

Household time use, carbon footprints, and urban form: a review of the potential contributions of everyday living to the 1.5 °C climate target

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The 1.5 °C mitigation challenge for urban areas goes far beyond decarbonizing the cities' energy supply and needs to enable and incentivize carbon-free everyday living. Reviewing recent literature, we find that dense and mixed urban form enables lower direct emissions from mobility and housing, while income is the major driver of total household carbon footprints; importantly, these effects are not linear. The available urban infrastructure, services and societal arrangements, for example on work, all influence how households use their time, which goods and services they consume in everyday life and their subsequent carbon footprints and potential rebound effects. We conclude that changes in household consumption, time use and urban form are crucial for a 1.5 °C future. We further identify a range of issues for which a time use perspective could open up new avenues for research and policy.

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Introduction

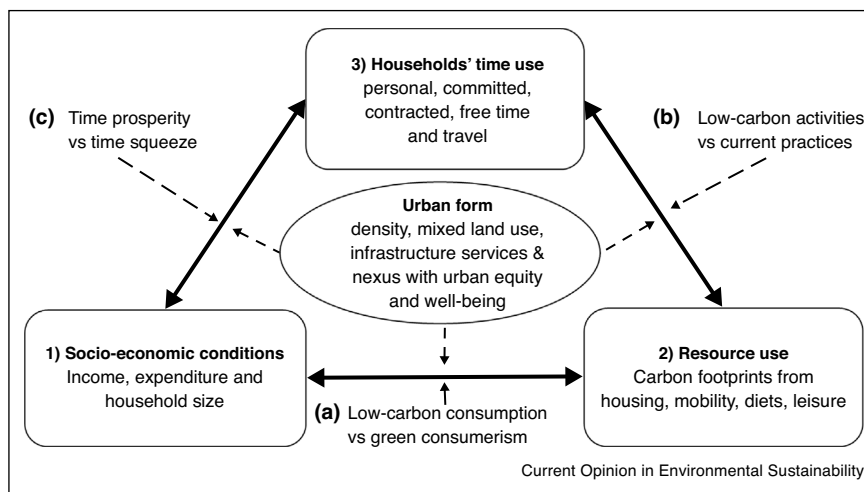
Limiting global warming to 1.5 °C over pre-industrial levels requires carbon-neutrality to be achieved between 2045 and 2060, making absolute reductions of emissions necessary much earlier [1^{*}]. More than half of global population currently lives in cities and suburban areas; this proportion will rise further cite special issue intro. Cities are embedded in global networks of production and consumption and their impacts go far beyond their administrative boundaries [2–4]. Methods to quantify carbon footprints (i.e. emissions occurring ‘indirectly’ in supply chains supporting local consumption) as well as direct emissions (e.g. from locally used fuels) are quickly improving, as are systematic monitoring approaches for cities [2–5].

From a consumption-based footprint perspective, globally more than 65% of carbon emissions from fossil fuels and cement production can be attributed to household consumption [6,7].⁶ Direct and indirect emissions from mobility, housing, diets and leisure are responsible for over 75% of total household footprints [6–8]. Urban form, density and transport costs are widely seen as key factors for less direct energy use and emissions from mobility and housing [9–11]. However, total footprints of urban households depend on the sum of habitual routines and practices in everyday living [12–15,16^{*},17]. Deep decarbonization therefore requires not only major changes in energy supply [1^{*}], but also transformations of urban form, household consumption and social practices in everyday life [18^{**},19^{**},20–22].

One critical, but so far under-researched, perspective on deep decarbonization is the relationships between socio-economic conditions of households, time uses, and carbon footprints [15,16^{*},17,22,23^{**},24] (Figure 1). Arrangements on working hours and income strongly structure everyday living; most other activities are also organized around them. Income and available time also influence which goods and services are required to conduct everyday life. The objective and perceived pressures on individuals to accommodate multiple responsibilities for their families,

⁶ The categories capital formation, which includes investments and infrastructure construction, amounts to 24%, while government consumption induces 7% of the global carbon footprint [6]. The remainder of the non-household emissions is related to nonprofit institutions (1%) and inventory changes 3% [6]. Government and investments indirectly support households as well, although in the literature they are reported separately. Additionally, non-fossil-fuel GHG emissions from agriculture, forestry and other land uses are so far not systematically included into footprint studies [7,8].

Figure 1



Conceptual framework of the relations between socio-economic conditions, households' time use, and carbon footprints used in this review. The broad options to intervene into these relationships are also shown (a–c).
Source: Adapted from [36,37].

their work, their social life and themselves (in more popular terms: their work-life balance) has been described as a time squeeze; in contrast, time prosperity is the perceived adequacy of time availability and responsibilities. These pressures and trade-offs for individual time use in turn shape patterns of consumption and prospects for adopting 'pro-environmental' practices [25–28].

A time use approach offers opportunities to investigate the carbon implications of everyday life and to examine the role of time squeezes versus prosperity on household footprints [16^{*},17,23^{**}] (Figure 1). Organizing everyday life by consuming goods and services perceived as quicker may follow from attempts to save time, for example, taking an airplane instead of a train, buying your own tools versus sharing them in the community, or using one's car versus cycling and walking. By contrast, time prosperity could reduce the need for faster, high-carbon options, reduce the pressure to work in order to earn more income and open up time for activities contributing to human well-being, the family and the community [20,26,29^{**}]. Yet, these strategies need to be assessed in respect to the role of cities as accelerated hubs of social and economic activity [20,30–32].

We organize this review around the role of urban form in structuring the relation between household consumption, time use and carbon footprints (Figure 1). We present a concise review of recent literature; rather than aiming for a comprehensive overview, we focus on recent work from 2014 to 2017, to identify robust insights and new research avenues. Urban form is usually operationalized as population density [9,33], however spatial planning for mixed

land use, availability of infrastructure services, and the nexus with urban equity and well-being are similarly important [34]. For example, the literature on socio-economic conditions of households and their carbon footprints, as situated within specific urban forms, provides a number of robust findings ('Does urban form affect household carbon footprints?' section). Also, the growing research area investigating the carbon footprints of households' time use is yielding some interesting preliminary insights ('A time use perspective on household footprints: the carbon implications of everyday life' section). Decarbonizing consumption is too often discussed either as asceticism or green consumerism (a, Figure 1) [14,19^{**},35^{**}]. However, time prosperity and work-life balance (c, Figure 1), as well as spending more time on low-carbon activities (b, Figure 1), should also be a part of deep decarbonization and improved human well-being [16^{*},20,26,29^{**}]. We conclude on key points emerging from these strands of literature for urban decarbonization.

Does urban form affect household carbon footprints?

A steadily growing body of literature mostly from medium-income and high-income countries, provides insights into the footprints of urban, suburban and rural households [8,17,24,38,39^{*},40,41^{**},42,43^{*},44–49]. Firstly, income is a major predictor of total household footprints, hence income inequality has a substantial impact on their distribution [8,40,43^{*},44,45,50^{*}]. In 2010, the top 10% affluent households induced 34% of global carbon emissions, while the lower half of the global income distribution, 50% of global population, only induced 15% of emissions [50^{*}]. In 2012, the top 10% urban income group

in China induced 30% of the national and 41% of the urban household carbon footprint [43^{*}]. Due to growing agglomerations of population and affluence in urban areas around the world, the majority of carbon footprints are increasingly concentrated in cities and affluent suburbs [51^{*}]. Importantly, while eradicating extreme poverty seems to be a very small contributor to carbon emissions, the emergence of a global consumerist middle class is most probably not compatible with 1.5 or 2 °C climate policy targets [1^{*},50^{*},52^{*}].

Secondly, household size is consistently identified as a key factor in reducing per-capita carbon footprints, when income differences are controlled for [8,38,40,47,49,53]. This is due to 'household economies of scale', for example, sharing appliances and heated/cooled living spaces within the household [40,47,53].

Thirdly, education, gender and age usually have small and mixed effects, when controlling for income and depending on the country and socioeconomic group studied [8,40,48,54,55]. Interestingly, studies for Sweden [54], the Netherlands [56] and Canada [57] investigated socioeconomic, physical and psychological factors all emphasize the overriding relevance of income and physical factors. An updated cross-country analysis of the predictors of household footprints [55], constitutes an important research gap.

Finally, for the specific footprints of mobility, housing, diets and leisure the major socio-economic and physical predictors can differ, depending on the socioeconomic conditions and (sub)urban location of households [38,40,41^{**},47,48]. This indicates that interventions targeting specific everyday consumption will affect households differently.

Urban form and population density are globally seen as key factors enabling lower direct energy use and emissions from everyday mobility and housing [9–11,33]. This effect has been described as 'urban economies of scale' [47], which include higher potentials for collaborative consumption and for more efficient uses of infrastructure — for example, shorter distances travelled, higher shares of public transit, cycling and walking. For example, apartment buildings in cities offer comparative low-carbon advantages due to less living space per capita requiring heating/cooling, additionally they often have better thermal insulation than single family houses [9,10,39^{*},46,58,59]. Interestingly, in the UK the relationship between density, income and direct mobility emissions is non-linear; above a threshold of ~50 persons/ha higher density results in strong decreases of emissions per capita, while at lower densities, income remains as main predictor [58]. The density which cities should have in order for these effects to occur is part of an ongoing investigation; country-specific, climate-specific and city

specific characteristics as well as aspects of urban form beyond population density affect these interrelations [9,10,33,38,39^{*},46,47,49,58,59].

Importantly, recent research emphasizes that income and differences in everyday living must be situated in specific urban forms in order to understand overall carbon footprints [17,24,33,38,39^{*},40,41^{**},47–49,53,54,60^{**}]. For example, in Finland renovated energy-efficient dwellings in dense urban areas tend to be inhabited by relatively more affluent households, usually resulting in larger overall carbon footprints than for those living in less efficient and less central dwellings [60^{**}]. Affluent German, Finish and British households in dense urban areas also tend towards consuming more airplane trips for leisure, which can partially negate the reductions from a car-free everyday life [41^{**},61,62]. In many cities specific attractive suburbs are inhabited by high-income households, resulting in large mobility and housing footprints and substantial overall carbon footprints [24,39^{*},41^{**},46,49,51^{*},60^{**}]. Therefore, the composition of footprints and potentials for absolute reductions will vary along differences in urban form and everyday life, making it necessary to investigate these relationships within and across cities more closely and to develop targeted interventions.

In summary, these findings clearly complicate the established view of dense urban form being more sustainable than low-density suburban or rural areas. Although household and urban economies of scale potentially lower direct energy use and emissions, opposing effects from income, consumption and suburbanization drive up total carbon footprints.

A time use perspective on household footprints: the carbon implications of everyday life

Linking socioeconomic conditions and carbon footprints to the time use by households (Figure 1), broadens the scope beyond the scale and patterns of consumption, by focusing on the activities during which goods and services are consumed (b, Figure 1). Functional time-use analysis takes a systemic approach to individuals as part of households, families, society and the economy [63]. (Re)producing the person, household, community and the economy requires time and guides daily routines that influence when incomes are earned and which goods and services are used [16^{*},23^{**},36,63]. Table 1 shows an operationalization of time-use categories and examples for the respective activities, consumption categories and their energy uses and emissions, as well as relationships to aspects of urban form.

Systematically linking household time use with the carbon footprint has only recently been achieved for the UK, similar efforts for energy have been conducted for

Table 1

Functional time-use analysis systematically summarizes specific activities from time-use surveys and relates them to the carbon footprints from goods and services consumed.

Time-use category (TUC)	Relation of TUC to	Activities from time-use surveys allocated to TUC	Examples of energy use and carbon footprints related to TUC	Aspects of urban form influencing TUC and carbon footprints
Personal time	Person	Personal care & sleep	Residential energy use for heating and cooling, use of (hot) water for hygiene	Form, age and density of buildings: dwelling space/cap, thermal quality, heating/cooling systems, for example, district heating
Committed time	Household	Household chores, food preparation, family care	Food preparation, household appliances, heating/cooling, repairs, furniture, dwelling maintenance	Mixed land-use: short distances to urban infrastructure, that is, shops, administrative, educational and caring facilities
Contracted time	Economy	Employment & study	<i>Not applicable, see caption of Figure 2</i>	<i>Mixed land use: availability of workplaces; changes in working arrangements, that is, teleworking, shared workspace</i>
Free time	Community	Social and community activities, recreation, culture	Entertainment activities, TV, pets, sports, socializing, shopping	Mixed land use: public green areas, recreational public amenities, public space
Mobility time enables other activities and is allocated specifically to them, based on time-use survey information. For example, commuting is part of contracted time, driving to an elderly family member is part of committed care, while leisure travel is free time.			Direct emissions from mobility, embodied emissions in transport equipment	Access to urban services: quality and quantity of roads, public urban transport and means of intercity mobility (trains, planes, buses, motorways, so on); availability and costs of urban parking spaces; conditions for non-motorized transport: bike-ability and walkability

Source: Adapted from [16*,23**,36,63,64].

Finland and France [16*,17,23**,65]. Time use surveys discern primary and secondary activities happening in parallel, such as listening to the radio while commuting. Carbon footprints are estimated using input–output analysis and data on household expenditure for the entire year, which is then allocated to respective time use categories. Important limitations are that long-lived durable goods bought in the years before, as well as second-hand purchases do not ‘carry’ their footprints into the year of analysis. Additionally, discerning the emissions implications of working practices such as teleworking and home offices versus ‘other’ time spent at home is another challenge. Achieving a comprehensive allocation, which is free of double counting for carbon footprints and all time uses in a day, is therefore subject to further methodological developments.

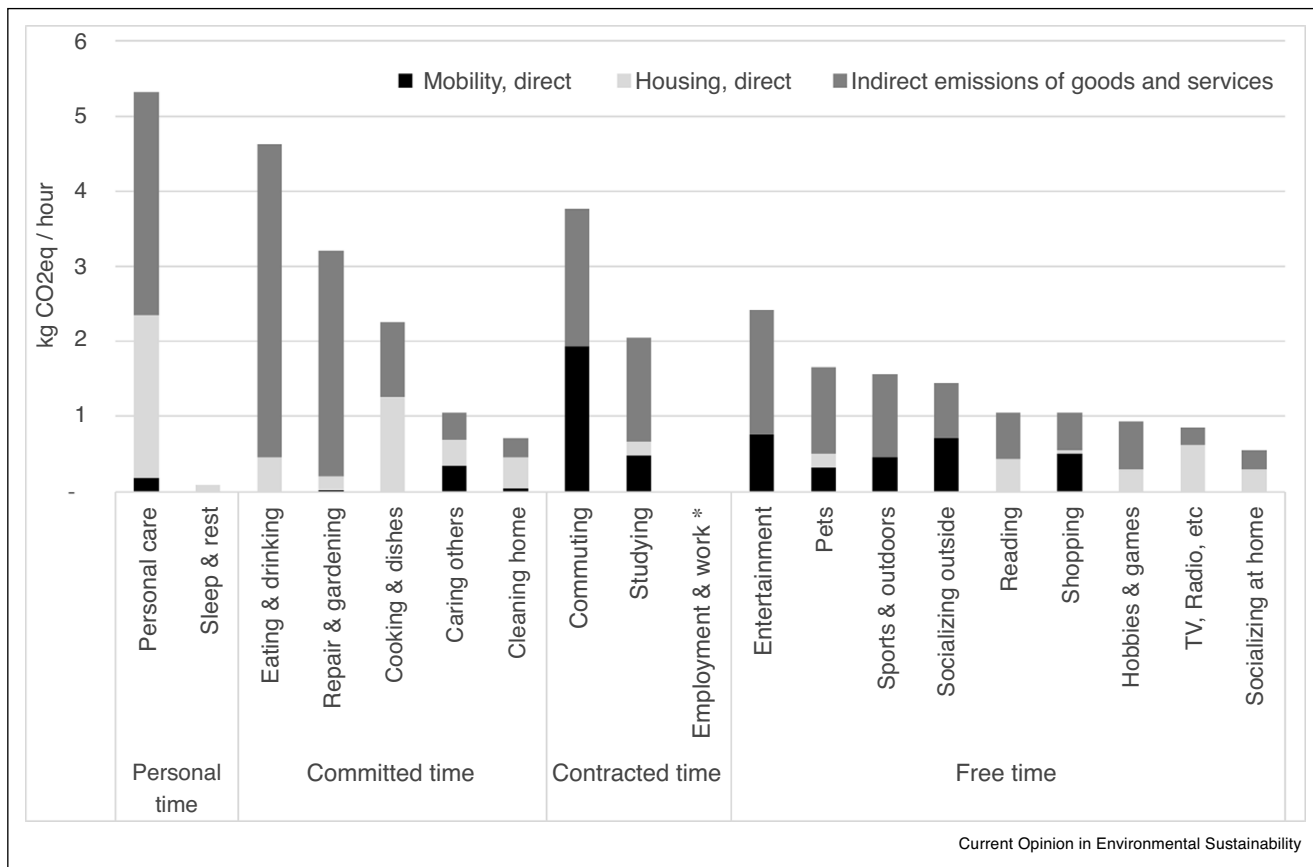
Figure 2 shows carbon footprints per hour of activities for an average British adult in 2005, along the broad time-use categories introduced above. The highest emissions intensities per hour result from personal care, eating & drinking, commuting and repairs & gardening. The lowest emissions intensities per hour were found in home-based activities including sleep and resting, socializing at home and cleaning the home. Caring for others, reading, shopping, hobbies & games and watching TV all have similarly low carbon footprints per hour. Although direct

emissions from mobility and housing contribute significantly to the emissions intensities per hour, indirect emissions due to goods and services bought and used during these activities determine the majority of the emissions intensities (Figure 2).

Personal time includes sleep, rest and personal care. Its emissions intensity depends mainly on household size (sharing of appliances and heated/cooled living space), and consumed goods (e.g. body care, cosmetics) and services (e.g. bathing vs. showering) [16*,23**]. Daily routines form between social norms, provisioning systems (e.g. specific heating system & its energy supply, timing of services, temperature) and material arrangements (e.g. bathtubs vs. showers) [66–68]. Only scant evidence exists on the impacts of urban form on personal time. Counter to the thesis of urban busy life [31,32], people in Finland, on average, seem to sleep more in dense urban high-rise environments [24].

Committed time includes provisioning for the household and caring for family and friends. The carbon footprint strongly depends on the goods and services consumed, for example, on diets [69,70], products used in repairs and gardening, and activities requiring hot water and heated/cooled rooms (Figure 2) [16*,23**]. Mobility is an issue when caring for others in different locations. The range of

Figure 2



The carbon footprint of activities of an average British adult in 2005, along the time use categories from Table 1. Results and labels were adapted from Druckman et al. [23^{**}]. Please note that from a consumption-based perspective, hours spent in employment and paid work do not have a footprint because this is when incomes are earned which enable consumption of goods and services during all other activities. All workplace emissions are included in the supply chain of goods and services consumed.

appliances and therefore energy substituting for human time (e.g. dish-washers and clothes washers) has increased substantially over the last decades, in parallel with an increase of female labor market participation [71]. With available income, some committed activities are substituted by contracted services, for example, daycare centers, cleaning or eating out, which shifts energy use and emissions from households into the service sector. Urban form affects the availability and use of such services [24]. On the other hand, dense urban living enables lower energy intensities of domestic activities [65], due to potentials for collaborative consumption unlocking household and urban economies of scale [47,53].

Contracted time in employment, self-employment and study strongly structures everyday life, through societal arrangements, laws and urban form, for example, regulations on working hours, employers' expectations, opening hours of educational institutions and resulting mobility requirements. These responsibilities and their time and mobility demands can lead to perceived time squeeze

[25,26]; the reduction of working hours for example is widely discussed as an approach to reducing environmental pressures and improve well-being [20,26,28,72^{*},73].

Free time has been the focus of much research on sustainable lifestyles, especially from income and leisure perspectives. These activities are where personal preferences manifest more easily and gender differences in the carbon implications become visible [23^{**}]. Free time activities often have relatively lower carbon intensity (Figure 2). However quite some time is spent on them and mobility, therefore urban form is an important factor in the resulting footprints [16^{*},23^{**}] (Figure 2). Density and particularly the ownership of a car both contribute to spending relatively more hours away from home [24]. Also, long-distance leisure travel, usually by plane, is more common among affluent urbanites [41^{**},61].

In summary, time use analysis highlights some of the functional constraints in everyday life and the role of urban infrastructure and services in enabling specific

practices. To identify more or less carbon intensive practices requires further developing these methodological approaches and critically investigating differences between socioeconomic groups. So far, national time use surveys provide a largely untapped resource for understanding carbon footprints. More fine-grained analysis can for example elucidate the role of different forms of contracted time on time squeeze and other time use categories. Time use data is also in a key position to track informal sharing and collaborative consumption, which remains partially invisible in household expenditure surveys, but constitutes an important contribution to climate change mitigation [47,53,74]. Increasingly also new data such as smart electricity meters and GPS tracking of mobile devices complement traditional diary-based survey methods [67]. The inclusion of such data and existing questions of location of activities means of transport, and with whom the activity is performed call for further development of surveys and international harmonization.

Absolute reductions of urban household carbon footprints: insights and research needs

Much policy and research have focused on individual attitudes, behavior and choices [12,19^{••},75,76^{*}] and the subsequent gap between attitudes, knowledge and behavior [19^{••},75]. Clearly, attitudes and knowledge can be important for specific behavioral changes [56] and for political support for climate policy [19^{••},77]. However, an excessive focus on individual choices [19^{••},35^{••},75,78] and incremental product efficiency improvements has been criticized as consumer scapegoatism [14], given the limited agency of consumers in inducing fundamental changes in the current consumerist system [14,20,35^{••},75,78]. Research on the role of individual and household values towards adopting less consumerist behavior demonstrate that situational and contextual factors have a strong impact on attitudes and values [21,54,56,57,77]. The presence of, or access to, low-carbon infrastructure and services predetermines the ability for individuals to actualize 'pro-environmental' values through behavioral patterns [14,77,79]. Especially in an urban context, where provision systems, (mobility) infrastructure, housing costs and obligations due to contracted time are heavily predetermined, a critical approach beyond consumer scapegoatism is warranted.

In response to such concerns, research efforts increasingly address social practice as ongoing and repeated resource consuming patterns of humans in everyday life [19^{••},22,68]. Within such an activity-based view on consumption, the coordinating and conditioning pivotal role of (energy) infrastructures becomes visible [15,80]. Indoor [81] and comfort arrangements [66,82] have been addressed in this regard. Yet, debates concerning urban form, density and the carbon footprints of increasing wealth and consumption require integrative perspectives

that cut across detailed observations of the changes in the physical settings and specific practices, towards systematically including the role of infrastructures and alternative overlapping systems of provision [12,15,35^{••},83], and addressing institutional changes and power [35^{••},78,84].

Importantly, income remains as the major driver of overall carbon footprints. Reducing contracted working time to overcome work and consumption cycles is widely and sometimes controversially discussed [26,85]. So far, three potential consequences of reducing contracted working hours have been identified [72^{*},86^{*},87]:

- (I) Less work in combination with proportionally less but still adequate income can reduce carbon footprints due to reduced expenditure and shifts in consumption patterns [72^{*},86^{*},88].
- (II) More time could be spent in activities more favorable to well-being, the community and family [26,28,86^{*},87], potentially easing the time squeeze and enabling community development and more inclusive cities [26–28,86^{*}].
- (III) Total available contracted working time could be shared among more people, potentially reducing unemployment; however this aspect depends on many other factors as well [20,72^{*},73,86^{*}].

Controversy surrounds the validity of these statements across very different working practices (standard working hours, single or dual earner models, teleworking, shared workspaces); impacts across socioeconomic groups, especially on lower-income households; the emissions implications of alternative time uses; and the overall socio-political acceptability within a growth-based consumerist system [20,26,35^{••},72^{*},86^{*},87,88]. Key conditions include an adequate minimum wage or even a basic income, short commuting distances, the availability of workplaces and access to education and training [72^{*},73,87]. These issues link to broader debates about the possibilities for deep decarbonization within a growth-based economy [21,35^{••}], which are, among others, led under the umbrellas of socio-ecological transformation [84,89], degrowth [84,90,91] and prosperity without growth [20,26].

Reduced contracted time also opens up opportunities for other activities. In Germany, reduced working hours were spent on leisure, but more importantly on voluntary work and care activities, intensified social contacts and social engagement in the community [86^{*}]. In Australia more discretionary free time is positively related to the adoption of low-carbon activities, even when controlling for income [27]. In the UK, lower objective time squeeze did not seem to affect 'pro-environmental' behavior, however higher subjective work-life imbalance could have a negative effect on more time-demanding 'pro-environmental' activities [28].

However, interventions towards low-carbon activities and consumption need to anticipate so-called rebound effects, which are unintended consequences of improved efficiency due to changes in time-use and consumption. A recent review found, that these rebounds potentially cancel out on average 20–40% of the envisioned savings in emissions [92*]. Direct rebounds result from increased consumption of goods or services whose price or time-needs have fallen. A commonly cited example is that the emission reductions due to the use of more efficient cars, which require less fuel and therefore cause lower costs, may be partially compensated by increased driving [62,92*,93,95]. Much more important however are indirect rebounds, where savings of time and money are used on other goods, services and activities [62,92*,93–95]. For example, it has been shown that Finish and German households in dense urban areas with little car use in their everyday lives, tend to have more leisure travel by plane, negating some of the carbon reductions of the former and shifting the burdens from direct emissions in the city towards the international airspace [61,62]. Additionally, rebounds can also solely occur due to changes in time uses, for example when reduced contracted time allows for more leisure trips by car or plane [73]. However, in a German study this effect was rather small, when controlling for income [86*]. Depending on the socioeconomic group, country, as well as activities and consumption area studied, rebounds can be substantially smaller or larger [62,92*,93–95]. One important but underutilized aspect of the rebound debate is that efficiency gains also enable improved access to infrastructure services, potentially contributing to urban equity and well-being, depending on who is ‘consuming’ the rebound.

Discussion and conclusions

Cities are well poised to influence household time use patterns and enable experimentation with new forms of low-carbon activities in everyday living [12,15,68,83] as an important contribution to deep decarbonization pathways [1*,18**,19**,20]. Thriving urbanization consolidates growing human populations and offers opportunities towards environmentally efficient urban forms and social arrangements. Dense urban areas with mixed land use and appropriate infrastructure enable low-carbon or even carbon-free mobility. Attractive public transport services, higher costs of private car use and parking, shorter distances between work, living spaces and urban services are crucial. Additionally, inclusive places where people can recreate without pressure to consume, public green areas as well as sports and leisure amenities reachable in short time also enable low-carbon everyday living [16*,23**,96]. At similar incomes, urban residents usually have smaller homes and more efficient residential energy use than single-family houses in the suburbs; close proximity of people also enables more sharing and collaborative consumption in the community [22,47,53,74]. These effects

have been denoted as household-level and urban-level economies of scale [47]. For affluent households, attractive conditions for reductions in income and contracted time can provide a useful approach to reducing footprints and potential rebounds. One potential synergy could be shifts towards low-cost and low-carbon, but time-intensive mobility practices, including alternatives to private motorized mobility and airplane trips. These interventions potentially also contribute to urban equity, well-being and a general shift in time use towards less resource-intensive practices.

Yet low-carbon urban living is not without difficulties. Cities tend to bring a faster paced life, more wealth creation, and innovation [30–32]. Ongoing trends towards smaller households, larger living space per capita and suburbanization seem to counteract potential emissions reductions from urban and household economies of scale [41**,46,47,51*,53]. When energy efficient dwellings in central locations which are well served by public transport are only available to high-income households, the same households will have larger overall carbon footprints, despite their energy-efficient living and mobility arrangements [60**]. Furthermore, status oriented conspicuous consumption [19**,22], for example in the form of long-distance leisure flying [61], contributes to the concentration of carbon footprints with upper income households [43*,50*] in affluent cities and suburbs [46,51*,60**]. Inequality therefore directly affects carbon footprints and options for change [97]. Because everyday life is situated in the prevalent urban form, targeted and place-specific interventions towards absolute reductions are therefore required.

Finally, while changes in time use and consumption for mobility and housing have immediate impacts on territorial urban carbon emissions, much of the emissions and therefore potential mitigation occurs indirectly in global supply chains [2,3,6,76*]. Such shifts in emissions can also be expected due to direct and indirect rebound effects occurring because of cost-saving and time-saving efficiency gains, which should be anticipated for any intervention [86*,92*,93–95].

From our assessment of the literature, the following steps therefore seem vital to leverage urban decarbonization potentials in everyday life. Firstly, comprehensive city-level territorial, consumption and activity-based emissions monitoring is necessary to accurately target interventions and minimize simply shifting the burdens along supply chains, while at the same time making emissions reductions observable and attributable. Secondly, policy interventions need to go beyond consumer scapegoatism [14] and recognize limitations of individual and household agency, as against the structurally and contextually predetermined influences to patterns of time use and consumption. This could include promoting flexibility

in patterns of work, removing obstacles for less consumerist everyday lives in urban areas and planning for urban forms allowing for diverse carbon-free leisure and community activities. Finally, deep decarbonization towards a 1.5 °C climate target probably also requires broader innovative approaches to social change, such as time prosperity, sufficiency and collaborative consumption.

Conflict of interest statement

The authors declare no conflicts of interest.

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- of special interest
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