit for the ecological footprint and biocapacity accounts.)

Table 3 shows the details of the items in the first column of Table 2. Columns D and E illustrate the potential reduction in the ecological footprint that can be achieved by avoiding meat and dairy products.

The current study used literature data to estimate the reduction potential by dwelling type, revealing a significant difference in potential reduction (Figure 2, Figure 3). We calculated the maximum improvement if the consumer adopted a vegan diet, abstained from alcohol and tobacco, relied solely on renewable energy, and drove no cars at all.

Table 3
Household-related food consumption footprint according to main food (COICOP) categories (gha/person, 2022, own calculation based on GFN coefficients)

	A Panel buildings	B Suburbs	C=A-B Difference	D Reduced panel	E Reduced suburb
Bread and cereals	0.24	0.21	0.03	0.24	0.21
Meat	0.18	0.16	0.02	0	0
Fish	0.023	0.02	0.003	0	0
Milk, cheese, eggs	0.064	0.054	0.01	0	0
Oils/fats (plant)	0.1	0.089	0.011	0.1	0.089
Oils/fats (animal)	0.037	0.032	0.005	0.037	0.032
Fruit	0.078	0.066	0.012	0.078	0.066
Vegetables	0.077	0.066	0.011	0.077	0.066
Sugar, jam, honey, chocolate	0.039	0.033	0.006	0.039	0.033
Food (not elsewhere classified)	0.022	0.018	0.004	0.022	0.018
Total	**0.87**	**0.74**	0.13	0.593	0.514

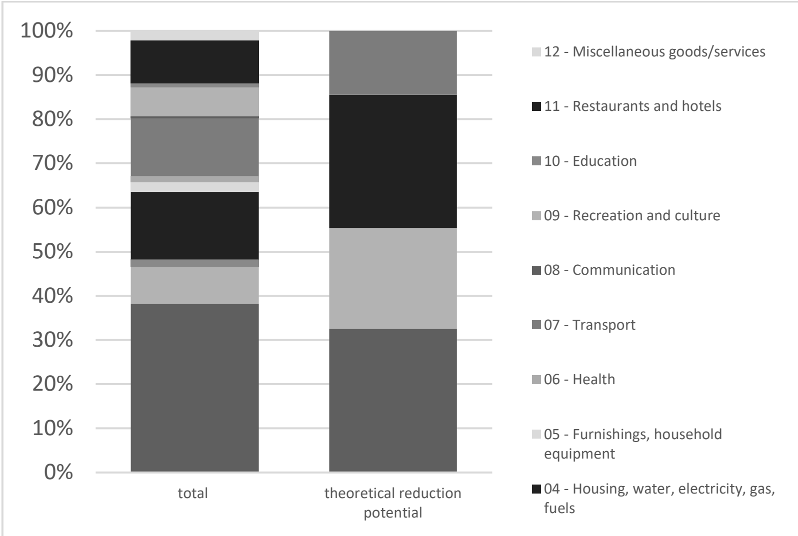

Figure 2

The structure of the ecological footprint and the footprint reduction potential in the Budapest Panel sample area

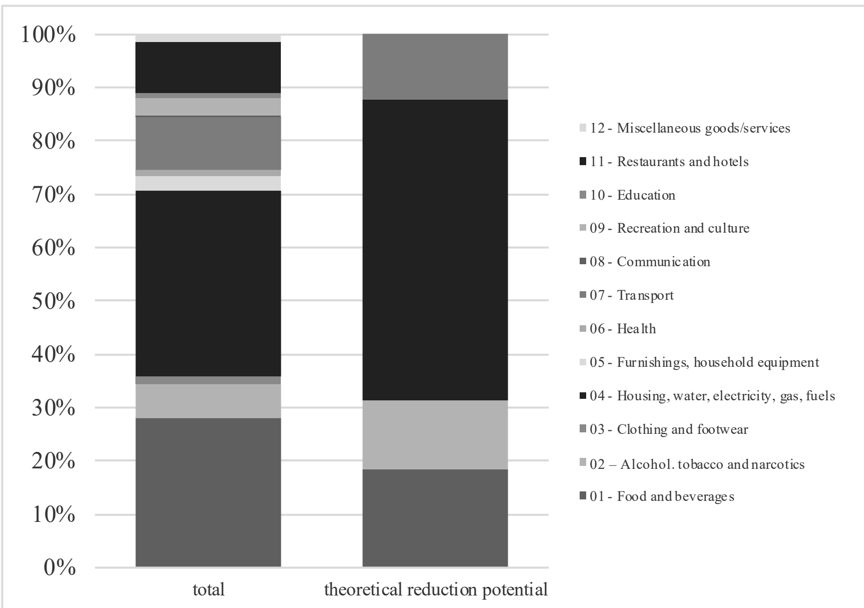

Figure 3

The structure of the ecological footprint and the footprint reduction potential in the Budapest Suburb sample area

The consumer survey provided interesting insights into the data analysis results. Adding up the number of responses of 6, 5, and 4 points, we see that 85% of respondents consider themselves rather environmentally conscious, 81% collect waste selectively, and 75% feel personally responsible for the waste problem. However, only 35% strive to avoid buying packaged products. Students consider themselves environmentally conscious, recognize their individual responsibility in reducing waste, and generally collect waste selectively. However, their commitment is significantly lower when it comes to shopping (which has a significant impact on their ecological footprint) (Figure 4).

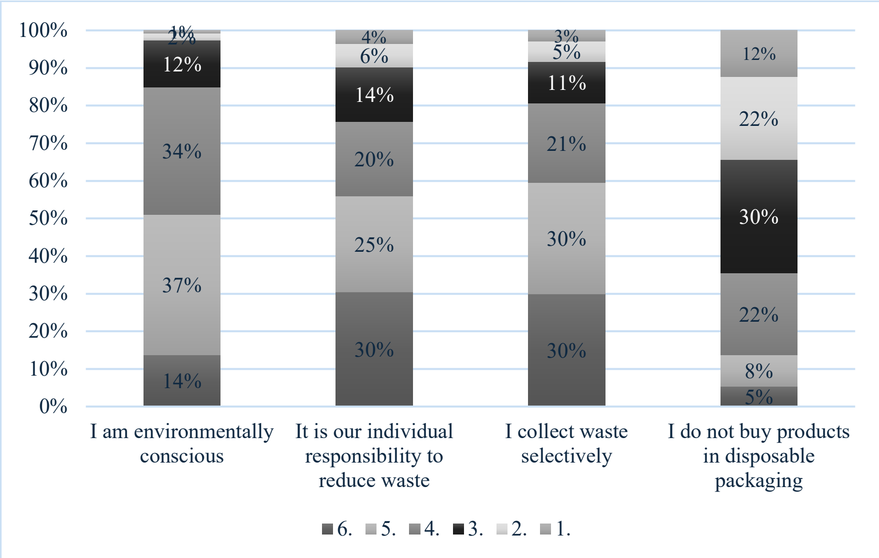

Figure 4

Environmental consciousness of respondents in the sample (n = 1667, (1 = totally disagree, 6= completely agree)

Discussion and Conclusions

Literature also confirms that in more developed areas, the difference between the footprint of urban and rural households is smaller than in less developed areas [26]. This underscores the need for further research to shift its focus from static disparities to opportunities for change. The geographical location of the dwelling and residential areas, its basic infrastructure, and the size and technical characteristics of the dwelling or house are key determinants of the size of the ecological footprint and the potential for reducing it. Other research has also identified improving urban eco-efficiency, achieving a comprehensive green transformation, and promoting regional sustainable development as key sustainability challenges [14]. According to NeÉS data [27], the worst performing buildings are detached houses built before 1980, which account for nearly half

(42%) of all residential properties. Thus, the greatest potential for specific energy savings exists for detached houses built before 1990, with primary energy use reductions of up to 60–70%. Large, non-prefabricated apartment buildings built before 1990 have medium savings potential. Prefabricated buildings have a moderate potential for savings, while all buildings constructed after 1990 have a minimal potential for savings. According to MEHI [28], the detached house, the most common building type, has the highest potential for energy savings. Additionally, family houses have the lowest renovation rates, making it essential to target them with the building renovation program [29]. Additionally, it is crucial to upgrade the energy efficiency of housing estates, a topic that has been extensively researched in the literature, primarily focusing on China. There is significant potential to reduce the ecological footprint of energy industry transformation [30] [31], followed by the adoption of vegan lifestyles [16], and the development of public transport [15].

Instead of single-family houses with gardens, it is more sustainable to have centrally located and easily accessible apartments with shared services, easy maintenance, smaller living units, and (for the elderly) single-story flats. In large housing estates, many dwellings meet these requirements [32]. Housing estates can also provide an opportunity for the site-specific application of certain components of the smart city or the sharing economy concepts. Thus, refurbished and well-maintained panel housing estates can offer a real alternative for a reurbanising population seeking an urban lifestyle. Although Budapest, the case-study city, has experienced massive suburbanization in recent decades, there have been numerous signs of reurbanization and rejuvenation in the inner city in recent years. Young households staying in or returning to the core city can also provide good opportunities for programs aimed at reducing the ecological footprint.

At this stage of the research, energy efficiency programs are a key issue for sustainability, and this is clearly the responsibility of both local and central governments, as well as the creation and maintenance of an accessible, well-functioning, and efficient public transportation system. Indeed, their responsibility extends to awareness-raising programs to encourage use. Mitigating energy poverty should be a crucial focus of these initiatives, ensuring that underprivileged households also derive advantages from energy-efficient advancements and sustainable urban development [33]. Figures 2 and 3 reveal a similar ecological footprint structure for Budapest Panel and Suburb areas, yet they offer fundamentally different reduction potential. In the suburban areas, energy efficiency measures and investments have a strong individual margin (COICOP 04), whereas in the Budapest Panel areas, multiple types of changes can yield significant gains.

The generation and management of waste, particularly municipal solid waste, serve as a profound reflection of societal consumption patterns and individual behavioral choices [34]. This is because the discarded materials, or waste, are the tangible outcomes of consumer decisions, encompassing everything from product selection and usage to disposal methods [35]. This direct link makes waste behavior an invaluable metric for understanding the underlying motivations and impacts of consumption, offering insights into both economic trends and environmental stewardship [36].

Although our research did not directly examine consumer or individual willingness to decrease consumption and thus ecological footprint, our analysis examined the openness of the younger generations concerned about sustainability-related issues like waste reduction, but are less open to more meaningful reduction in their consumption patterns. To better understand these patterns, academic literature provides evidence to further discuss individual motivations, willingness, and obstacles to reducing the ecological footprint. A better understanding of these drivers is crucial to bridging the gap between openness and actual behavioral change regarding ecological footprint reduction.

From a motivational perspective, pro-environmental behavior is strongly driven by values, norms, and perceived responsibility. Different frameworks, like the norm-activation theory and value–belief–norm approach show that individuals are more likely to reduce environmentally harmful consumption and thus ecological footprint, when personal norms are activated and responsibility is internalized [37, 38]. The findings that young respondents are concerned about waste issues, but avoid deeper consumption changes imply that motivation alone is not sufficient to achieve meaningful behavioral change. This is in line with studies finding that incremental actions, demanding little efforts from consumers (e.g. selective waste collection) are widely adopted and practiced. On the contrary, more radical changes in consumption patterns (but parallel, with higher impact, like changes in diet, reduction of mobility, considering low ecological footprint options related to housing choices) are considered with greater resistance [39, 40]. Beyond environmental considerations, other, non-cognitive factors (such as frugality) can also contribute to the reduction of ecological footprint [41].

Willingness to reduce ecological footprints is also mediated by perceived behavioral control and lifestyle lock-ins. Structural factors - such as housing type, transport, and energy infrastructure - strongly influence individual willingness to change consumption patterns, especially in the suburban context. This is in line with earlier findings that even highly motivated individuals have difficulties achieving a reduced ecological footprint lifestyle, if less supportive external conditions (like infrastructure) apply [42, 43]. In this sense, willingness should be interpreted not as a purely psychological condition, but in relation to spatial and socio-technical systems.

Key obstacles further include economic considerations, habits, and social norms. Energy-efficient renovations or dietary transitions may involve upfront costs or perceived social trade-offs, which disproportionately affect younger or lower-income households. Empirical studies show that rebound and substitution effects can partially (or even fully) decrease ecological footprint reductions, and thus confuse individual decision making and possibly discourage people from changing their habits [44, 45]. Furthermore, "carbon-intensive" social norms - such as meat consumption or car ownership - tend to normalize unsustainable behavior and high levels of ecological footprint.

Considering the results of the EEIO-based household ecological footprint analysis and additional academic literature, model scenario analysis can be conducted to estimate the impact of lifestyle changes. As our results indicated that - among different product categories - food consumption is responsible for the highest share of ecological footprint (around 38% in Budapest panel housing estates and 28% in the suburban areas), this field is further discussed in possible footprint reduction along different scenarios.

A partial dietary shift (flexitarian diet) scenario, with a reduction of red meat and dairy consumption by 30-50%, and replacement with plant-based foods, can already reduce the ecological footprint by approximately 5-10%. Empirical studies [40, 46] also indicate that a decrease in the ecological footprint can be achieved through modest dietary modifications, delivering significant environmental benefits relative to the behavioral effort required. However, as also mentioned before, rebound effect may emerge [44], if reduced meat consumption is compensated by consuming more fruits and vegetables imported from far countries or processed meat substitutes with high energy and transport footprints, that at least partially reduces the benefits of this scenario.

Literature confirms that a fully vegan diet has typically the lowest ecological footprint [47, 48]. In a complete vegan scenario (with the exclusion of meat consumption, and even fish and dairy products), the food-related ecological footprint can be reduced by around 30-35%, equivalent to a total household footprint reduction of about 12-15%, depending on dwelling type. Again, same with the previous scenario, this estimation is sensitive to the substitution of excluded food products (if these are replaced by exotic fruits, etc., benefits can be partially lost [49].

Based on the results and implications of this study, we can formulate new research directions. Responsibilities of different stakeholders should be better defined and related to, e.g., infrastructure, public support, corporate responsibility [36, 50], and individual awareness [51, 52]. We also need to address the provision of infrastructure (especially related to transportation and energy) in more details. A more detailed exploration of young people's motivations may also be necessary. Deeper scenario analysis for the consumption of the most influential product groups (beyond food, also mobility and household energy use) can add better understanding to the potential in ecological footprint reduction.

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