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Activity spaces and leisure travel emissions: A case study in Reykjavík, Iceland

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ABSTRACT

Concerned by the increasing environmental impact of urban areas and the mobility sector, the study examines mobility in Reykjavík, Iceland. Reykjavík residents have been found to have high emissions in both local and leisure travel. The study aims to explore the connections between urban mobility and leisure travel behaviour using a novel method – activity spaces. The relationship between activity spaces and travel emissions is examined for the first time, based on data of about 700 respondents from a softGIS survey. Connections between activity spaces, local and domestic travel were found. High levels of urban mobility were connected to higher engagement in domestic leisure travel, indicating the presence of a highly mobile lifestyle among Reykjavík urbanites. The reasons for the travel could stem from compensation behaviour, or social network dispersion. In addition, the study points at a lack of functioning 15-minute neighbourhoods and public transit in the capital area. Some differences between income groups were noticed, particularly in urban mobility, pointing at the need to examine the social floor of mobility even within generally affluent societies, so that disadvantaged groups do not get left behind in the sustainable mobility transition. As it has been suggested that people travel for their well-being and to escape the tumult of urban life, the relationship between urban mobility, especially environmental exposure during daily travel, and well-being should be studied. Therefore, the study urges for sustainable mobility transitions and urban planning policies that consider the needs and well-being of citizens in all socio-demographic groups.

1. Introduction

Climate change has become an existential threat to our living environment, vastly due to anthropogenic impact on global systems (IPCC, 2021; Steffen et al., 2015). To limit global warming to 1.5 degrees Celsius, global CO2 emissions need to decrease by 48 % from 53 GtCO2eq by 2030. Therefore, urgent action is needed across all sectors (Mukherji et al., 2023; UN-Habitat, 2022). With urban populations continuing to grow, cities are crucial to climate change mitigation efforts (Bai et al., 2018; Hertwich and Peters, 2009; Yan et al., 2016; UN-Habitat, 2022; Mukherji et al., 2023).

Cities are hubs of mobility. Almost half of all transport related emissions come from the passenger transport sector, which is largely attributed to private driving and air travel (Ritchie and Roser, 2020; Ottelin et al., 2014). Studies on 1.5-degree compatible lifestyles have indicated that affluent countries, such as the Nordics, are emitting multiple times more in travel than the recommended levels. Personal transport footprints (footprints from travelling locally or for leisure either with one's own vehicle or shared/public transport) should be reduced from 3.7 tCO2eq to 0.96 tCO2eq by 2030 to meet the 1.5-degree warming limit in the Nordic region (Akenji et al., 2021). The sector has complex technical and social challenges, as the emissions are dependent on many aspects, including urban form, infrastructure for transport and behaviour of urban residents (IPCC, 2021).

A common urban planning strategy to reduce emissions has been densification, with the aim of reducing car use and daily travel distances, as well as living space and infrastructure per capita (Ewing and Cervero, 2010; Glaeser and Kahn, 2010). Densification also reduces the

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amount of open land used for the built environment (UN-Habitat, 2022). Compact cities and densely built neighbourhoods have been associated with lower rates of car ownership and use than other kinds of settlements, and hence lower emissions from local mobility (Sims et al., 2014). According to Ivanova et al. (2020), car-free lifestyles have a climate mitigation potential of up to 3.6 tCO2eq per capita (average level 2.0 tCO2eq), whereas reduced living space (including co-housing) can reduce up to 1.0 tCO2eq per capita (average level 0.3 tCO2eq).

However, although people living in central densely built urban areas might be less likely to own a car (Heinonen et al., 2021), they partake in more long-distance leisure travel compared to residents of other areas, counteracting the emissions reduced from daily travel (Reichert et al., 2016; Czepkiewicz et al., 2018a, 2019; Ottelin et al., 2014, 2017; Holden and Linnerud, 2011; Holden and Norland, 2005). The pattern is partially explained by residential sorting wherein people who happen to live in central areas also happen to travel more or have certain mode preferences guided by the environment they already live in (Næss, 2014).

Raudsepp et al. (2021) found that people are influenced by both their immediate and broader urban environments, reflecting in how they travel both within and outside of the city. Urban form related factors, such as lack of quality green or open spaces for leisure activities, might be drivers of long-distance leisure travel (Raudsepp et al., 2021). Increasing urban green and blue infrastructure could therefore be a viable method aimed at reducing travel related greenhouse gas (GHG) emissions. A useful method to examine the influence of the immediate and broader urban environment is through activity spaces (Järv et al., 2014), a method which has previously been employed in urban planning and geographical studies. AS is a method used to understand human-environment interactions in space and time, consisting of one's frequently visited locations and the area around them (Golledge and Stimson, 1997; Schönfelder and Axhausen, 2004).

The aim of the study is twofold. Firstly, the study aims to examine the connection between activity spaces and urban form at the 15-minute-neighbourhood level. Secondly, the study builds upon previous literature and explores the connection between activity spaces and GHG emissions from local travel, and from leisure travel, which is divided into domestic and international components, using softGIS survey data. The study focuses on young adults living in Reykjavík, Iceland. Icelandic urbanites have been found to be highly mobile, resulting in high average emissions due to the high rates of deeply rooted car-ownership and car-use for daily travel (Heinonen et al., 2021) and frequent long-haul flights (Czepkiewicz et al., 2019). As previous studies have indicated that the urban environment might drive some of leisure travel behaviour (Czepkiewicz et al., 2019; Raudsepp et al., 2021), this study will employ activity spaces as a novel method in studying how the broader urban environment could be connected to leisure travel and to mobility-related GHGs. The connection between activity spaces and leisure travel, both domestic and international, and their associated GHGs, has yet to be examined. This study aims to fill that gap by investigating the first such connection in a case study about Reykjavík, Iceland. The paper will first provide an overview of some common theories explaining leisure travel in connection to the urban environment, followed by relevant literature on urban form and activity spaces, and finishing with hypothesised connections between activity spaces and leisure travel. Then, an overview of the research design is provided. This is followed by a joint results and discussion section. Finally, the main takeaways are covered in the conclusions section.

2. Literature review

2.1. Activity spaces

Activity space (AS) can be defined as the subset of locations or areas with which the individual has direct contact and visits regularly as the result of daily activities (Golledge and Stimson, 1997; Schönfelder and Axhausen, 2004). AS are often dominated by home and work locations (Horton and Reynolds, 1971). AS can provide insights into which urban spaces an individual interacts with on a regular basis and how (Järv et al., 2014), especially outside of the person's residential environment. AS is described spatially as a surface area (Horton and Reynolds, 1971), formed using one's home location and regularly visited locations (Schönfelder and Axhausen, 2016). Activity spaces have been used in a variety of domains, including research in health sciences (i.e., Laatikainen et al., 2018; Holliday et al., 2017; Vallée et al., 2011), epidemiology (i.e., Perchoux et al., 2013), urban planning (i.e., *Parthasarathi et al., 2015), transportation planning (i.e., Tribby et al., 2016), and society (i.e. Silm and Ahas, 2014; Wong and Shaw, 2011).

Smith et al. (2019) summarised various studies on activity spaces and their relationship to the urban environment. They note size as a common parameter and independent variable in AS studies. It is equally important to understand whether activities take place inside or outside of the residential neighbourhood (Smith et al., 2019). Perchoux et al. (2014) identified centricity (activity points within and outside of the residential neighbourhood) as a significant AS characteristic. Hasanzadeh et al. (2021) refined the method to determine centricity clusters. Hasanzadeh et al .(2019) define size, centricity and elongation as geometrically observable parameters of activity spaces, where size notes the overall broadness of the urban environment within which a person moves, centricity covers whether visited locations are in or out of the immediate living environment, and elongation describes the one-directionality of one's mobility. They highlight three types of centricities – monocentric, bicentric and polycentric – based on the number of activity centres outside of one's home range (Hasanzadeh et al., 2021). It can be deduced that small size and monocentricity are related to a compact AS, whereas large size and polycentricity are related to a broader, more dispersed AS. Schönfelder and Axhausen (2003) find that AS size is strongly correlated with the number of unique locations visited, based on how many the respondent marks within a survey, for example.

2.2. Urban form, activity spaces, and local travel

The interactions between the urban environment, activity spaces and local travel emissions are in many ways interconnected. According to literature, the key influencing factors relate to land use mix, travel modes, and people's socio-demographic background (Table 1). Furthermore, the built environment influences people's attitudes and, through it, their mobility behaviour (Ramezani et al., 2021).

Despite the multi-faceted relationships between urban form, socio-demographic background and activity spaces, the connection between local activity spaces and GHG emissions from local travel is relatively straight-forward. Large activity spaces and polycentricity are associated with driving and travelling longer distances, which both correlate positively with GHG emissions. Smaller activity spaces and monocentricity are associated with shorter distances and active modes, and hence lower GHG emissions (e.g. Næss et al., 2018; Næss et al., 2021; Ramezani et al., 2021; Harding et al., 2013; Chen and Akar, 2016; Perchoux et al., 2014; Hasanzadeh et al., 2021). However, the relationship with long-distance travel is more complex.

2.3. Urban form, activity spaces and leisure travel

Several theoretical concepts have been developed to explain the relationships between urban form, urban mobility and leisure travel in different contexts. However, the association does not yet appear in AS literature. Common theories in literature cover the relationship between residential location, local travel behavioural peculiarities that stem from residential location, and the resulting engagement in leisure travel. These theories include compensation or escape hypothesis, cosmopolitan attitudes, monetary rebound effect, time budget rebound effect, residential self-selection or sorting, and social networks. The key

Table 1
Summary of key themes connecting urban form, activity spaces and local travel emissions.

Theme	Influencing factors	Relationship to AS and local travel emissions
Urban form	• Diverse land use mix • Higher density • Availability and proximity of jobs	Reduced driving/commuting distances that contribute to a smaller, more compact AS (Zhang et al., 2018; Fan & Khattak, 2008; Næss et al., 2018; Perchoux et al., 2014). Smaller, more compact ASs support the use of active travel modes (Ramezani et al., 2021). Both reduced travel distances and active travel modes reduce local travel emissions (Næss et al., 2018; Heinonen et al., 2013a,b; Næss et al., 2021).
Transport	• Active travel modes • Good access to public transit	Smaller, more compact AS have been connected to active travel modes and good public transit access (Harding et al., 2013; Chen & Akar, 2016; Perchoux et al., 2014; Hasanzadeh et al., 2021; Hirsch et al., 2014; Sanchez et al., 2017), although the relationship is not one-directional (Ramezani et al., 2021). Reduced car use is also expected to reduce local travel emissions by proxy (Næss et al., 2018; Heinonen et al., 2013a,b; Næss et al., 2021).
Socio-demographic background	● Age ● Gender ● Income ● Education level ● Employment status	Mixed results in different urban contexts. Younger adults have been connected to polycentric activity spaces (Hasanzadeh et al., 2021) and larger AS (Tana et al., 2016; Perchoux et al., 2014). However, in Chicago, the opposite pattern has been noted (Tana et al., 2016), likely due to suburbanisation (Ramezani et al., 2021; Schönfelder & Axhausen, 2002). Women may have smaller, more compact AS (Perchoux et al., 2014). Low income and low education levels have been associated with both polycentric AS and smaller AS sizes (Perchoux et al., 2014; Sharp et al., 2015; Chen & Akar, 2016). Unemployment or partial employment has been associated with smaller and more compact AS types (Perchoux et al., 2014).

concepts behind the theories are briefly presented, followed by a discussion of the literature gap.

2.3.1. Compensation or escape hypothesis

The compensation or escape hypothesis suggests that living in densely populated and built urban areas increases the need to escape the urban environment, compensating for its negative aspects through leisure travel. The negative aspects include, but are not limited to, higher urban form and population density (Große et al., 2019; Strandell and Hall, 2015; Czepkiewicz et al., 2020b), no access to a private yard (Czepkiewicz et al., 2020b; Holden and Norland, 2005), lack of (good quality) green spaces (Næss, 2006; Raudsepp et al., 2021), and commuting/traffic-related stress (Raudsepp et al., 2021; Mouratidis et al., 2019).

2.3.2. Rebound effects

Monetary rebound effect pertains to a shift in consumption-based GHG emissions from one consumption category to another. Densification of the urban form, which aims to reduce car use and shorten local travel distances, can reduce expenditure on local travel, thus increase spending in other categories, namely for long-distance travel and consumption of goods and services (e.g., Heinonen et al., 2013a; Muñiz et al., 2013; Næss, 2012, 2016; Strandell and Hall, 2015; Ottelin et al., 2014, 2017). However, in highly affluent societies, such as in Iceland, it has been found that people travel regardless of cost while still maintaining high levels of car use (Czepkiewicz et al., 2020a; Heinonen et al., 2021).

Similarly, studies on travel time budgets indicate a strong relationship between income level, gender, employment status, car ownership, urban density, service accessibility and how much time is spent on travel (Mokhtarian and Chen, 2004). Having more free time might enable engaging in more leisure travel and thus lead to higher travel emissions. However, working less has been associated with reduced emissions, mainly due to the consequential reduced income (Wiedenhofer et al., 2018). The rebound effect from reduced working hours to enable more leisure travel is likely dependent on the motivation behind wanting more free time (Buhl and Acosta, 2016).

2.3.3. Residential self-selection and sorting

A potential counterbalance to the compensation hypothesis, residential self-selection involves the thought that people choose to live in an area which best matches their travel-related attitudes and preferences (Große et al., 2019; Maat and de Vries, 2006; Czepkiewicz et al., 2018c; Næss, 2006; Haybatollahi et al., 2015). It could prevent the compensation hypothesis from appearing in quantitative studies (Czepkiewicz et al., 2020b) due to, for example, residents who enjoy nature travel choosing to live in a green and calm area of the city (Czepkiewicz et al., 2020b; Maat and de Vries, 2006).

Another possible explanation is spatial sorting of residents. For example, those with high-income or well-educated people might tend to live in city centres because the central area homes may be more financially accessible to them (although not applicable everywhere as a general trend) and take more long-haul flights at the same time (Czepkiewicz et al., 2020a,b; Næss, 2014; Oswald and Ernst, 2021). Living in a certain urban area may further guide attitudes and preferences in travel modes and travelled distances (Næss, 2014). For example, living further away from the city centre may cultivate a car-positive attitude since a car enables one to travel within the city to desired destinations (Næss, 2014).

2.3.4. Cosmopolitan attitudes

Cosmopolitan attitudes are reflected in people's internal desire to explore the world through visiting cities and experiencing different cultures (Muñiz et al., 2013; Næss, 2006, 2016). In urban areas, there is an agglomeration of cosmopolitan attitudes and lifestyles (Czepkiewicz et al., 2018c, 2019, 2020a,b; Holden and Norland, 2005; Næss, 2006), reflected even in one's preference for trying different cuisines both locally and abroad (Raudsepp et al., 2021). Cosmopolitan attitudes have been connected to higher mobility, particularly international air travel, and downtown living (Oswald and Ernst, 2021; Czepkiewicz et al., 2020a,b).

2.4. Gap in literature

As evidenced by the multitude of theoretical explanations for travel behaviour, the connections between urban form and travel behaviour remain complex and offer various avenues for further studies. The theoretical concepts focus mainly on the influence of residential location and residential environment on travel behaviour. However, there are indications of the broader urban environment impacting leisure travel behaviour, for example through daily commutes and related stress (Raudsepp et al., 2021; Mouratidis et al., 2019). Considering that activity spaces help understand urban mobility and how people interact with the urban environment, it can be a useful method in unpacking the connection between urban mobility and leisure travel. Previous studies have shown the merit of activity spaces as a method for understanding local travel. Activity spaces help us go beyond the residential level and look at the broader urban environment as well, providing a new perspective within travel behaviour literature. In addition, in the age of climate change and with the urgency to mitigate the anthropogenic GHGs, connecting activity spaces to GHGs provides a valuable new perspective to mobility-related GHGs and their mitigation. What is more, prior studies conducted on young adults in Iceland have found potential evidence of hypermobility wherein people lead a highly mobile lifestyle both locally and in leisure travel (e.g. Heinonen et al., 2021; Czepkiewicz et al., 2019), regardless of socio-economic background (e.

g., Czepkiewicz et al., 2020a), which makes it an interesting context wherein to apply the novel method.

3. Materials and methods

3.1. Study area

The study employed a case study approach in the Reykjavík Capital Area (Reykjavík; in icelandic: Höfuðborgarsvæðið). With its very high affluence, low-density urban design connected to highly car-oriented lifestyles, generally high level of aeromobility and isolated location make Reykjavík an interesting case to study the connection between activity spaces and GHG emissions. Activity spaces were used to assess the travel behaviour of young adults within Reykjavíḱs urban structure.

Iceland is a sparsely populated island nation categorised by low population density, with a total population of 390,830, about 2/3 of which resides in the Reykjavík Capital Area (249,240 people) (Statistics Iceland, 2023). Reykjavík consists of the municipalities of Reykjavík City, Kópavogur, Hafnarfjörður, Garðabær, Mosfellsbær, Seltjarnarnes, and Kjósarhreppur. The central area is located on a peninsula only accessible by land from one side, with no tunnels or bridges connecting to the outskirts. The geographical context contributes to traffic since many individuals are commuting from the suburbs towards the central area. Transport is dominated by private automobile use, and public transportation is limited to one mode consisting of a bus system (Næss et al., 2021). The city has a sub-polar oceanic climate, and the weather is prone to great variability, which affects mobility in multiple ways. For example, extremely windy and rainy weather has been shown to restrain active modes of transport (Saneinejad et al., 2012). Iceland has a low amount of vegetation due to its proximity to the Arctic Circle, thus green space is limited. However, the city sits on the Atlantic coast, which results in a higher availability of blue spaces.

3.2. Study sample

The data was collected in late 2017 using a map-based online questionnaire (i.e., a geo-questionnaire or softGIS survey), in which traditional survey questions are combined with questions that require respondents to mark locations on interactive maps (Brown and Kyttä, 2014; Czepkiewicz et al., 2018b). The questionnaire included questions about the residential location, destinations visited within the urban region, locations and characteristics of international and domestic leisure trip destinations, as well as questions about their attitudes, and various background variables. Participants marked the approximate locations of their residences and most frequently visited locations in the previous 3 months in Reykjavík on an interactive map and answered questions about them. Questions about visited locations included frequency of visits, trip purposes, primary travel mode, and typical trip origin (from home, from work- or study place, or on the way). Average number of visited locations was 7.42 (SD = 5.84). Since the number of locations is partly influenced by travel patterns and partly by participant's engagement in the survey, the number of marked points were controlled for in statistical analysis to check for potential influence of under- or overreporting of points on the analysis.

Data collection was part of a project aimed at studying travel behaviour of young adults and the target population of the survey was 25- to 40-year-old people living in Reykjavík Capital Region. This particular target group was chosen to reduce the influence of generational differences, as individuals in this age group typically live independently, have joined the workforce, and were raised in a globalised environment with ample access to communication and information technologies. Sampling was based on a geographically stratified random sample of 6000 individuals derived from the Registers Iceland. Two rounds of personal letter invitations were sent in September and October 2017. The response rate was 13.6 %, with 706 responses out of the 5184 invited individuals. Out of them, 667 responses were usable for geographical analysis. The data collection was done according to Icelandic data protection regulations. An overview of the study sample is provided in Table 2.

3.3. Activity space modelling

This study uses the individualised home range model toolbox (Hasanzadeh, 2018) to map activity spaces. Compared to a simple minimum convex polygon (MCP) or an ellipsoid, this model dynamically accounts for individual-specific variations by incorporating frequently visited points and mobility patterns, providing a more accurate and flexible representation of personal spatial behaviour (Hasanzadeh et al., 2017). The model employs the minimum convex polygon method—a geometric technique that defines the smallest convex shape enclosing a given set of points—using two key distances: D1, a 500 m buffer surrounding the immediate home location, and D2, a 140 m buffer surrounding frequently visited points. Specifically, we first limited the visited locations to those within the geographical Reykjavík capital region, then applied the D1 and D2 buffers, and subsequently applied the MCP to enclose the buffered features. This approach addresses one of the key issues in using polygons for AS modelling, where boundaries are often assumed to be rigid and precise (Hasanzadeh et al., 2017).

When studying urban form, it has been suggested to look at size, polycentricity and elongation, as well as destination type, volume of trips, and intensity of activities (Hasanzadeh et al., 2019). In this study we focus on the geometric parameters of AS – size, centricity, and elongation, all of which were calculated using the abovementioned toolbox.

AS size was calculated based on the km^2 area of the AS polygon, which includes all visited activity points within Reykjavík (Hasanzadeh et al., 2019). AS based on the individualised home range model (Hasanzadeh et al., 2017) does not consider the road network when calculating the AS polygon, therefore the size described in this study is an estimate that is likely to differ in a different model.

Centricity was calculated based on how many activity centres (Hasanzadeh et al., 2019; Hasanzadeh et al., 2021) were within the 15–20-minute walking range (1.6 km) of the home. The distance was chosen to represent potential 15-minute neighbourhoods. If all activity points fell into this range, one would have a monocentric AS type. If a person had only one centre outside of this range, they would have a bicentric AS type. If the respondent had multiple centres outside of this range, they would have a polycentric AS type (Fig. 1).

Elongation is the major to minor axis ratio of the activity space (Hasanzadeh et al., 2019). It describes the extension of the AS in one main direction and should therefore be interpreted with care. Monocentric activity spaces will have low elongation values, whereas bicentric ones will have high elongation values. A polycentric AS can also have a low elongation value as it extends in multiple directions (i.e. Fig. 1).

3.4. GHG emissions

Consumption-based local travel emissions, along with both domestic and international leisure travel emissions were examined in the study (Table 3). Local travel emissions include travel within the Reykjavík Capital Area, but not outside of it. Domestic leisure travel emissions include leisure trips made within Iceland,while international leisure travel emissions include leisure trips made outside of Iceland. The GHG emission estimates were calculated Well-to-Wheel using life-cycle assessment. Therefore, the emissions associated with vehicle manufacturing were excluded, and direct and indirect emissions for fuel and electricity use were included in this study, for example the emissions associated with fuel extraction and electricity production. The emission calculations are explained in more detail in Czepkiewicz et al. (2019). The approach taken is consumption-based, meaning that the emissions related to each trip are allocated to the person taking the trip.

Table 2
Descriptive statistics for socio-demographic background of the study sample.

	N	% of total	Mean	Median	Min	Max	SD	Kurtosis	Skewness
Age	667	–	32.62	33	24	40	4.594	−1.206	−0.108
Gender (Female)	398	60 %							
Gender (male + other)	269	40 %							
Education level (low)	145	22 %							
Education level (medium)	254	38 %							
Education level (high)	243	36 %							
Income level (low)	40	6 %							
Income level (medium)	151	23 %							
Income level (high)	153	23 %							
Income level (very high)	270	40 %							
Household type (single)	142	21 %							
Household type (with kids)	140	21 %							
Household type (couple)	368	55 %							
Household type (shared)	17	3 %							

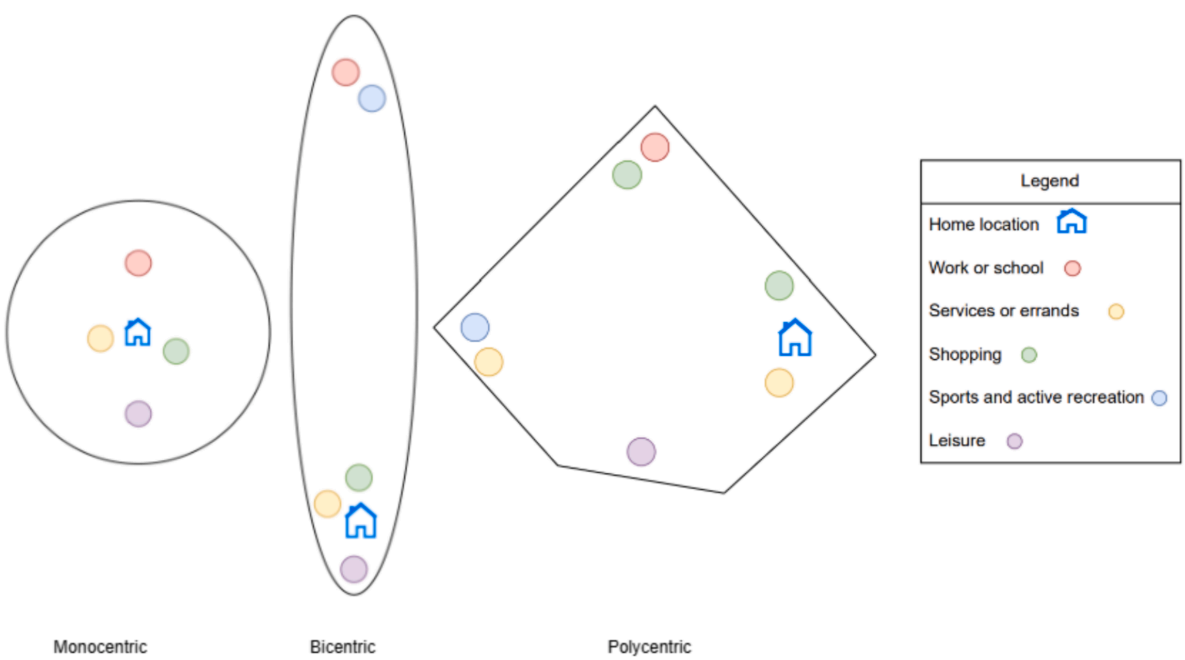

Fig. 1. Simplified example of activity space centricity (following Hasanzadeh et al., 2019). A monocentric activity space in which activities are centred around the home location. A bicentric activity space characterised by high elongation has a cluster of activity spaces around the home location and an additional cluster outside of the home vicinity. A polycentric activity space has two or more activity clusters outside of the home vicinity.

Table 3
Descriptive statistics for leisure travel variables used in the study.

	N	Mean	Median	Min	Max	SD	Kurtosis	Skewness
Domestic leisure travel emissions (annual; kgCO2eq)	667	267	149	0	4357	385	28.562	4.135
International leisure travel emissions (annual; kgCO2eq)	667	2534	1877	0	25,019	2909	9.853	2.418
Local travel emissions (annual; kgCO2eq)	667	725	468	0	7104	845	11.232	2.750
Participated in domestic leisure travel	548							
Participated in international leisure travel	487							

3.5. *Spatial analysis*

All spatial analysis was done using ArcGIS Pro 2.9. This includes calculations on trip frequencies, distances between home and visited locations, and AS modelling and mapping. A more detailed description of the calculation process behind various spatial measures can be found in Czepkiewicz et al. (2019). The variables mentioned below were included in the analysis to help explain any underlying factors that might influence AS characteristics or travel emissions (Table 4).

Population density was measured as the number of residents per

Table 4
Descriptive statistics for spatial variables used in the study.

	N	Mean	Median	Min	Max	SD	Kurtosis	Skewness
Distance to city center (CC) (km)	667	6.158	5.108	0.196	17.395	4.180	−0.841	0.461
Population density (1 km radius; residents per hectare)	667	27.310	27.730	2.030	48.710	10.417	−0.733	−0.068
Open spaces (1 km radius)	667	0.334	0.299	0.087	0.832	0.160	−0.121	0.701
Blue spaces (1 km radius)	667	0.099	0.030	0.000	0.651	0.132	1.807	1.523
Public transport zone 1 (10 + departures)	46							
Public transport zone 2 (4–10 departures)	278							
Public transport zone 3 (Less than 4 departures)	201							
Public transport zone 4 (No departures)	142							

hectare (Czepkiewicz et al., 2019). Population density at the respondent's home was measured within a 1 km radius buffer.

The distance to the city centre was calculated based on the shortest driving distance between home and city centre using the Network Analyst tool in ArcGIS. The city centre was represented by an intersection of three main streets in the downtown area (Czepkiewicz et al., 2018). Distance to the city centre was split into distance bands as follows: Less than 1 km, 1–3 km, 3–7 km, 7–12 km, more than 12 km following Næss et al (2021) who show a pattern of increased driving as one moves away from the city centre in Reykjavík.

Public transportation zones were allocated based on accessibility of public transportation within a 5-minute walking distance, or 400 m along the street network, from the home (Czepkiewicz et al., 2019) in four categories based on the number of daily departures per hour within the 14-hour daytime period:

- Zone 1: 10 + departures within a 5-minute walking distance
- Zone 2: 4–10 departures within a 5-minute walking distance
- Zone 3: less than 4 departures within a 5-minute walking distance
- Zone 4: no bus stop within a 5-minute walking distance

Open space and blue space (classifications from the Copernicus Programme Urban Atlas land-use dataset for the year 2018 (European Environment Agency, 2020)) were measured in relation to a respondent's home location and calculated as the percentage of open or blue space within a 1 km radius buffer around the respondents' home (Czepkiewicz et al., 2020).

3.6. Variable computing

The following variables were generated from the original data and are used in the regression analysis in this study. They are based on 34 statements (Likert scale from 1 to 5 (1 = strongly disagree, 3 = neither agree nor disagree, 5 = strongly agree) answered by the survey respondents, and a factor analysis to find the common factors. Since the factors were assumed to correlate with each other, principal axis factoring with oblique rotation was used. The resulting factors were named as follows, and factor scores were used in the analysis.

Pro-environmental attitude

Pro-environmental attitude (PEA) was calculated based on the following six statements which were found to load the same factor:

1. I want to live as ecologically as possible
2. I am very concerned about environmental issues
3. I think about how I can reduce environmental damage when I go on holiday
4. I think about environmental impact of services I use
5. When shopping, I rarely think about the environmental impact of the things I buy (negative score)
6. I am willing to reduce my use of air travel because of the environment

Cosmopolitan attitude

The Cosmopolitan attitude variable was constructed of answers to five statements:

1. Experiencing different cultures is very important for me
2. Experiencing different cultures and destinations is more important than saving natural resources
3. Exploring new places is important part of my lifestyle
4. It is easy for me to jump to a plane and go on a trip
5. I feel at home wherever in the world I go.
6. Sometimes it is necessary to take a break from urban life.

Climate awareness

The Climate awareness variable is the result of the following four statements loading the same factor:

- I am very concerned about environmental issues
- There is evidence of global climate change
- The main causes of global warming are human activities
- Global warming will bring about some serious negative consequences

Prefers leisure in urban areas vs in nature

The following three statements were found to load the same factor, and constitute the variable Prefers leisure in urban areas vs in nature:

1. Sometimes it is necessary to take a break from urban life (negative score)
2. I find it more interesting on a city street than out in the forest looking at trees and birds
3. I would rather spend my weekend in the city than in wilderness areas

Preference for living in suburb

The Preference for living in suburb variable was constructed of the following seven statements loading the same factor:

1. I prefer to live in a suburban neighbourhood, even if it means travelling longer distances
2. If I could live anywhere I would live in suburbs
3. Suburban life is boring (negative score)
4. I like living in a neighbourhood where there is a lot going on (negative score)
5. I don't mind travelling a bit longer for the everyday services I use
6. I appreciate tranquillity and calmness in a residential area
7. I want to live close to vast nature and recreational areas
8. Having shops and services within walking distance of my home is important to me (negative score)

Pro-car attitude

The result of the following four statements loading the same factor was labelled as Pro-car attitude:

1. Car is my preferred way of getting around the city
2. I appreciate good travel connections by car
3. I prefer getting around in an active way such as walking or cycling (negative score)

4. I don't mind getting around using public transportation (negative score).

Preference for shared housing and transport

Four statements were found to form a variable that was named as Preference for shared housing and transport:

1. I can be comfortable living in close proximity to my neighbours
2. Living in a multiple family unit would not give me enough privacy (negative score)
3. I am comfortable riding with strangers
4. The neighbourhood park is enough nature for me

Preference for nature and privacy

Six statements were used to construct the Preference for nature and privacy variable:

1. I appreciate tranquillity and calmness in a residential area
2. I want to live close to vast nature and recreational areas
3. I prefer getting around in an active way such as walking or cycling
4. I can be comfortable living in close proximity to my neighbours (negative score)
5. Living in a multiple family unit would not give me enough privacy
6. I like to have a large yard at my home.

3.7. Statistical analysis

Statistical analysis was conducted using SPSS. Regression analysis was the primary statistical analysis because it allows for the evaluation of relationships. Two model blocks were developed. Block one consists of models 1a-1c involving three AS parameters (size, elongation, centricity) as the dependent variable, with various socio-demographic and urban form variables as the independent variables (Table 5). Block two consists of models 3a and 4a for participation in domestic and international leisure travel respectively, and models 2a, 3b and 4b for local, domestic leisure, and international leisure travel emissions respectively as the dependent variable, for those who participated in travel emissions. Participation and emissions were modelled separately to firstly see whether there is any difference in travel engagement and secondly to minimise the impact of non-normal character of the dependent variables. Local travel participation was not modelled separately as most young adults in our dataset contributed to local travel emissions to some extent.

A selection of known background variables were controlled for based on Czepkiewicz et al. (2019) in models 2a-b, 3a-b (Table 5). For domestic travel emissions, the following variables were controlled for: gender, working time, access to private yard, access to cabin, having a car in the household, PEA, cosmopolitan attitude, climate awareness, and preferring urban areas to nature. For international leisure travel, the following variables were included in the models: income level, household type, access to private yard, access to cabin, having a car in the household, language skill, PEA, cosmopolitan attitude, climate awareness, and preferring urban areas to nature. AS characteristics were added as additional variables to all four models in block two to help understand their relationship to domestic and international leisure travel when known variables are controlled for.

Table 5
Additional variables used in the study.

		N	% of total
Type of residence	Apartment	428	64 %
	Other	239	36 %
Home ownership	Yes	484	73 %
	No	180	27 %
Bedrooms	One bedroom	117	18 %
	Two bedrooms	212	32 %
	Three or more bedrooms	338	51 %
Access to private yard	Yes	318	48 %
	No	347	52 %
Car in household	Yes	592	89 %
	No	75	11 %
Working time (weekly)	Part-time (<35 h/week)	123	18 %
	Full time (35–45 h/week)	377	57 %
	Overtime (>45 h/week)	166	25 %

4. Results & discussion

In this section, the results are presented and discussed in relation to the existing literature. After bivariate and spatial results are presented, the activity spaces are described and examined in a regression setting. This is then followed by an examination of the relationships between activity spaces, local travel and leisure travel, both international and domestic.

4.1. Activity spaces in the Reykjavík capital area

The mean area of the activity spaces of young adults living in the Reykjavík capital area was 14.97 km^2 (Mdn = 9.04, SD = 16.55), ranging between 0.79 km^2 to 136.11 km^2. The mean AS size increases with distance from the city centre (Fig. 2). Most respondents have multiple regularly visited activity centres. Out of 667 respondents, 6.1 % had a monocentric AS, 20 % a bicentric AS and 73.8 % respondents had a polycentric AS type. A polycentric AS type is indicative of a vastly larger AS size (mean = 19.09 km^2; SD = 17.43) compared to bicentric (mean = 3.93 km^2, SD = 2.23) or monocentric (mean = 1.15 km^2, SD = 0.44) AS types. Individuals residing in zones with better public transportation connectivity had larger activity spaces. Access to a yard did not make much difference in AS size, as both having and not having access showed similar averages of AS size. A shared adult household had a substantially larger average AS size compared to singles, couples, and households with children (Fig. 2).

Smaller activity spaces were concentrated in the city centre and up to 7 km from the centre, whereas large activity spaces were more commonly found in the suburban parts of the capital area (Fig. 3). This is in line with prior studies (e.g., Ramezani et al., 2021; Perchoux et al. 2014). Emerging spatial patterns hint that living closer to downtown might enable more of people's regular mobility needs (i.e., going to work/school, shopping for groceries, leisure activities) nearby their home (Zhang et al., 2018; Fan and Khattak, 2008), whereas in the suburban areas people have two or more activity centres outside of their local environment (Ramezani et al., 2021). Suburban centres with small AS sizes were expected to emerge (Perchoux et al., 2014; Zhang et al., 2018; Fan and Khattak, 2008), but that was not the case in this study, apart from the centre of Kópavogur municipality, which is located within 5–7 km of the central capital area and is the second largest municipality in Iceland after Reykjavík City. This is likely due to centrally oriented job-related mobility (Harding et al., 2013; Perchoux et al., 2014) or a lack of local opportunities and social ties to the neighbourhood (Fan and Khattak, 2008).

The most significant determinant for AS size, elongation and centricity was the distance from the home to the city centre. As the distance increases, so do AS sizes (Figs. 2-3). Similarly, elongation, or one-directional travel, and polycentricity increases the further one lives from the centre, which indicates a strong commuting pattern from the outskirts of the capital area to the centre, likely because of job-related mobility and further distances to activity locations (Hasanzadeh et al., 2021; Harding et al., 2013; Ramezani et al., 2021; Perchoux et al., 2014).

Having two bedrooms was indicative of smaller AS size compared to one-bedroom homes (Table 6) but having a three or more bedroom home was associated with bigger AS size than one or two bedroom homes (Fig. 2). Bigger homes are more likely to be situated in the suburbs and therefore living there can be linked to longer travel distances

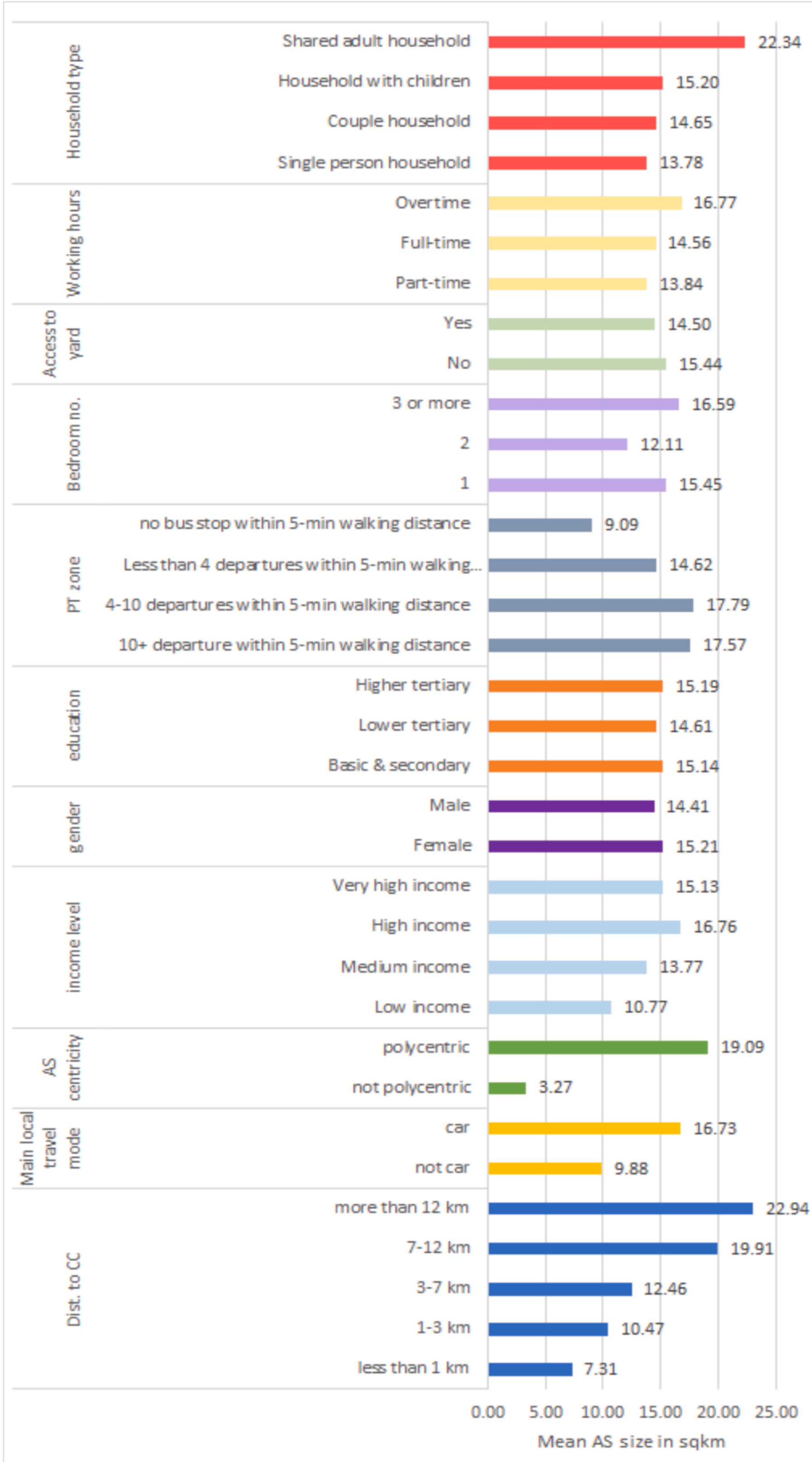

Fig. 2. Mean AS size in km^2 split by background variable categories.

locally. This was also reflected in local travel emissions, wherein three or more bedrooms were linked to higher local travel emissions compared to having fewer bedrooms in a home (Appendix 1).

Similarly to previous studies (Harding et al., 2013; Chen and Akar, 2016; Perchoux et al., 2014; Hasanzadeh et al., 2021), good public transportation access indicated reduced one-directional mobility (elongation, B = −0.728) (Table 6). Having a medium amount of bus departures (4–10) within a 5-minute walking distance increased the

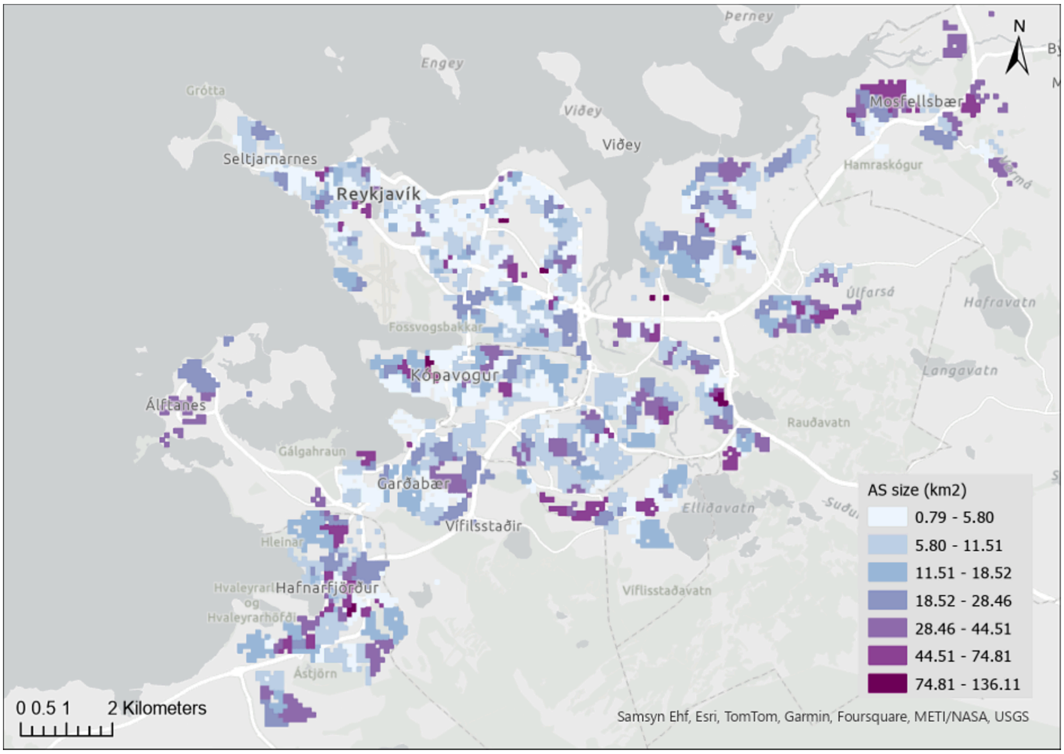

Fig. 3. AS size spatial distribution in Reykjavík, extrapolated to the population grid by calculating the average AS sizes within or closest to each grid cell. Scale determined using Jenks natural breaks.

likelihood of having a polycentric AS by 91 % (Table 6) and more bus departures were associated with larger AS sizes (Fig. 2), which is slightly contrasting to previous studies, where good access to public transport was indicative of more compact activity spaces (i.e. Hasanzadeh et al., 2021; Chen and Akar, 2016). Having a car in the household indicated a seven times higher likelihood of having a polycentric AS type but was not significantly associated with AS size or elongation (Table 6). However, having a car as the main travel mode locally led to nearly twice the AS size (16.73 km^2) as not driving a car (9.88 km^2). Our result is similar to previous studies where driving has been connected to larger and more dispersed activity spaces (Harding et al., 2013; Ramezani et al., 2021). Furthermore, it seems that in Reykjavík having any kind of access to motorised transport, public or private, enables people to reach a wider variety of destinations, reflected in polycentricity, mean AS size and mean local travel emissions (Table 6; Appendix 1).

Living in a higher density area and in an area with a higher ratio of open spaces increases the likelihood of having a polycentric AS type (Table x). The findings contradict previous studies which indicate that higher density is connected to higher land use diversity and therefore to a more compact AS type (Zhang et al., 2018; Fan and Khattak, 2008; Perchoux et al., 2014). People who have access to a private yard are more likely to have a smaller and non-polycentric AS (Table 6). As private yards are more likely to be utilised than available open spaces, it supports previous findings about the importance of green space usability and its connection to reduced urban mobility (i.e. Raudsepp et al., 2021).

Working overtime was connected to having a larger AS and higher local travel emissions, which could be partially due to work-related mobility within the city. This follows findings by Perchoux et al (2014) where unemployment and partial employment were associated with more compact activity spaces.

Households without children were connected to larger AS sizes compared to households with children (Table 6). Single person households were three times more likely to have a polycentric AS type than households with kids (Table 6). In a previous study by Tana et al. (2016), it was found that two-person households have smaller activity spaces compared to larger households (including those with children), which in Reykjavík only holds true when comparing with multi-adult households but not households with children (Fig. 2). In addition, Ramezani et al (2021) found that a higher number of children in the household supports polycentricity, whereas in this case study the single person households were more likely to have a polycentric AS compared to households with kids.

A low income level was associated with smaller activity spaces (Fig. 2), lower local travel emissions (Appendix 1) and was indicative of 2.4 higher likelihood ($p = 0.119$) of having a polycentric AS type compared to medium income level. The results are in line with previous studies (Perchoux et al., 2014). The relationship between socio-economic status and mobility-related opportunities should be investigated further. Low income might lead to reduced opportunities, reflected in smaller AS size, and possible money-saving behaviour which could be reflected in visiting multiple locations (polycentricity) for the best priced goods and services (Perchoux et al., 2014; Sharp et al., 2015; Chen and Akar, 2016), however conclusions cannot be made based on the current results.

4.2. Relationships between AS and travel emissions

4.2.1. Local travel emissions

Local travel emissions were tightly connected to activity spaces. Mean local travel emissions of the study sample were 724 kgCO2eq (SD = 843.56). Most people in our sample use a car for local travel, which is also reflected in 26.5 % higher emissions (M=878 kgCO2eq) compared to their non-car using counterparts (Table 7; Appendix 1). A pro-car attitude significantly increased local emissions by 20 %. Heinonen et al. (2021) discuss similar findings of strongly rooted car ownership in Iceland.

At the same time, having better bus connectivity near the home was connected to higher emissions from local travel (Table 7), possibly reflecting the capacity of having public transit access enabling visiting

Table 6
Regression models on AS characteristics. 1a – OLS regression of AS area in km^2; 1b – OLS regression of AS elongation; 1c – binomial logistic regression of having a polycentric vs not having a polycentric AS type. Significance levels: p < 0.001 ***, p < 0.01 **, p < 0.05 *, p < 0.1^.

		1a. AS area in km2		1b. AS elongation		1c. Has polycentric AS type	
		(n = 662)		(n = 662)		(n = 662)	
		B	Sig.	B	Sig.	Exp(B)	Sig.
(Constant) (B)		−15.610	0.028*	4.780	0.000***	0.000	0.000***
Age		0.116	0.353	−0.016	0.388	1.016	0.574
Gender	Female	−1.185	0.273	−0.007	0.967	0.848	0.501
	Male + other	ref	ref	ref	ref	ref	ref
Education level	Low	−0.060	0.964	−0.200	0.306	1.028	0.927
	Medium	ref	ref	ref	ref	ref	ref
	High	0.649	0.575	0.219	0.191	1.084	0.761
Income level	Low	−1.968	0.397	−0.199	0.553	2.460	0.119
	Medium	ref	ref	ref	ref	ref	ref
	High	1.905	0.189	−0.344	0.100	1.720	0.105
	Very high	0.920	0.505	−0.210	0.290	1.391	0.277
Working time	Part-time (less than 35 h/week)	0.138	0.922	0.117	0.562	1.402	0.292
	Full time	ref	ref	ref	ref	ref	ref
	Overtime (more than 45 h/week)	2.983	0.015*	−0.189	0.285	0.921	0.763
Household type	Single person household	5.481	0.000***	−0.193	0.377	3.036	0.002**
	Household with children	ref	ref	ref	ref	ref	ref
	Couple household	3.292	0.025*	−0.075	0.723	1.704	0.115
	Shared adult household	7.567	0.022*	0.483	0.309	1.932	0.385
Number of bedrooms	One	ref	ref	ref	ref	ref	ref
	Two	−3.121	0.045*	0.011	0.960	0.791	0.510
	Three or more	−0.872	0.608	0.020	0.934	0.765	0.492
Type of residence	Apartment	−1.275	0.318	0.230	0.212	0.761	0.350
	Other	ref	ref	ref	ref	ref	ref
Home ownership	Yes	−1.023	0.432	0.038	0.838	0.766	0.362
	No	ref	ref	ref	ref	ref	ref
Access to private yard	Yes	−2.171	0.064^	0.247	0.144	0.552	0.027*
	No	ref	ref	ref	ref	ref	ref
Population density		−0.020	0.800	−0.002	0.838	1.033	0.081^
Open spaces		0.619	0.915	−1.274	0.128	91.114	0.003**
Blue spaces		8.158	0.130	0.874	0.260	0.424	0.512
Public transport zone	10 + departures within 5 min walking distance	0.370	0.877	−0.728	0.035*	1.953	0.230
	4–10 departures within 5 min walking distance	0.730	0.641	−0.127	0.573	1.904	0.056^
	Less than 4 departures within 5 min walking distance	1.047	0.506	0.046	0.840	1.302	0.417
	No departures within 5 min walking distance	ref	ref	ref	ref	ref	ref
Car in household	Yes	1.314	0.468	0.165	0.528	7.047	0.000***
	No	ref	ref	ref	ref	ref	ref
Distance to city center	Less than 1 km	ref	ref	ref	ref	ref	ref
	1–3 km	4.889	0.031*	−0.333	0.308	5.923	0.000***
	3–7 km	9.297	0.000***	−0.611	0.091^	12.276	0.000***
	7–12 km	17.314	0.000***	0.279	0.467	12.005	0.000***
	More than 12 km	21.866	0.000***	1.725	0.000***	12.055	0.000***
Number of marked points		1.568	0.000***	−0.051	0.000***	1.512	0.000***
Participation in leisure travel	International	0.642	0.605	0.178	0.321	1.230	0.458
	Domestic	2.586	0.082^	−0.791	0.000***	1.985	0.023*
	R2	0.443		0.155			
	Adjusted R2	0.415		0.113			
	F-statistic	16.135		3.719			
	Durbin-Watson	2.015		1.974			
	Nagelkerke R2					0.463	
	Chi-square					14.489	0.070
	Omnibus test					251.236	0.000
	Predictive power					84 %	

more locations. However, considering that the majority of our sample use a car as their main mode of transport, and that the public transportation connectivity indicator considers numbers and frequencies of connections, but does not consider the usability aspect of the transport (whether the transport gets people to where they need to go), the result could also indicate that the current public transport network does not meet people's needs of daily transport.

Living further from the centre, having a bigger home and a preference for suburban living were connected to higher emissions, likely due to extended travel distances (Table 7; Appendix 1). These factors can be linked to bigger, more elongated, and polycentric activity spaces, and therefore align with previous studies (Schönfelder and Axhausen, 2002; Perchoux et al., 2014; Heinonen et al., 2013a,b; Næss et al., 2021; Ramezani et al., 2021). In addition, in Reykjavík, car ownership increases along the distance gradient (Heinonen et al., 2021), which also explains this finding.

Higher population density around the home was associated with a significant decrease in local emissions. Central locations have higher population density and require less travel to reach daily destinations due to diversified land use, leading to more compact activity spaces (Heinonen et al., 2013a,b; Næss et al., 2021; Ramezani et al., 2021). In addition, a higher ratio of open spaces around the home was associated with lower emissions. The finding might be related to people's preference for nature and privacy, which also was linked to lower local emissions (Table 7). Previously, studies have suggested residential self-selection as a possible explanation, with attitudes driving the choice of home location (e.g., Große et al., 2019; Haybatollahi et al., 2015), while others have explained it with residential sorting, wherein attitudes

Table 7
Regression models on local travel emissions. 2a – OLS regression of local travel emissions. Significance levels: $p < 0.001$ ***, $p < 0.01$ **, $p < 0.05$ *, $p < 0.1$ˆ.

		2a. Local travel emissions	
		(n = 502)	
		β	Sig.
(Constant) (B)		3.382	0.000***
Education level	Low	−0.001	0.969
	Medium	ref	ref
	High	0.013	0.698
Working time	Part-time (less than 35 h/week)	−0.083	0.011*
	Full time	ref	ref
	Overtime (more than 45 h/week)	0.054	0.102
Household type	Single person household	−0.119	0.001**
	Household with children	ref	ref
	Couple household	0.012	0.729
	Shared adult household	−0.026	0.415
Number of bedrooms	One	ref	ref
	Two	−0.012	0.792
	Three or more	0.072	0.180
Type of residence	Apartment	0.029	0.442
	Other	ref	ref
Home ownership	Yes	0.021	0.555
	No	ref	ref
Access to private yard	Yes	−0.026	0.476
	No	ref	ref
Population density		−0.117	0.012*
Open spaces		−0.097	0.048*
Blue spaces		0.005	0.891
Public transport zone	10 + departures within 5 min walking distance	0.065	0.069ˆ
	4–10 departures within 5 min walking distance	0.051	0.276
	Less than 4 departures within 5 min walking distance	0.023	0.598
	No departures within 5 min walking distance	ref	ref
Car in household	Yes	0.265	0.000***
	No		
PEA		0.009	0.833
Cosmopolitan attitude		0.053	0.099ˆ
Climate awareness		0.004	0.915
Prefers leisure in urban areas vs in nature		−0.025	0.471
Preference for living in suburb		0.124	0.004**
Pro-car attitude		0.208	0.000***
Preference for shared housing and transport		−0.091	0.019*
Preference for nature and privacy		−0.087	0.017*
AS Centricity	Polycentric	0.360	0.000***
	Not polycentric	ref	ref
AS size (km^2)		0.184	0.000***
AS elongation		0.117	0.000***
	R2	0.569	
	Adjusted R2	0.542	
	F-statistic	20.753	0.000
	Durbin-Watson	2.031	

adjust based on where one lives (e.g., Næss, 2014).

After controlling for known variables (Czepkiewicz et al., 2019), all three examined AS characteristics were significantly related to local travel emissions. It is important to note that distance from the home to the city centre was not included in the regression model due to multicollinearity between distance to city centre, AS size and local travel emissions. AS size, elongation and polycentricity, which increase with distance from the city centre (Table 6), were positively correlated with local travel emissions at a significant level (Table 7). The results connect well to previous studies on the matter (e.g. Ramezani et al., 2021; Perchoux et al., 2014; Harding et al., 2013; Næss et al., 2021; Chen and Akar, 2016; Hasanzadeh et al., 2021).

4.2.2. Domestic leisure travel emissions

Mean domestic leisure travel emissions of the study sample were 266 kgCO2eq (SD: 384). A categorical comparison of means is presented in Appendix 2. Domestic leisure travel participation was linked with all AS characteristics across models, where higher participation indicated slightly higher AS size and higher likelihood of having a polycentric AS. On the other hand, participating in domestic leisure travel was also associated with notably lower elongation, or lower one-directional mobility, within the city (Table 6). This means that people with dispersed and large activity spaces are more likely to participate in domestic travel as well. Their AS type (polycentric, large size, low elongation) indicates a highly mobile urban lifestyle in which they interact with multiple urban spaces. Despite the diversity of locations they likely interact with locally, these people still engage in domestic leisure travel, which is possibly explained by the compensation effect (e.g. Holden and Norland, 2005; Næss, 2006; Strandell and Hall, 2015) stemming from stress from hectic urban life (Raudsepp et al., 2021).

Having access to a private yard or garden was associated with lower domestic leisure travel emissions. In addition, access to a cabin is a potential catalyst of domestic leisure travel, increasing the likelihood of participation by 95 % and having a positive association with emissions (Table 8). This has also been noted in prior studies (Czepkiewicz et al., 2020; Xue et al., 2020; Næss et al., 2019). Another possible explanation, although typically noted for international travel, is family and social ties. Although most of the population live in the Reykjavík Capital Area, Icelanders often have ties all over the country and it is a reason for them to travel domestically (Raudsepp et al., 2021).

Contrary to previous research in the same location, where domestic travel was identified as a driver of car-ownership (Heinonen et al., 2021), and car ownership predicted the number of domestic trips (Czepkiewicz et al., 2020), car ownership did not significantly affect domestic leisure travel participation in this analysis. This could be due to high car ownership in our sample, coupled with domestic leisure trips usually being taken with other people (Pucheanu et al., 2020) who may own cars, which is then reflected in reduced emissions. It could also be evidence of having a mobile urban lifestyle being more relevant in predicting domestic leisure travel than simply having a car in the household. Also, it seems that women are more likely to engage in domestic travel than men (Table 8).

After controlling for gender, working time, private yard access, car ownership, distance to city centre, open spaces, and attitudes (Czepkiewicz et al., 2019), all three AS characteristics were still significantly related to engagement in domestic leisure travel but not to domestic leisure travel emissions. Having a polycentric AS type increases the likelihood of participating in domestic leisure travel threefold. Engaging in more one directional mobility within the city (higher elongation) and having a smaller AS was associated with reduced likelihood of participating in domestic leisure travel.

The results could be an indication of a highly mobile lifestyle among Reykjavík urbanites, which has been hinted at in prior studies (e.g. Czepkiewicz et al., 2019). A busy urban mobility pattern is reflected in large AS size, polycentricity and low elongation. At the same time, AS characteristics were not connected to emissions from domestic leisure travel of those that participate in it, but only the likelihood of participation. In addition, in our models, a cosmopolitan attitude was associated with higher domestic leisure travel emissions and preferring urban areas instead of nature during leisure travel was associated with lower emissions (Table 8).

Although there are some indications of compensatory behaviour related to domestic leisure travel, it seems to mainly stem from the hectic nature of urban living (Raudsepp et al., 2021), which is reflected in large AS size, polycentricity and low elongation, and less from lack of

Table 8
Regression models on domestic leisure travel emissions. 3a – binomial logistic regression of participation in domestic leisure travel; 3b – OLS regression of domestic leisure travel emissions. Significance levels: p < 0.001 ****, p < 0.01 ***, p < 0.05 **, p < 0.1^.

		3a. Engages in domestic leisure travel		3b. Domestic leisure travel emissions	
		(n = 512)		(n = 464)	
		Exp(B)	Sig.	β	Sig.
(Constant) (B)		4.554	0.035*	5.231	0.000***
Gender	Female	1.953	0.051^	−0.023	0.633
	Male + other	ref	ref	ref	ref
Working time	Part-time (less than 35 h/week)	1.472	0.422	−0.012	0.812
	Full time	ref	ref	ref	ref
	Overtime (more than 45 h/week)	1.529	0.303	0.024	0.627
Access to private yard	Yes	0.807	0.544	−0.079	0.097^
	No	ref	ref	ref	ref
Open spaces		0.220	0.225	−0.010	0.858
Access to cabin	Yes	1.946	0.063^	0.123	0.009**
	No	ref	ref	ref	ref
Car in household	Yes	1.230	0.682	0.010	0.844
	No	ref	ref	ref	ref
Distance to city center	Less than 1 km	ref	ref	ref	ref
	1–3 km	0.813	0.732	0.049	0.531
	3–7 km	0.649	0.475	−0.020	0.816
	7–12 km	1.013	0.985	−0.040	0.674
	More than 12 km	8.928	0.123	−0.021	0.773
PEA		0.938	0.751	0.064	0.248
Cosmopolitan attitude		1.115	0.566	0.080	0.085^
Climate awareness		0.828	0.335	0.076	0.155
Prefer urban areas to nature		0.800	0.246	−0.166	0.000***
AS centricity	Polycentric	3.491	0.004**	0.022	0.674
	Not polycentric	ref	ref	ref	ref
AS size (km^2)		1.049	0.093^	0.061	0.257
AS elongation		0.803	0.014*	−0.068	0.168
	R2			0.080	
	Adjusted R2			0.042	
	F-statistic			2.140	0.004
	Durbin-Watson			1.892	
	Nagelkerke R2	0.249			
	Chi-square	7.744	0.459		
	Omnibus test	62.879	0.000		
	Predictive power	91.00 %			

greenness in the home vicinity as found in some previous studies (e.g. Næss, 2006; Strandell and Hall, 2015). However, having access to a private yard displayed a negative association with domestic leisure travel emissions, which matches previous findings suggesting that it matters less for people to go on domestic leisure trips when they have a relaxing set-up in their own yard (e.g. Raudsepp et al., 2021).

4.2.3. International leisure travel emissions

Mean international leisure travel emissions of the study sample were 2587 kgCO2eq (SD = 3232). A categorical comparison of means is presented in Appendix 3. Living closer to the city centre was linked to higher international leisure emissions (Appendix 3).

A low income level was associated with over 60 % lower likelihood of participating in international leisure travel compared to a medium income level, while a very high income was related to 12.9 % higher emissions from international leisure travel. Couple households were three times more likely to engage in international leisure travel compared to households with children (Table 9).

After controlling for income, household type, private yard access, cabin access, car ownership, language skill, distance to city centre and attitudes (Czepkiewicz et al., 2019), none of the examined AS characteristics were significantly associated with international leisure travel. However, having a polycentric AS type increased the likelihood of participating in international leisure travel by around 50 % (Table 9)

Table 9
Regression models on international leisure travel emissions. 4a – binomial logistic regression of participation in international leisure travel; 4b – OLS regression of international leisure travel emissions. Significance: p < 0.001 ****, p < 0.01 ***, p < 0.05 **, p < 0.1^.

		4a. Engages in international leisure travel		4b. International leisure travel emissions	
		(n = 512)		(n = 414)	
		Exp(B)	Sig.	β	Sig.
(Constant) (B)		1.312	0.723	7.935	0.000***
Income level	Low	0.383	0.042^	0.062	0.243
	Medium	ref	ref	ref	ref
	High	1.370	0.369	0.080	0.182
	Very high	1.548	0.175	0.129	0.037*
Household type	Single person household	1.287	0.464	0.023	0.683
	Household with children	ref	ref	ref	ref
	Couple household	3.156	0.004**	0.087	0.105
	Shared adult household	0.816	0.781	0.030	0.557
Access to private yard	Yes	1.326	0.286	0.011	0.836
	No	ref	ref	ref	ref
Access to cabin	Yes	1.335	0.271	0.004	0.940
	No	ref	ref	ref	ref
Car in household	Yes	1.956	0.109	−0.060	0.287
	No	ref	ref	ref	ref
Languages spoken	One	ref	ref	ref	ref
	Two	0.952	0.932	−0.046	0.728
	Three or more	1.091	0.883	0.017	0.896
Distance to city center	Less than 1 km	ref	ref	ref	ref
	1–3 km	0.848	0.770	−0.028	0.737
	3–7 km	0.737	0.576	−0.124	0.180
	7–12 km	0.417	0.126	−0.015	0.877
	More than 12 km	0.348	0.127	−0.040	0.578
PEA		0.999	0.993	0.002	0.967
Cosmopolitan attitude		2.110	0.000***	0.110	0.026*
Climate awareness		1.083	0.548	0.096	0.086^
Prefer urban areas to nature		0.936	0.640	−0.023	0.654
AS centricity	Polycentric	1.498	0.236	0.084	0.147
	Not polycentric	ref	ref	ref	ref
AS size (km^2)		1.002	0.772	−0.049	0.409
AS elongation		1.091	0.260	−0.067	0.211
	R2			0.075	
	Adjusted R2			0.023	
	F-statistic			1.439	0.092
	Durbin-Watson			1.709	
	Nagelkerke R2	0.217			
	Chi-square	9.341	0.314		
	Omnibus test	74.263	0.000		
	Predictive power	82.60 %			

and was associated with higher emissions compared to people with a non-polycentric AS type (Appendix 3), which could indicate a highly mobile urban lifestyle (visiting many locations) being reflected in international leisure travel. Previous qualitative research found that a hectic urban life and commuting stress can be a driver of leisure travel (Raudsepp et al., 2021), which may well be the explanation behind this association.

That said, the attitudinal variables were more significant in our model for predicting international leisure travel. As in previous studies (e.g. Czepkiewicz et al., 2019), cosmopolitan attitude was a notable predictor of participation in international leisure travel and was associated with higher emissions. Interestingly, climate awareness was positively related to international leisure travel emissions (Table 9). It has also been noted in previous studies, where people seemingly travel regardless of their awareness of climate-related issues and concerns (Árnadóttir et al., 2019).

4.2.4. *Summary*

When considering urban form and transportation access, it seems that there were very few people living in a functioning 15-minute neighbourhood within our sample. Broadly, access to any kind of motorised transport seemed to enable visiting more destinations, which was reflected in larger AS size, polycentricity and higher local emissions. More densely populated areas are usually associated with higher land use diversity, but in the case of Reykjavík, living there encourages more dispersed urban mobility as polycentric AS types prevail. To reduce urban mobility emissions, more local living should be encouraged (Heinonen et al., 2013a,b; Næss et al., 2021) and improved local opportunities would support this development (Fan and Khattak, 2008). The focus in planning should be to increase accessibility without using cars and creating a healthy and liveable local environment, and generally aiming to reduce necessary travel (Holz-Rau and Scheiner, 2019). One way could be to establish co-working hubs in suburban centres. But to reduce transport related emissions, interventions should be on a national and supranational scale, and also consider that local travel is mainly driven by needs (Holz-Rau and Scheiner, 2019).

Interestingly, although previous studies have noted that Iceland is a generally wealthy society where income has little effect on travel emissions (i.e., Czepkiewicz et al., 2020a; Heinonen et al., 2021), the case study showed that the low income group had a more compact AS, which could stem from their lower income. Furthermore, lower income could lead to reduced opportunities in residential selection, transport accessibility and service accessibility potentially stemming from the lower income level. Although planners might desire a more compact urban environment, for many it still represents a lack of opportunities. Planning should be careful to consider the needs of people as well, particularly if compact, local living is driven by low socio-economic status rather than by choice (Sharp et al., 2015; Chen and Akar, 2016; Perchoux et al., 2014).

A relationship between participating in domestic leisure travel and AS characteristics was found, but not with a notable effect size. It can be hypothesised that the underlying reason for the relationship is a combination of compensation, nature-seeking behaviour and social ties (Holden and Norland, 2005; Næss, 2006; Strandell and Hall, 2015; Raudsepp et al, 2021; Ramezani et al., 2021). No significant relationship between AS size, elongation and international leisure travel was found. However, polycentricity was indicative of higher likelihood of participation in international leisure travel. The connections hint at a highly mobile lifestyle among Reykjavík urbanites, likely stemming from cosmopolitan attitudes which drive people to visit a diverse set of locations and seek cultural diversity (e.g. Czepkiewicz et al., 2018, 2019).

5. Conclusion

The study employed a novel method of individual-based activity spaces to provide a deeper understanding of the complex interactions between the urban environments, local mobility and leisure travel behaviour in a case study of Reykjavík, Iceland. Firstly, the study aimed to understand the connection between urban form and activity spaces at a 15-minute neighbourhood level. Secondly, the study examined the connections between activity spaces, local travel emissions and leisure travel emissions.

At the local level, the study highlights the lack of functioning 15-minute neighbourhoods and adequate public transit in the capital area, pointing to a need for improved urban planning and infrastructure. The results showed that people living near a higher number of public transportation connections have higher local travel emissions, likely meaning that the public transit is not used to its full potential, as previous research has suggested (Heinonen et al., 2021). It is established that activity spaces are closely connected to local travel emissions, particularly due to high car use in Reykjavík. This is reflected in generally large average AS size, a pro-car attitude, and dominating polycentricity among the sample. This is considered as evidence of a highly mobile urban lifestyle among Reykjavík urbanites. Moreover, our findings reveal that high levels of urban mobility are linked to higher engagement in domestic leisure travel. This indicates that a possible underlying reason for domestic leisure travel could be compensation behaviour from high levels of urban mobility which fuels commuting stress, as suggested in prior studies. Another possible reason is social network dispersion.

As the first of its kind to study activity spaces and travel emissions, the study provides several new avenues of exploration. However, it is important to discuss the limitations of the study in question. When using a case study approach, the results cannot be generalised over other locations or all the population of the Reykjavík Capital Region. They are always highly dependent on the local context. At the same time, mobility is also very dependent on the local context, which makes case studies a useful tool. Moreover, similar approaches can and should be used in other case studies elsewhere to understand those locations better and to compare the results to those of this study to see which patterns might be more general. Also, our sample was collected in 2017, has under 700 participants, and covers only the young adults (25–40 years of age), the results are therefore telling about their lifestyles and the associated emissions, not about the whole population of the study area. This particular target group, young adults, was chosen to reduce the effect of life course variables and generational differences. People within this age group are often employed and already independent from their parents, and also have grown up in a globalised world with international leisure travel as something fully normal for them, and with good access to information and communication technologies. However, the choice limits the generalizability of the results.

As our data is from the pre-pandemic time, it would be useful to study mobility post-pandemic and to assess how the emissions from travel have changed. Also, when looking at the climate impacts of transport, future studies should be mindful of the targets for global warming and analyse how the footprints fit within those limits. Furthermore, such studies should consider the social floor of transportation, taking a closer look at transportation poverty among certain socio-economic groups and excess urban mobility that is driven by lack of opportunities (Dillman et al., 2021).

It could also be relevant for future studies to apply other methods of data collection. Other data collection methods such as mobile positioning data or GPS data can provide a more accurate assessment of mobility and visited destinations, but these types of data are difficult to access for many researchers. One alternative that could capture mobility over a longer period would be a survey with travel diaries (Hasanzadeh, 2022).

The use of a polygon-based approach to estimate activity spaces in this study facilitated extensive spatial analysis. However, this model is simplistic and may cause biases, such as overestimation of activity spaces (Hasanzadeh, 2018). Additionally, the study considered exposure to open spaces around the home but not during the commute, which might impact behaviour differently, for instance, by contributing to commuting stress (Raudsepp et al., 2021). While the customised home range model used in this study may have mitigated some limitations (Hasanzadeh et al., 2017), adopting a raster-based model like the individualised residential exposure model (IREM) in future research could address these issues by considering the most likely network routes and weighing exposure to various land use types by mode of transport and frequency of visit (Hasanzadeh et al., 2019). Exposure to various environments can also impact health and well-being (e.g., Laatikainen et al., 2018; Perchoux et al., 2014) so it would be interesting to see how exposure to various land-use types during daily commuting is connected to people's life satisfaction across various domains.

Theoretically, this research advances the understanding of activity spaces by employing an individualised home range model that incorporates frequently visited points and mobility patterns. Using PPGIS data, this model refines the traditional Minimum Convex Polygon method, offering a more accurate and flexible representation of personal spatial behaviour. However, limitations remain that can be addressed in future studies by using more comprehensive AS modelling approaches, such as raster-based exposure estimation models.

Practically, the research provides valuable insights for urban planners and policymakers aiming to reduce travel-related greenhouse gas emissions. It underscores the importance of designing compact urban forms and improving access to local amenities to minimise the need for extensive travel. Incorporating green and blue infrastructure is also recommended to reduce commuting stress and promote sustainable travel behaviours.

Overall, this study aimed to bridge the gap between theoretical models of activity spaces and their practical applications in urban planning, providing an analytical framework that can be further refined and reused in future research and policy development. By highlighting both the theoretical and practical contributions, this research underscores the critical role of urban design in fostering sustainable and equitable urban mobility.

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CRediT authorship contribution statement

Johanna Raudsepp: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Kayla M. Thorbjörnsson:** Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Kamyar Hasanzadeh:** Formal analysis, Methodology, Software, Supervision, Validation, Writing – review & editing. **Michał Czepkiewicz:** Data curation, Methodology, Supervision, Writing – review & editing. **Áróra Árnadóttir:** Supervision, Writing – review & editing. **Jukka Heinonen:** Data curation, Funding acquisition, Project administration, Supervision, Writing – review & editing.

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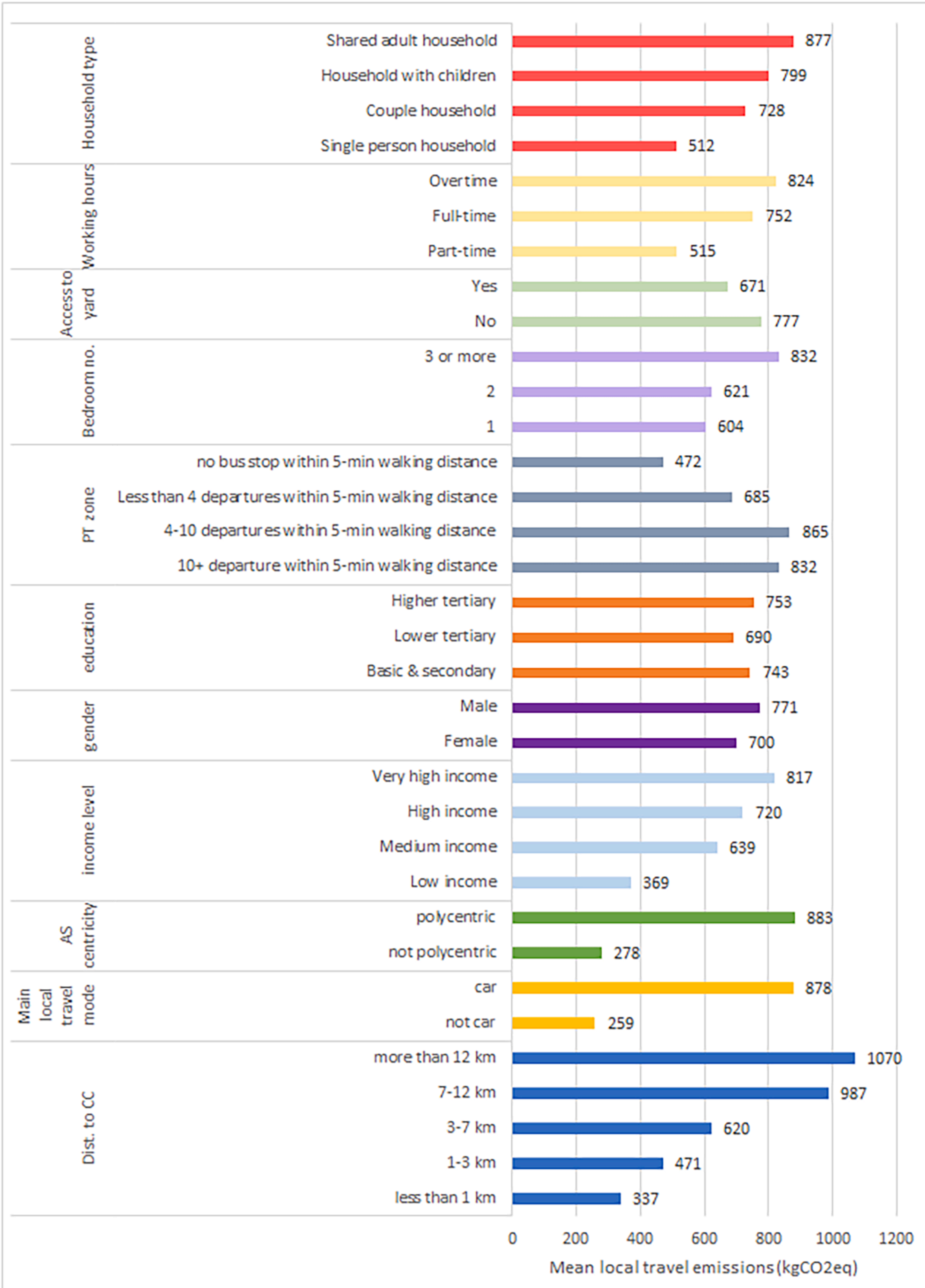
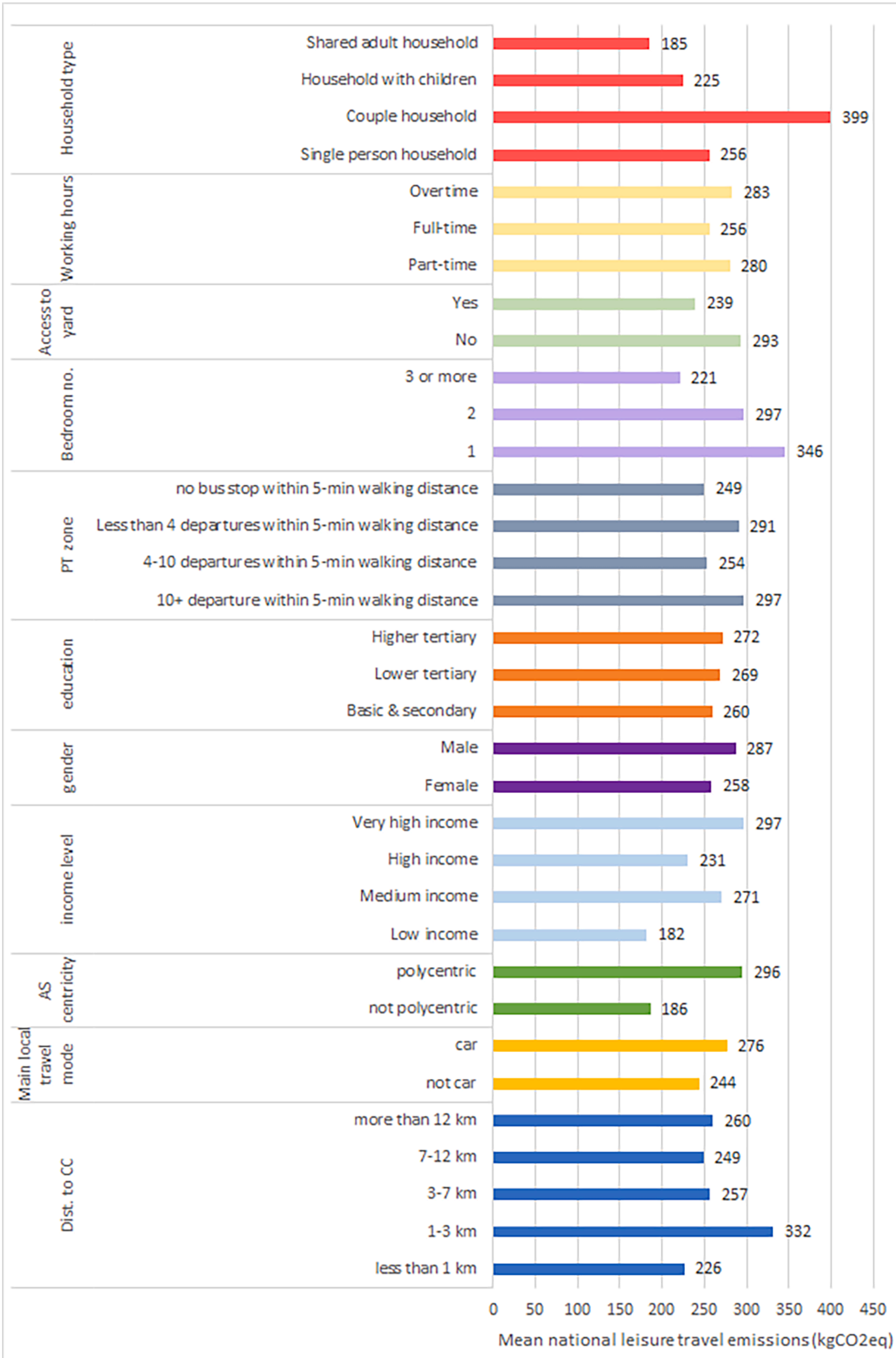
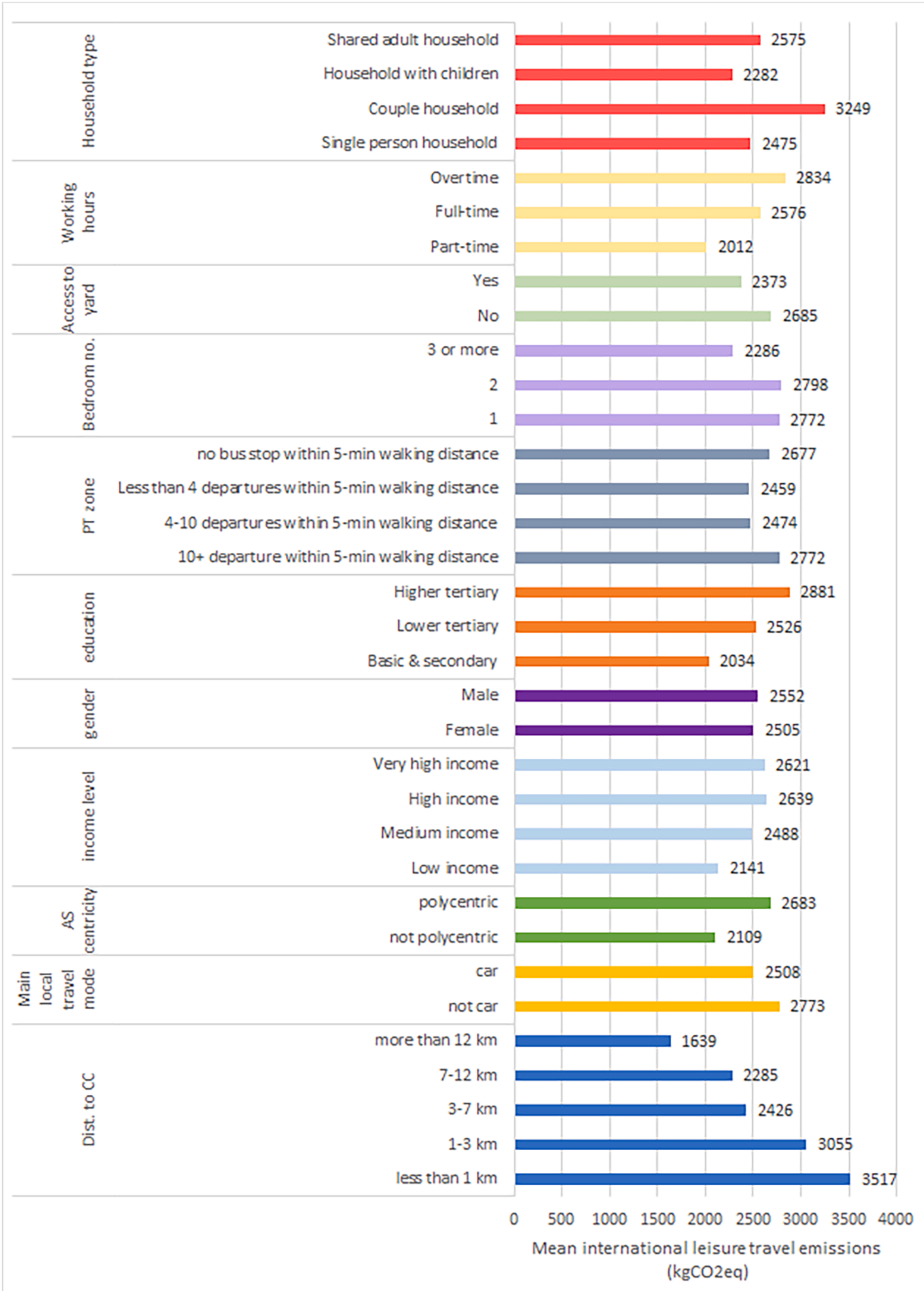
Appendix 1. Mean local travel emissions (kgCO2eq) split by background variable categories.



Appendix 2. Mean national travel emissions (kgCO2eq) split by background variable categories.



Appendix 3. Mean international leisure travel emissions (kgCO2eq) split by background variable categories.



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