UNIVERSITY OF ICELAND

Activity spaces: a novel approach to describing urban mobility and designing low-carbon development

Project report for Vegagerðin

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Project goals

1. Map activity spaces in Reykjavik for the first time.
2. Identify main origins and destinations based on the activity spaces
3. Analyse GHG emissions from travel in relation to activity space characteristics
4. Identify and analyse smallest activity spaces with the smallest GHG emissions

1 Background

1.1 Cities and climate change

Climate change has become an existential threat to our living environment, vastly due to anthropogenic impact on global systems (IPCC, 2018). We have already crossed the threshold of several planetary boundaries, indicating the urgency of climate change mitigation efforts to maintain favorable living conditions on our planet (Rockström et al., 2009; Steffen et al., 2015). Despite lockdowns during the global COVID-19 pandemic, annual anthropogenic greenhouse gas (GHG) emissions only declined by 6.4% (Tollefson, 2021). The remaining carbon budget for a 66% chance of keeping warming below 1.5 degrees is likely less than 400 Gt (IPCC, 2021), meaning that with the current pace it will be entirely used in less than 10 years. It is clear that action in all sectors is urgently and rapidly needed, but many questions remain about what is feasible and efficient.

Cities are crucial to climate change mitigation efforts (Bai et al., 2018; Hertwich & Peters, 2009). Urban areas are already home to more than half of the world's population, and this proportion is expected to grow to 66% in upcoming years (UN, 2014). Cities drive economies, consume the most energy and materials, and produce the most waste (Hoornweg et al., 2016), and therefore lead to environmental degradation (Battista & de Lieto Vollaro, 2017; Yan et al., 2016). Cities cause about 75% of global energy-related CO2 emissions (IPCC, 2014).

1.2 Cities and transport

Transportation is one of the dominant contributing sectors to climate change in populated areas, contributing not only to GHG emissions but also to air pollution and human exposure to fine particulate matter. 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). Reykjavik urbanites have been found to be highly mobile, resulting in high average emissions (Czepkiewicz et al., 2019) due to the high rates of deeply rooted car-ownership and car-use for daily travel (Heinonen et al., 2021). However, it is an issue that cannot solely be solved through decarbonizing transport with electric vehicles, despite Iceland's climate-friendly energy grid. Long-term impacts require changes in human behaviour and technology (Dillmann et al., 2021). Studies on 1.5-degree compatible lifestyles have indicated that personal transport footprints (that is footprints from travelling locally or for leisure either with one's own vehicle or shared/public transport) should be reduced to 0.71 tCO2eq by 2030 to meet the 1.5-degree warming limit (Akenji et al., 2021).

The most 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 & Cervero, 2010; Glaeser & Kahn, 2010). However, smaller living spaces in dense areas typically have more services around them, enabling people to expand their homes with shared public spaces (Heinonen et al., 2013). Furthermore, higher emissions from air travel have been noted as an unintended side effect of densification (Holden & Linnerud, 2011; Holden & Norland, 2005). Although people living in central densely built urban areas might use less cars (Heinonen et al., 2021), they partake in more long-distance leisure travel compared to residents of other areas (Árnadóttir et al., 2019; Czepkiewicz, et al., 2018b), counteracting the emissions reduced from daily travel (Czepkiewicz et al., 2018a, 2019; Ottelin et al., 2014, 2017). Previous studies have shown that even those who have pro-environmental attitudes take several long-distance leisure trips, increasing their GHG emissions (e.g. Árnadóttir et al., 2019; Czepkiewicz et al., 2019).

Changes in mobility behaviour should not only be encouraged by raising awareness and incentivising, but also through changes in infrastructure and the urban environment which supports long-term positive change. People are influenced by both their immediate and broader urban environments, reflecting how they travel both within and outside the city, and how they perceive their lives (Raudsepp et al., 2021). Therefore, it is crucial to understand which areas in the urban environment people interact with to reduce the climate impact of urban environments and improve cities so that the needs and wellbeing of people are met. Cities are, after all, for citizens.

1.3 Unpacking human mobility with activity spaces

Activity spaces (AS) describe the spatial and temporal dimensions of locations which people visit regularly (Golledge & Stimson, 1997; Schönfelder & Axhausen, 2004). They provide an understanding of which urban spaces an individual interacts with on a regular basis and how (Järv, Ahas & Witlox, 2014), especially outside of the person's residential environment. Activity spaces can be defined by home location, number of activity locations near the home, duration of living at home location, trips within the neighbourhood (that is the immediate environment), travel to and from regularly visited locations, and travel between and around centres of daily life (work, school, etc.) (Schönfelder & 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 & Ahas, 2014; Wong & Shaw, 2011). However, there are currently no studies that use this approach to understand GHG emissions and design GHG mitigation strategies. Furthermore, activity spaces have not yet been utilized in Iceland to study urban mobility in Reykjavik.

Higher population density has been linked with the use of active travel modes and fewer activity centers (Hasanzadeh et al., 2021). Active travel mode and good access to public transportation have also been found to be connected to smaller, compact activity spaces (Harding, Patterson & Miranda-Moreno, 2013; Chen & Akar, 2016), or conversely driving connected to large activity spaces (Harding, Patterson & Miranda-Moreno, 2013).

In addition to urban form, some socio-demographic factors could influence AS. Younger working age adults with higher incomes are more likely to have multiple activity centers and therefore a polycentric AS compared to older people (60+ years old) in Helsinki, Finland (Hasanzadeh et al., 2021). In Chicago, 20-29-year-olds have a much smaller AS compared to 40-49-year-olds, possibly stemming from suburban residential locations of the older age group. Two-person households are more likely to have a smaller AS compared to 4+ people in the household. However, the same study found that in Beijing it is the younger age groups that have larger AS (Tana et al., 2016). These differences highlight the importance of considering local geographical and cultural underlying factors that might be influencing people's mobility patterns.

Furthermore, lower income levels and living in a low-opportunity, disadvantaged neighbourhood could significantly reduce one's AS size (Sharp et al., 2015; Chen & Akar, 2016), showing how economic status could place a limit on one's mobility even within the city.

2 Data and methods

2.1 PPGIS survey data

The data was collected in late 2017 using an online survey based on the softGIS method (also known as Public Participation GIS, or PPGIS) in which a traditional survey is combined with questions that require respondents to map locations (Brown & Kyttä, 2014; Czepkiewicz et al., 2018c). The survey included questions about the residential location, destinations visited within the urban region, locations and characteristics of international and domestic trip destinations from the previous 12 months, attitudes, and various background variables.

The target population of the survey was 25-40-year-old people living in the Reykjavík Capital Region (consisting of Reykjavík, Kópavogur, Hafnarfjörður, Garðabær, Mosfellsbær, Seltjarnarnes, and Kjósarhreppur). Total number of respondents was 706, and after spatial anomalies were removed, 669 remained as the sample size. For the purpose of this project, questions about the home and home location, questions about travel habits, and frequently visited points (mapped by respondents) were used. The full questionnaire is available at https://app.maptionnaire.com/en/2294/.

2.2 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 activity space 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.

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

The **distance to the city center** was calculated based on the shortest driving distance between home and city center, which was located at the intersection of Laugavegur, Bankastræti, and Skólavörðustígur (Czepkiewicz et al., 2019) and driving distance (in m) from there was calculated using Network Analyst tool in ArcGIS. The distances were calculated in meters and converted into kilometers, and later into distance bands based on Næss et al (2021) to help identify any changes between distances.

Public transportation zones were allocated based on accessibility of public transportation within a 5-minute walking distance, or 400m, from the home (Czepkiewicz et al., 2019) as follows:

- 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

Green space and blue space (classifications were used from GMES Urban Atlas) were measured in relation to a respondent's home location and calculated as the percentage of green or blue space within a 1 km radius circular buffer around the respondents' home as the mean normalized difference vegetation index (NDVI).

2.3 Activity space modelling

In this project, the focus was on the individualised home range model (Hasanzadeh, Broberg, Kyttä, 2017). The model uses the minimum convex polygon method to model home range extents using three key distances:

- D1 - 500m buffer surrounding the immediate home location,
- D2 - 140m buffer surrounding frequently visited points,
- D3 - threshold distance from a respondent’s home.

Activity spaces were modelled using the individualised home range model toolbox published by Kamyar Hasanzadeh (2018). For the purpose of this study, visited location points were limited to those within the geographical Reykjavík capital region, and therefore D3 was not applied in the modelling.

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 is calculated based on the area polygon, which includes all visited activity points, in m2 and then converted into km2 for analysis (Hasansazdeh et al., 2019). AS based on the individualised home range model (Hasanzadeh, Broberg, Kyttä, 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 centers (Hasanzadeh et al., 2019; Hasanzadeh et al., 2021) were within the 15-20-minute walking range (1.6km) 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 (see Figure 1). If a person had only one center outside of this range, they would have a bicentric AS type (see Figure 2). If the respondent had multiple centers outside of this range, they would have a polycentric AS type (see Figure 3).

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 will have high elongation values. Polycentric AS can also have low elongation value as it extends in multiple directions, not just one main direction (i.e. Figure 3).

Figure 1. Example of a monocentric activity space. All visited locations are within the home range.

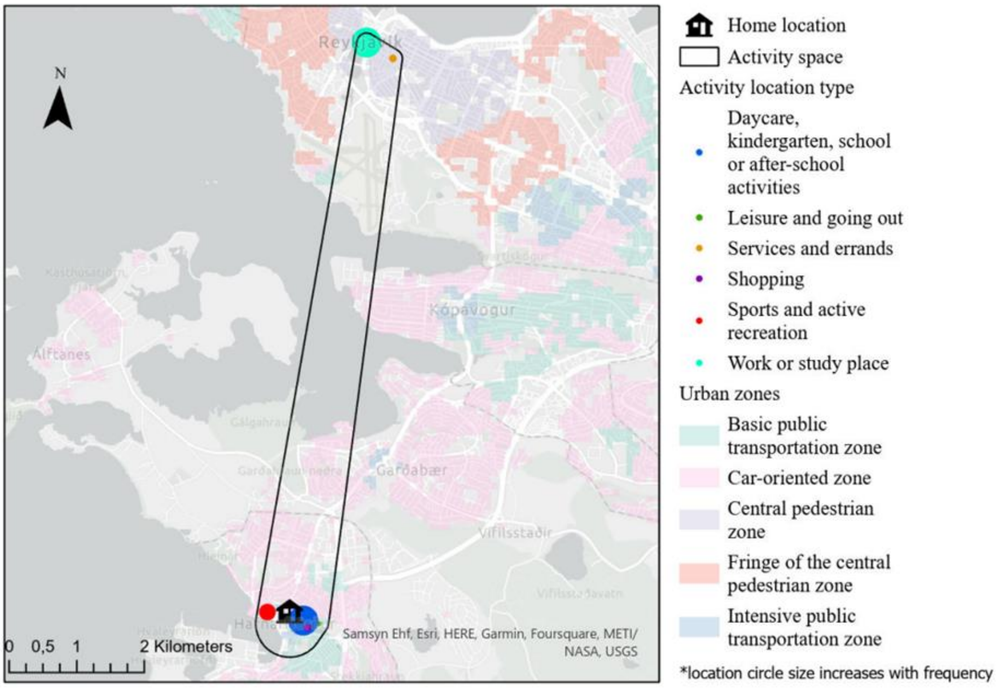

Figure 2. Example of a bicentric activity space. Two activity point clusters are within the home range, with one cluster outside of it.

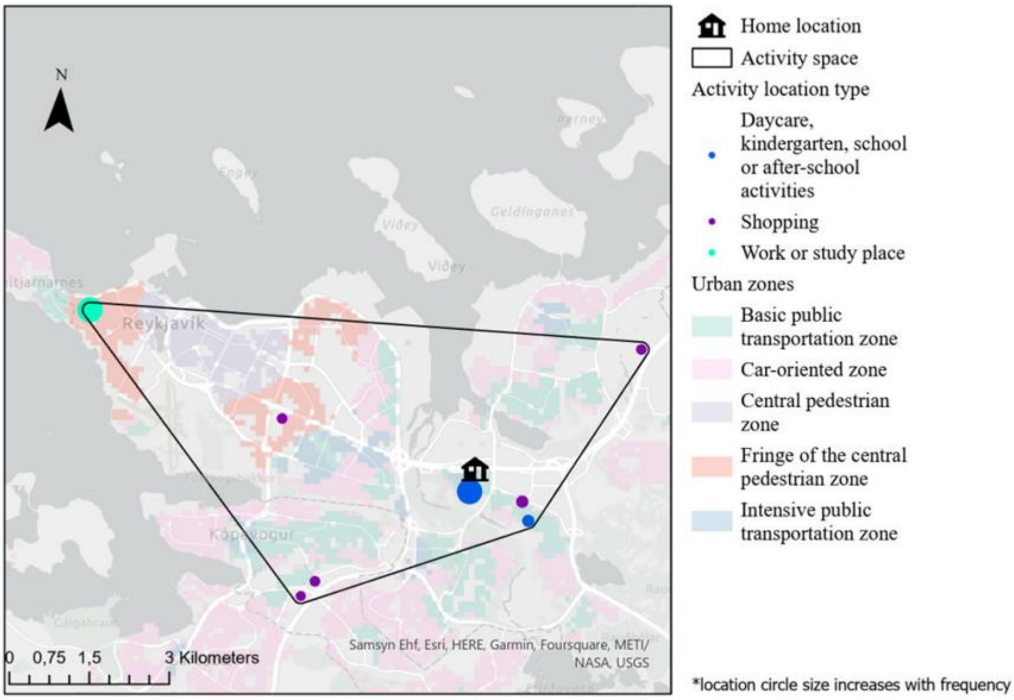

Figure 3. Example of a polycentric activity space. Several activity point clusters have formed outside of the home range, indicating polycentricity.

2.4 Greenhouse gas emissions calculation

Consumption-based local, national and international leisure travel emissions were examined in the study, focusing on direct emissions to narrow down the impact of one's consumption choices. The GHG emission estimates were calculated using life-cycle assessment for both direct and indirect emissions, which are explained in more detail in Czepkiewicz et al. (2019). Local travel emissions include travel within the Reykjavík Capital Area, but not outside of it. National travel emissions include leisure trips made within Iceland. International travel emissions include leisure trips made outside of Iceland.

2.5 Statistical analysis

To study the connections between AS characteristics and GHG emissions from leisure travel, linear regression modelling was used. In the analyses, socio-demographic variables, as well as some urban form-related variables described in the spatial analysis section, were controlled for to find potential underlying reasons for emerging relationships and patterns.

Then, a AS size was split into quintiles and the lowest two quintiles used to mark the smallest AS sizes. This was then used as an output in a binary logistic regression setting, with all prior variables used as input. The set-up of the statistical models is shown in Figure 4.

All statistical analysis was conducted using Jamovi 2.3.21.

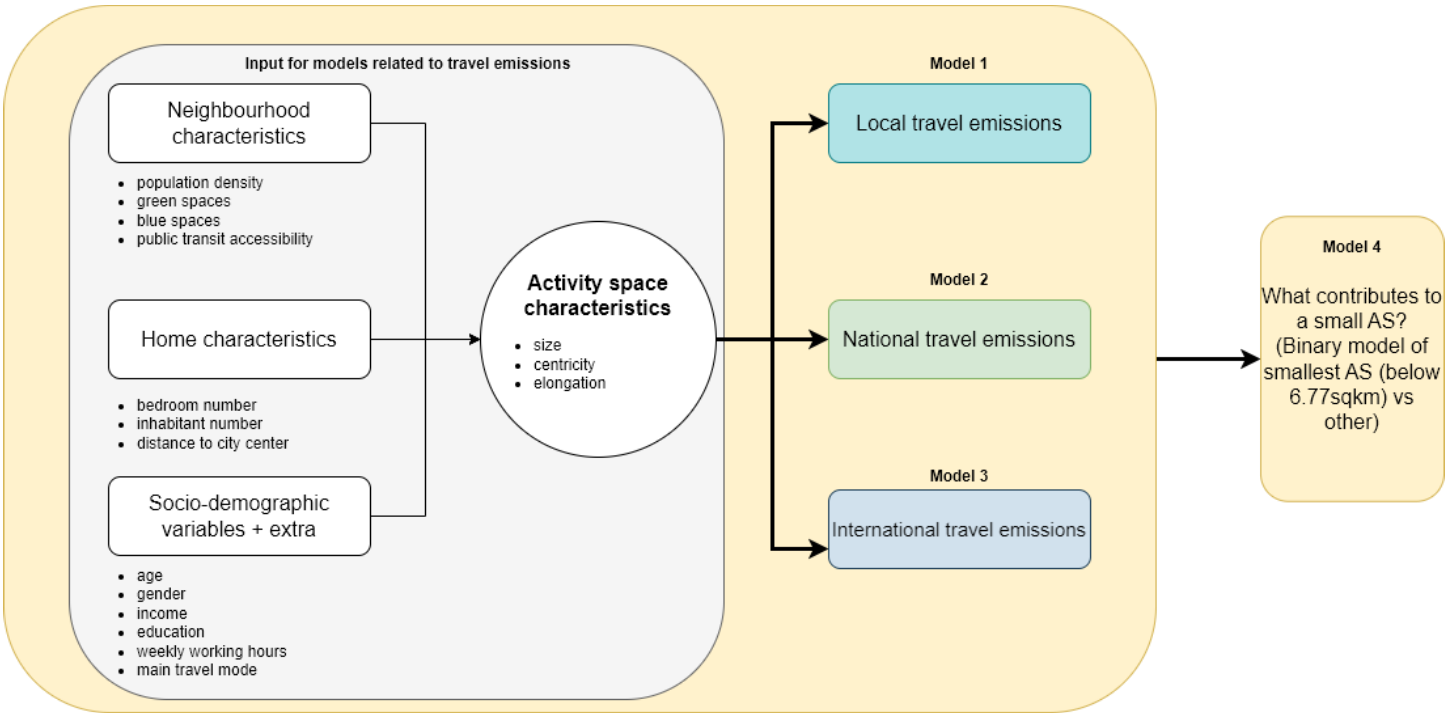

Figure 4. Set-up of input and output variables for statistical modelling.

3 Results & discussion

3.1 Activity spaces in Reykjavik

Activity spaces (AS) in Reykjavík varied quite a lot in size, ranging from 0.79-85.9 km^2 (mean: 14.95 km^2). We analysed the spatial distribution of AS sizes and found that small AS were located around the city center (101, 107, 104, 103, Fossvogur), but also a few further away (i.e. Hraunsholt (Garðabær), Hjallar and Hvammar (Kópavogur). Large AS were located more towards the periphery of the urban area, mainly in Hafnarfjörður, Mosfellsbær, Grafarholt, Árbær, Efra-Breiðholt, Kórar and Norðlingaholt (lower Kópavogur), Kárses (central Kópavogur) (Figure 5, Figure 6). Living furthest from the city center (12+km) is more likely to lead to a more elongated, possibly bicentric, AS ($p < 0.01$).

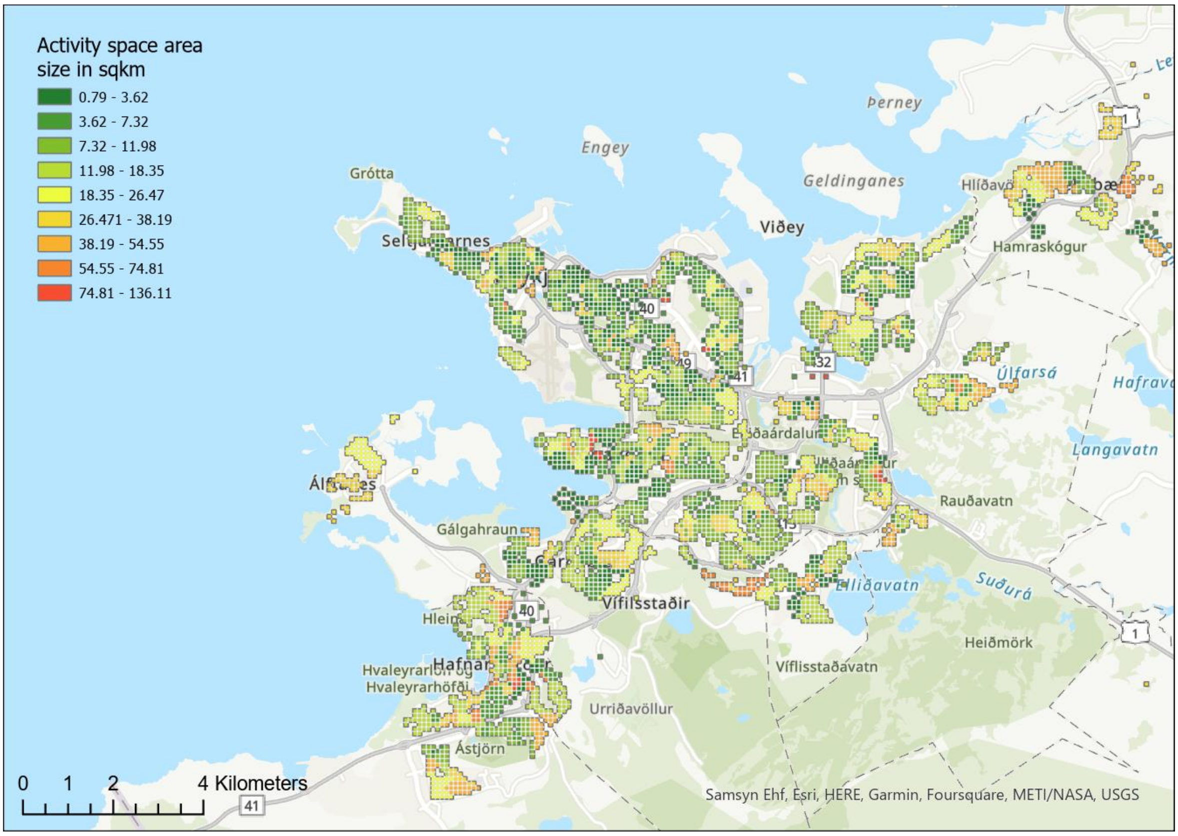

Figure 5. Activity space area size spatial distribution in Reykjavik, extrapolated to the population grid. Green areas are small activity space sizes, red and orange areas are large activity spaces.

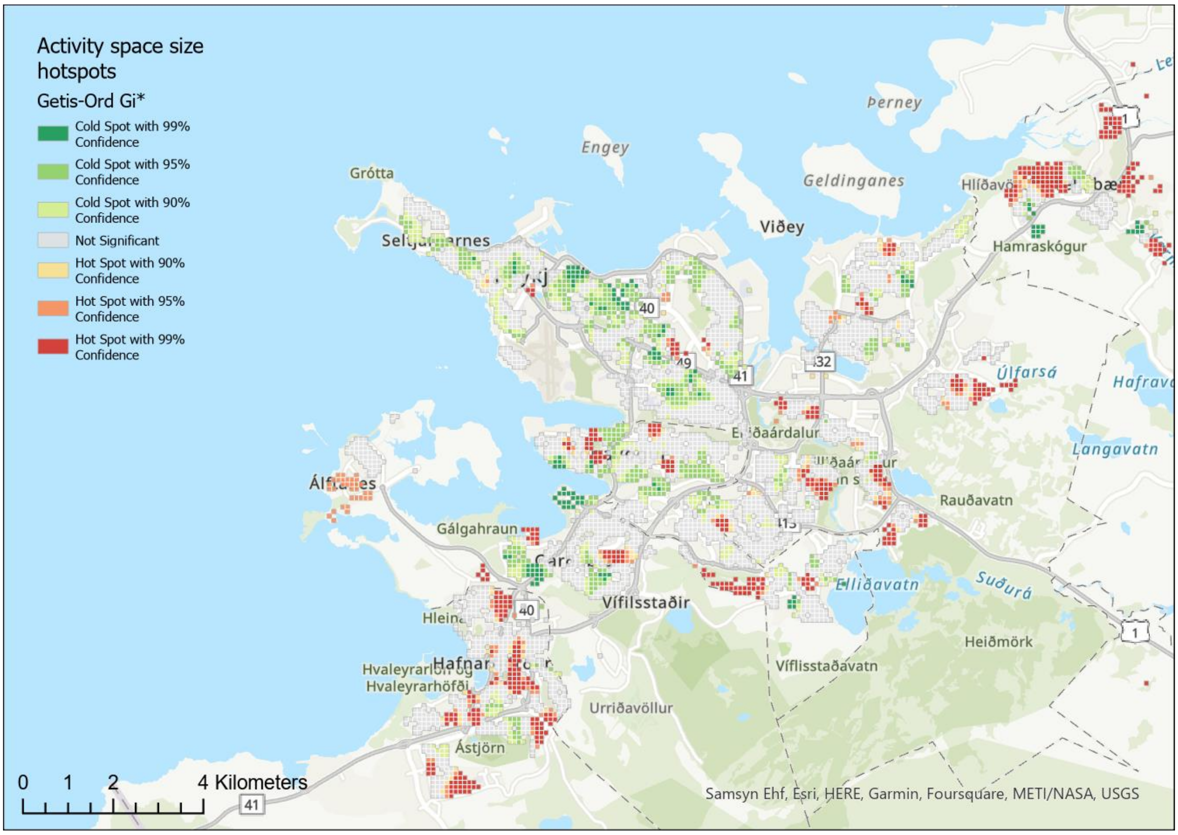

Figure 6. Activity space size hotspots highlighting the highest values and lowest values based on Getis-Ord Gi*, clustered using k-nearest neighbours method. Green areas mark the smallest activity space sizes, red areas mark the highest activity space sizes.

The spatial analysis hints at a wider variety of activities available when living closer to downtown, including destinations for needs-based visits, such as going to work/school, buying groceries, or leisure activities. On the other hand, it was more common for people living further from the city center to have more than two activity centers outside of their local environment (15-20-minute distance in this study). Interestingly, no local centers (i.e. Hamraborg or Hafnarfjörður or Mosfellsbær) emerged that would provide people with access to these common destination types. This was evident in the larger AS sizes as well. We speculate that this pattern likely occurs due to job-related mobility, as many jobs are located in the central area.

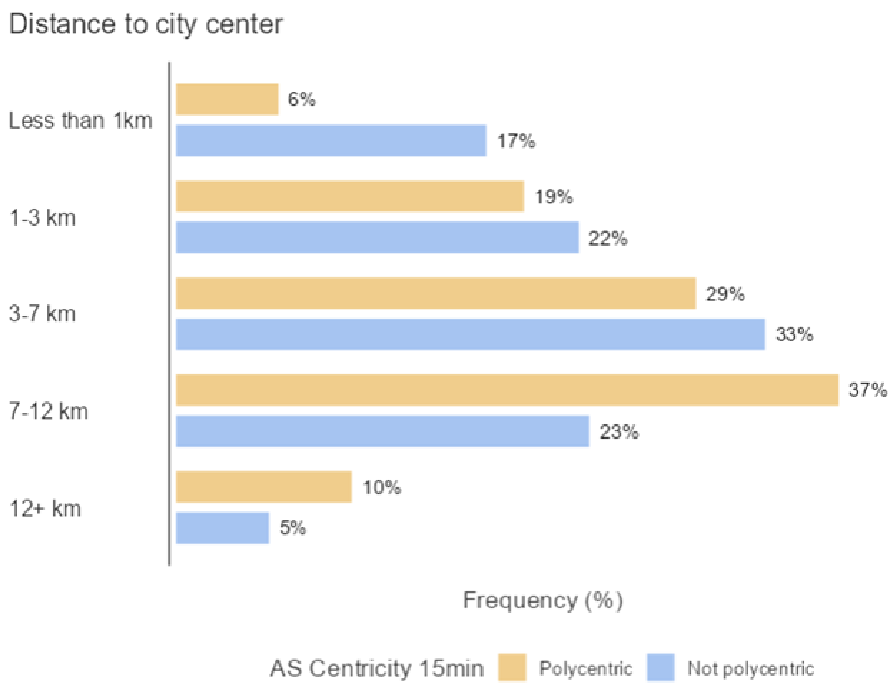

Figure 7. Distribution of polycentric and non-polycentric activity space types in relation to distance from home to city center.

Residents of Reykjavik could be characterized as highly mobile due to the prevalence of multiple activity centers, indicating polycentric AS (see also Figure 7). These activity centers are visited locations within 1km radius of each other, which are likely to be visited together in one trip. Considering that centricity was determined based on the 15-20-minute neighbourhood radius around the home (number of activity centers within the radius vs outside), it could be said that currently there are very few people who live in a 15-20-minute neighbourhood in which they could cover their regular needs. Most of these non-polycentric AS types were located within 3-7km distance from the city center, indicating potential functioning 15-20-minute neighbourhoods. Furthermore, polycentricity was strongly indicative of larger AS sizes at a significant level ($\beta = 0.82$, $p < 0.001$).

3.2 Socio-demographics

In our analyses, we controlled for various socio-demographic variables. There was no significant relationship between AS size and elongation with gender or education level or weekly hours worked. Age did not seem to have a significant influence in any model, which was expected because the sample included people of a similar age. It would be interesting to study differences between age groups as previous studies have noted younger working age adults having larger or polycentric AS compared to older adults who have more local AS (Hasanzadeh et al., 2021; Tana et al., 2016).

Having high income (600,000 - 900,000 ISK), however, was indicative of nearly 30% bigger activity space ($\beta = 0.29$, $p < 0.05$), stemming from higher urban mobility. The results are similar to previous studies in which higher income indicated higher mobility levels (Hasanzadeh et al., 2021). Conversely, the result could indicate that having a lower income pushes a person to reduce mobility, potentially by only engaging in necessary activities and cutting out leisure. Although socio-economic disparities have been suggested as a possible impact factor for AS dimensions, particularly disadvantaged neighbourhoods having to reduce AS sizes due to lack of transport accessibility (Sharp et al., 2015), we do not expect this to be prevalent in Iceland as the whole society is considered very wealthy.

3.3 Activity spaces and GHG emissions from leisure travel

We analysed the influence of AS characteristics on GHG emissions from leisure travel on a local, national and international level. Similarly to AS sizes, leisure travel GHG emissions were mapped and analysed in comparison to AS sizes.

3.3.1 Local travel

As expected, local travel emissions were closely connected to AS size, where for every 1km2 increase in AS size, local travel emissions increased by 22% ($p<0.001$), as well as being connected to centricity, where having a polycentric AS increases travel emissions by 72% ($p<0.001$). Furthermore, active travel modes can lead to more than 85% decrease in local travel GHG emissions ($p<0.001$), while taking a bus to 52% decrease ($p<0.05$).

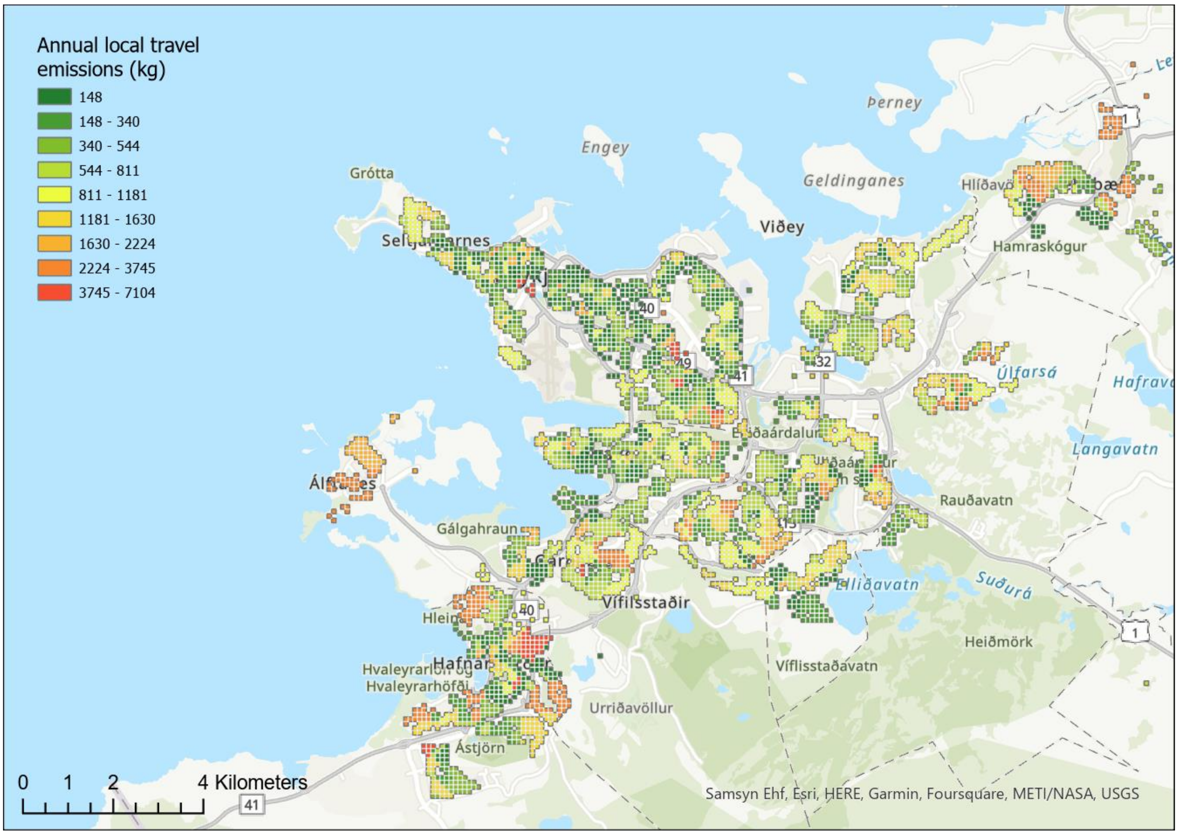

Figure 8. Spatial distribution of annual local travel emissions from the use-phase, in kgCO2eq, across Reykjavik, extrapolated over a population grid. Green - low emissions, red and orange - high emissions. Categories based on Jenks natural breaks.

Higher local travel emissions were clustered in Hafnarfjörður, as well as in other areas further from the city center. Conversely, lower emissions were concentrated closer to the city center (101,107, 104, 103, 108) and around Hamraborg, matching the spatial distribution of AS sizes in those areas. There were also areas where opposing patterns appeared, having small AS sizes but high local travel emissions, suggesting that people living there travel short distances but use a car to do it. Examples of such were in Garðabær and in lower Kópavogur (Figure 8).

3.3.2 National leisure travel

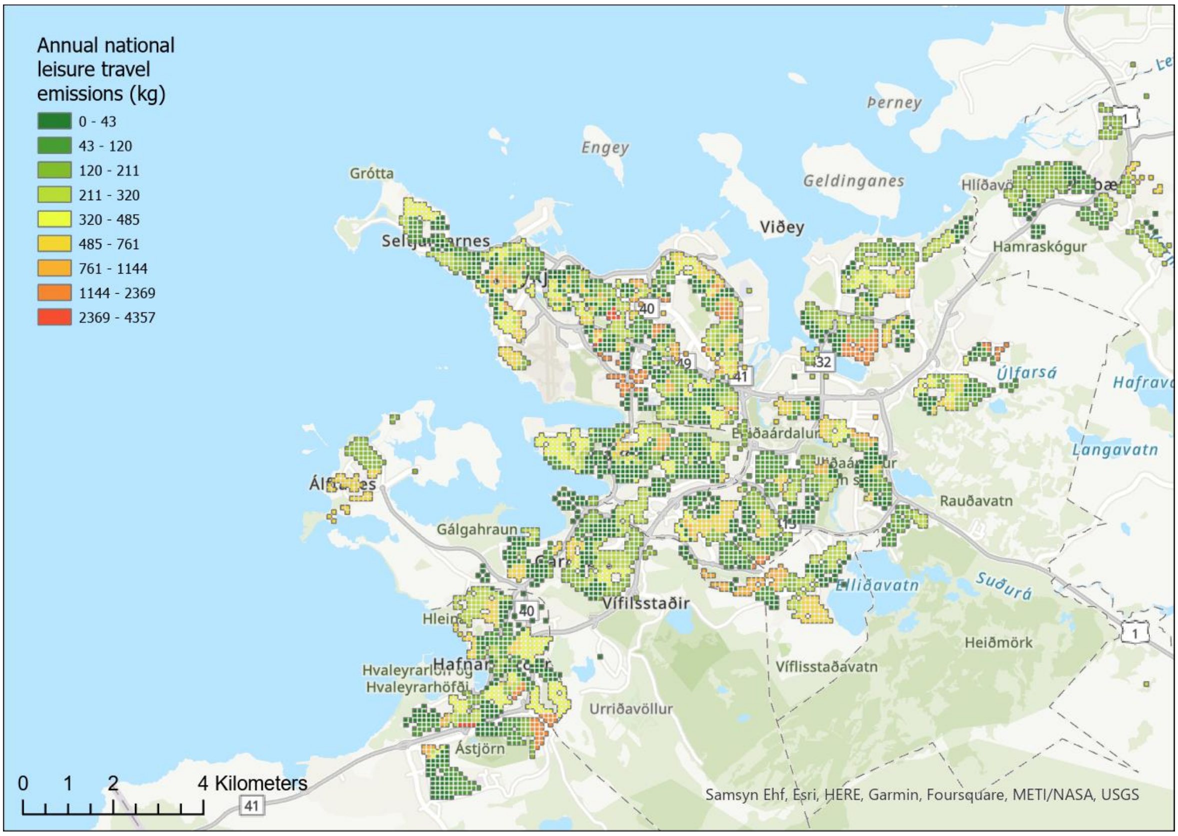

Figure 9. Spatial distribution of annual national leisure travel emissions from the use-phase, in kgCO2eq, across Reykjavik, extrapolated over a population grid. Green - low emissions, red and orange - high emissions. Categories based on Jenks natural breaks.

We found no significant relationships between AS characteristics and national leisure travel emissions, although polycentricity seemed to potentially contribute to 10% higher emissions ($\beta = 0.107$), which could be an indication of a generally mobile or active lifestyle (Czepkiewicz et al., 2018b). Although we noticed a significant negative relationship between population density and national travel ($\beta = -0.21$, $p<0.01$). Emissions increased with distance from the city center ($p<0.01$).

In addition to regression analysis, a spatial observation-based analysis was conducted. Higher national leisure travel emissions emerged in Hafnarfjörður (central area and Ásland), lower Kópavogur (Lindir and Kórar) and Grafarvogur (Foldir), but also close to Suðurhlíðar/Fossvogur and in scattered spots in 108 (Figure 9). The latter three areas, interestingly, have small AS sizes (Figure 5-6). One likely explanation is the compensation hypothesis (e.g. Næss, 2006; Czepkiewicz et al., 2018b; Holz-Rau et al., 2014), where people living in denser central areas wish to compensate for their poor quality urban environment by travelling into nature. Another explanation could be related to personal attitudes and a generally more active nature-based lifestyle, where people often engage in hiking or going out into the nature because they enjoy it (Czepkiewicz et al., 2018b).

In contrast, in Mosfellsbær, Hafnarfjörður (central and Vellir), Garðabær (Búðir), and Norðlingaholt people had lower emissions from national leisure travel (Figure 9), but larger AS sizes (Figure 5-6). Matching low value areas were in central Reykjavik (incl. Hlemmur), Kópavogur (Hjallar, Hvammar) and Garðabær (Lundir). Inversely, matching high value areas were located in lower Kópavogur (Kórar, Lindir), Hafnarfjörður (Ásland) and Álftanes (Figure 5, 6, 9). It can be speculated that these latter areas include people who have a highly mobile lifestyle.

3.3.3 International leisure travel

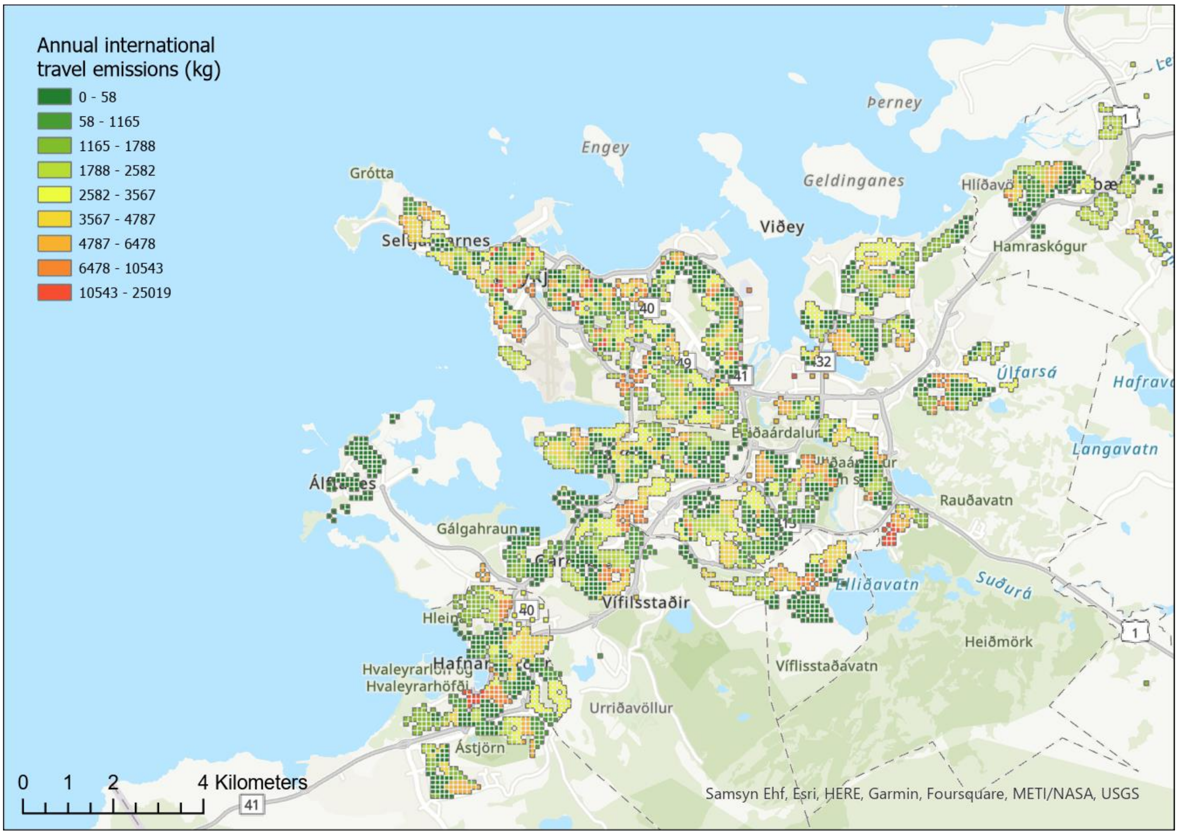

Figure 10. Spatial distribution of annual international leisure travel emissions from the use-phase, in kgCO2eq, across Reykjavik, extrapolated over a population grid. Green - low emissions, red and orange - high emissions. Categories based on Jenks natural breaks.

We found no significant relationships between AS characteristics and GHG emissions from international leisure travel. Therefore, spatial patterns were also studied. We found high international travel emissions concentrated in the city center and its vicinity (101, 107, 104 by Hlemmur, Suðurhlíðar/Fossvogur), Seltjarnarnes, as well as in the furthest areas from the center (Hafnarfjörður (central area, Ásland, Vellir), lower Kópavogur (Kórar), Norðlingaholt, Grafarvogur (Foldir), Grafarholt, Garðabær (Búðir), Mosfellsbær).

When comparing the spatial distributions of international travel emissions (Figure 10) and AS sizes (Figure 5-6), the focus was on identifying areas where high emissions are situated, since the overall aim for climate mitigation should be to reduce the high emissions from leisure travel. With that in mind, we found small AS but high emissions in 101, 107, 104, Seltjarnarnes, Suðurhlíðar/Fossvogur, Grafarvogur (Foldir). This is similar to what has been found previously by Czepkiewicz et al. (2019). Inversely, large AS and low international leisure travel emissions were spotted in Kórar, in Hafnarfjörður (Vellir and some central parts), and Álftanes. In addition, large activity spaces and high international travel emissions were found in Garðabær (Búðir) and Norðlingaholt.

3.4 Origins and destinations of trips

We also examined the origins and destinations of trips by locality in the city center (101), Hafnarfjörður and Grafarholt. These locations were chosen to illustrate the differences between living in the city center, in a suburban central area with a strong local core with many available services, and a newer suburban area without a central core.

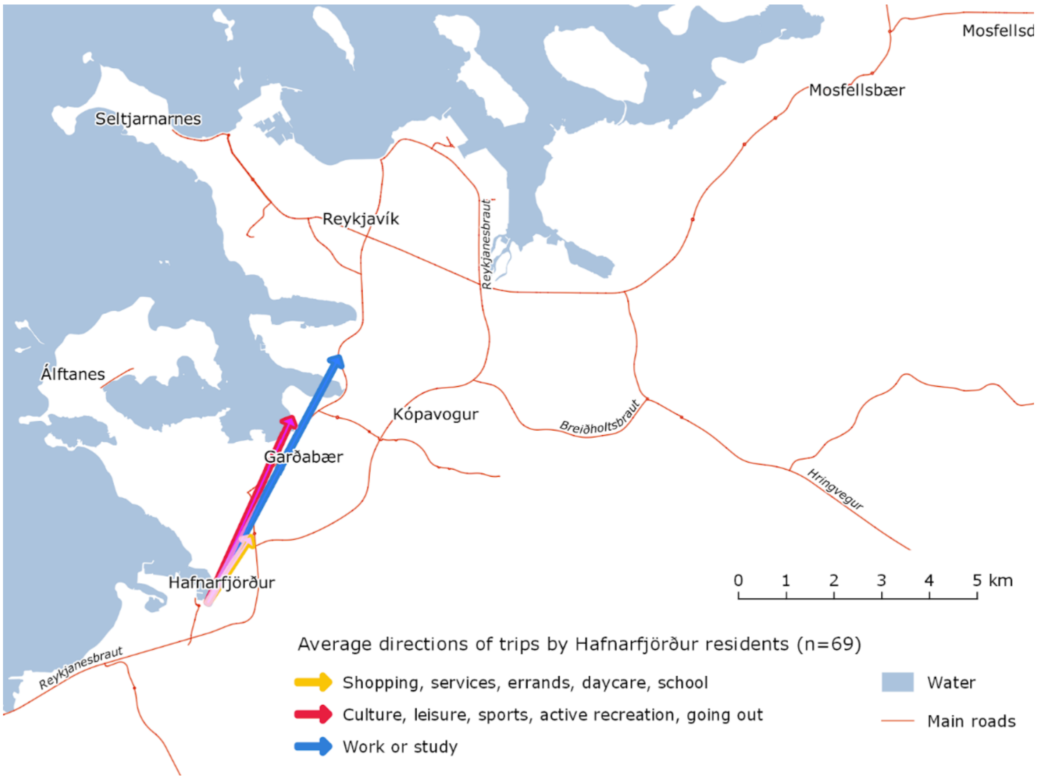

Figure 11. Average direction of trips by residents living in Hafnarfjörður. Arrow length shows average distance for each trip type.

In Hafnarfjörður, it is evident that people head towards the city center to work or for leisure activities. The furthest distances are travelled to work or study places, followed by leisure places. On the other hand, various services and errands are more likely to be reached within the Hafnarfjörður area, indicating that people can get these tasks done in their local area and do not have to travel far (Figure 11).

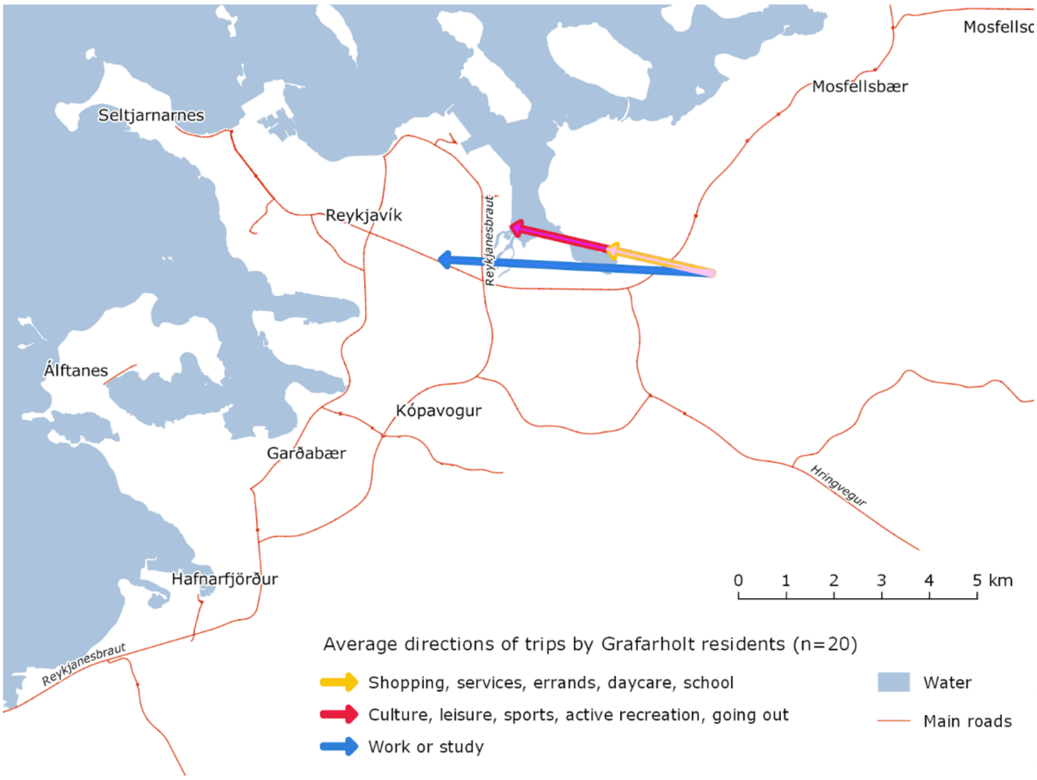

Figure 12. Average direction of trips by residents living in Grafarholt. Arrow length shows average distance for each trip type.

In Grafarholt, the picture changes slightly. Similarly to Hafnarfjörður residents, people in Grafarholt travel the furthest distances for working/studying or leisure activities and these activities are located in the central area of Reykjavik. However, people in Grafarholt also travel further to get to services or run errands. The direction of the yellow arrow indicates mobility towards the city center or the Höfði area, which has several options for various errands available (Figure 12).

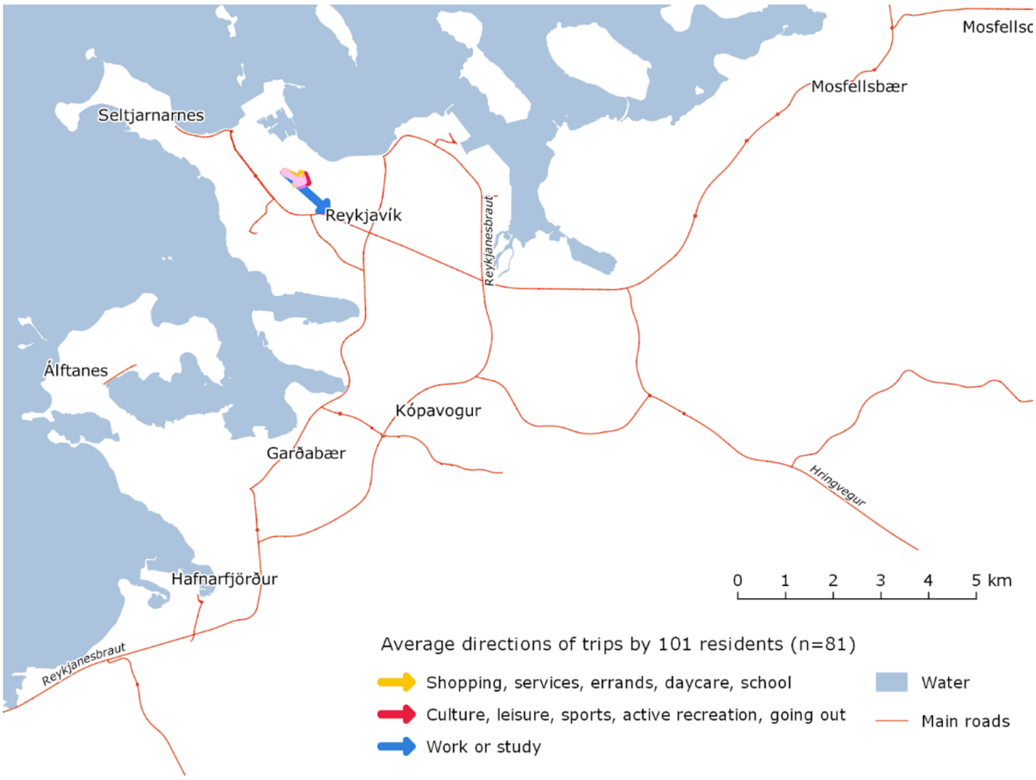

Figure 13. Average direction of trips by residents living in central Reykjavik (101). Arrow length shows average distance for each trip type.

In complete contrast to the previous two, people living in 101 travel on average less than 1km for services, errands, or leisure activities. Their workplaces are also much closer, generally within 2km of the home (Figure 13).

3.5 Where are small activity spaces in Reykjavik?

Activity spaces were sorted into quintiles. It was then determined that the lowest two quintiles together would constitute the smallest AS (under 6.77 sqkm). First, distributions of the two groups of AS sizes were compared in relation to travel emissions. Then, a binary logistic model was used to examine what urban form-related characteristics might contribute to having a small AS. In the model, socio-demographic variables were controlled for.

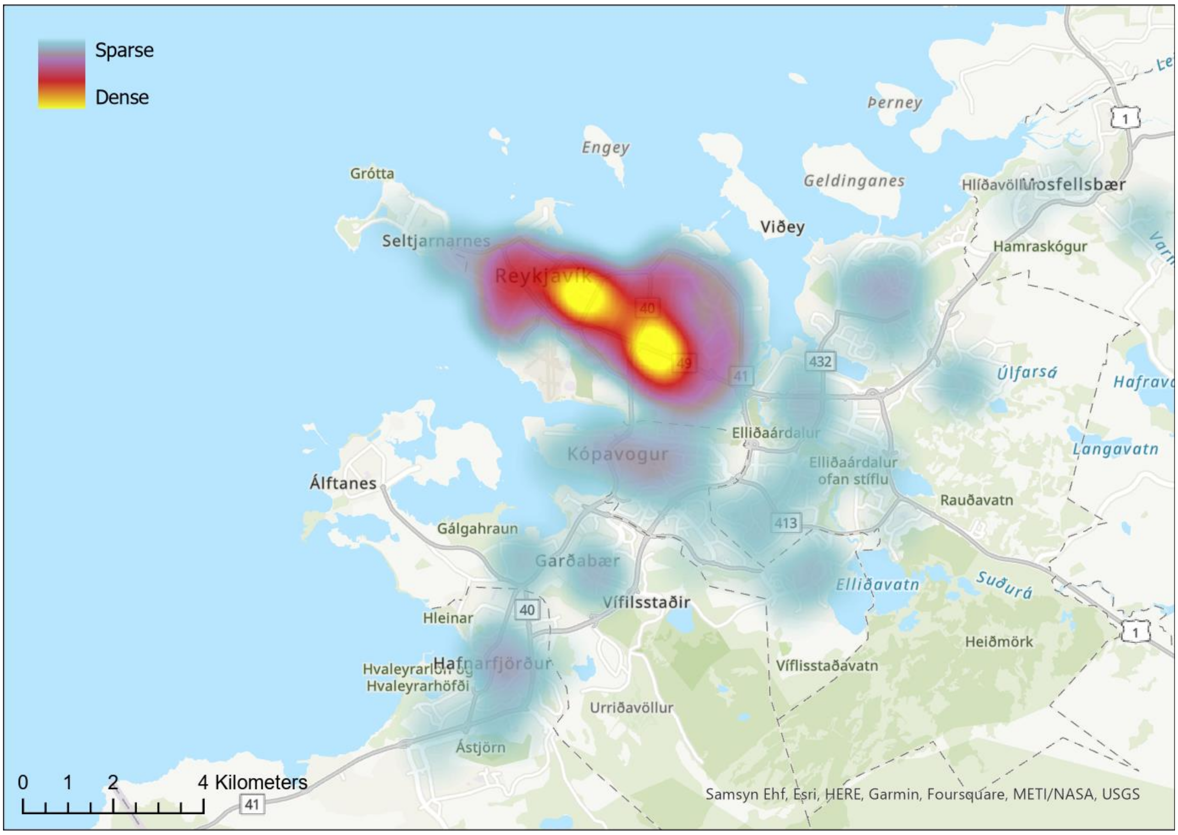

Figure 14. Heatmap showing the density of respondent home locations where the respondent was identified as having a small activity space (below 6.77sqkm). Blue - sparse concentration of people with small AS; red, yellow - dense concentration of people with small AS

After controlling for socio-demographic variables, a few urban environment-related variables emerged to potentially explain having a small AS. Having more blue spaces within 1km reduces the likelihood of having a small AS (Odds Ratio (OR): 0.05; p<0.01). We also found that private yard access could have an impact on having a small AS, wherein having access to one can increase the likelihood 1.2 times, albeit at a non-significant level (p=0.363). Having a small AS size seems to be closely connected to distance to the city center. Namely, living less than 1km from the city center increases the likelihood of having a small AS 14.46 times (OR: 14.46, p<0.001), living 1-3km from the city center increases the likelihood 10.62 times (OR: 10.62, p<0.001), and living 3-7km from the city center increases the likelihood 5 times (OR: 5.00, p<0.01) when compared to living 12+km away from the center. The result is somewhat expected when we consider the geography of the Reykjavik capital area, where proximity to blue spaces increases the further away we get from the city. This is confirmed by the strong connection between small AS and distance to city center. As can be seen in Figure 14, the majority of small AS (those smaller than 6.77

sqkm) were heavily concentrated in the city center and around it (101, 107, 104, 103, 108). Two noticeable hotspots of small AS emerged, one in the very center of 101 and the other by the Kringlan shopping mall.

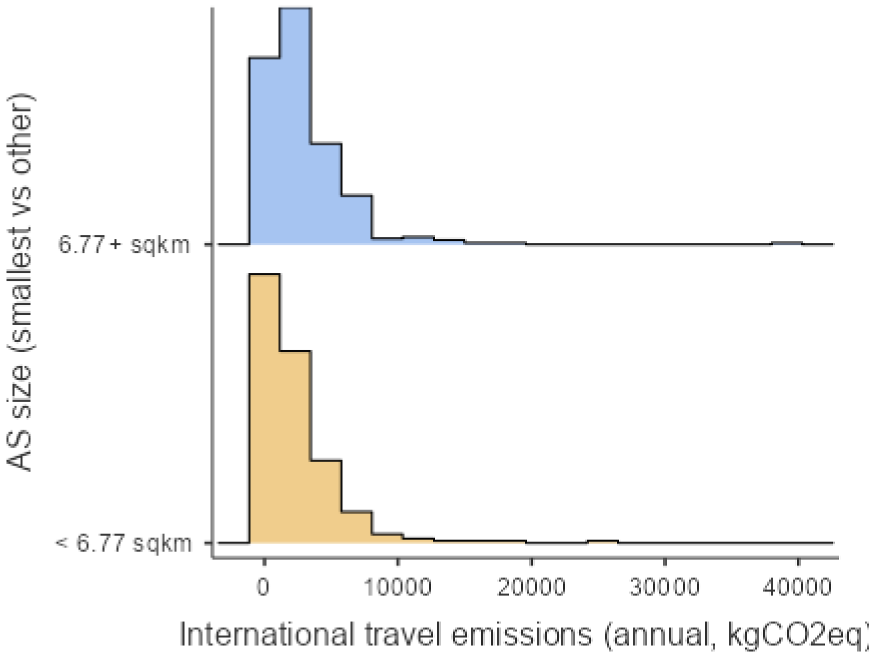

Figure 15. Distribution of annual international travel emissions (kgCO2eq) for people with a small AS (under 6.77sqkm) and those with a larger AS (6.77+ sqkm).

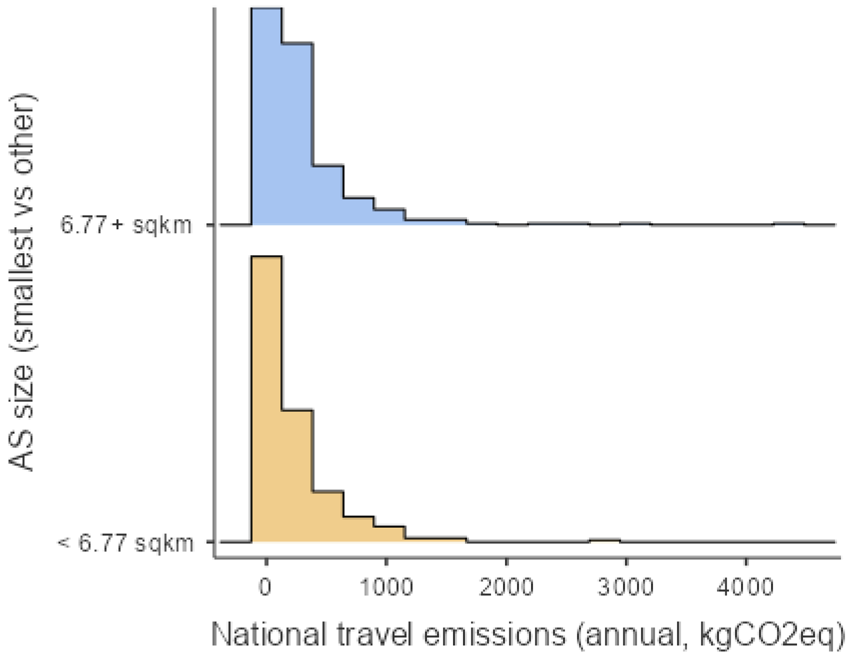

Figure 16. Distribution of annual national travel emissions (kgCO2eq) for people with a small AS (under 6.77sqkm) and those with a larger AS (6.77+ sqkm).

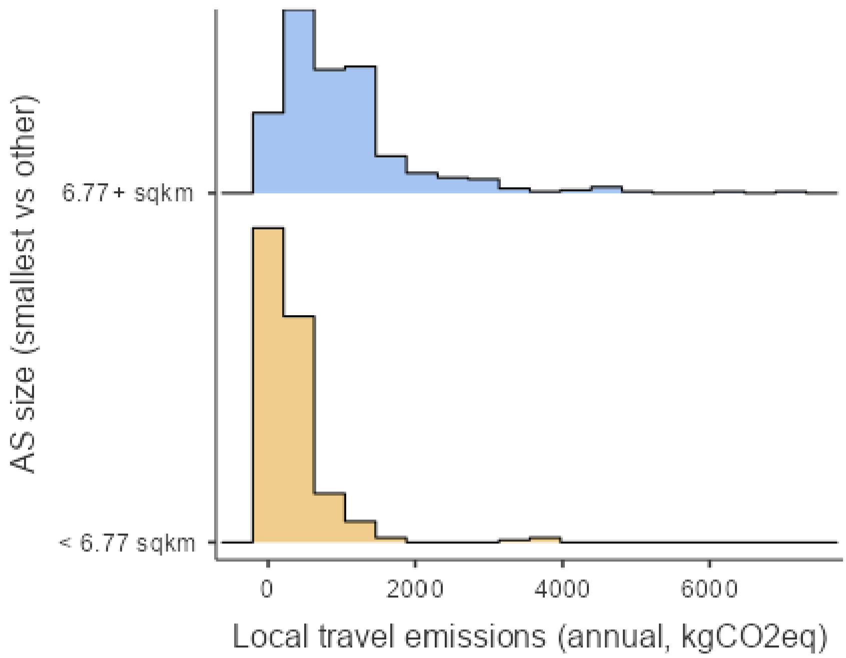

Figure 17. Distribution of annual local travel emissions (kgCO2eq) for people with a small AS (under 6.77sqkm) and those with a larger AS (6.77+ sqkm).

It can be seen from Figures 15-17 that for people with a smaller AS, all travel-related emissions were skewed to be lower than for those outside of the group. This was particularly evident for local travel emissions, as it is directly connected to AS size. For other categories, small AS had more low value peaks than larger AS, although broadly the distribution was quite even. This was also evident when examining correlation between the variables. AS size was most correlated with local travel emissions (r=0.409, p<0.001) and only slightly correlated with national travel emissions (r=0.122, p<0.01), but not at all correlated with international travel emissions. No evident connection can be made to connect local urban mobility to leisure travel footprints, which is a known culprit of high carbon footprints in Iceland. This indicates that there might be some underlying causes for people's leisure travel behaviour, most likely related to attitudes or possibly linked to life satisfaction.

We also noted a connection between public transportation access and small AS size. Having 10+ connections within 5-min walking distance of the home reduces the likelihood of having a small AS (OR: 0.41, p<0.05), and having 4-10 connections within the same distance reduces the likelihood of belonging to this group as well (OR: 0.55, p<0.05). This is an interesting result, as the small AS seem to be concentrated around the city center and Hlemmur area, as well as by Kringlan (Figure 14), which are both areas with good public transport access and higher frequency. Previous studies have indicated that good public transport access would lead to a smaller and compact AS (Harding, Patterson & Miranda-

Moreno, 2013; Chen & Akar, 2016), but our results indicate otherwise. However, not driving a car as the main travel mode increases one's likelihood of having a small AS 1.8 times (OR: 1.80, $p<0.05$), which could then indicate that active travel modes in particular are connected to small AS sizes, since public transport access seemed to have the opposite effect. It should be noted that this relationship could also be vice versa - having a small AS through residential selection contributes to not having to drive a car (Czepkiewicz et al., 2018b; Raudsepp et al., 2021).

4 Conclusion

The project “Activity spaces: a novel approach to describing urban mobility and designing low-carbon development”. Activity spaces (AS) were used to study mobility in Reykjavik for the first time. Particular emphasis was on analysing spatial differences between AS and travel emissions. The project set out four core aims:

1. Map activity spaces in Reykjavik for the first time.
2. Identify main origins and destinations based on the activity spaces
3. Analyse GHG emissions from travel in relation to activity space characteristics
4. Identify and analyse smallest activity spaces with the smallest GHG emissions

Activity spaces in Reykjavík varied quite a lot in size with a mean of 14.95 km^2, with sizes increasing with the distance from the city center. There were very few people in our sample that had a monocentric AS, meaning that they have all their activities within the 15-20-minute neighbourhood boundary. Potential 15-20-minute neighbourhoods were located within 3-7km from the city center. It was common for people living further away to have more than two activity centers (polycentric AS), likely due to job-related mobility. This was also evident in the origin-destination analysis. For example people living in Hafnarfjörður were able to run errands more locally, but had to travel to the city center for work and play, which highlights the high concentration of available activity locations in central Reykjavik, including jobs and study places. In contrast, for people living in 101 most activity points were on average within 1-2km of the home. This could also relate back to income - having high income was indicative of nearly 30% bigger activity spaces. The results are similar to previous studies in which higher income indicated higher mobility levels (Hasanzadeh et al., 2021). The interpretation could be two-fold. On one hand, people could be travelling further to have a job that results in a higher income. On the other hand, their higher income could enable them to engage in more activities, thus resulting in bigger AS.

Local travel emissions were closely connected to AS size, where for every 1km2 increase in AS size, local travel emissions increased by 22%. Furthermore, having a polycentric AS increases emissions by 72%. Using active travel modes can lead to more than a 85% decrease in local travel GHG emissions, while taking a bus to a 52% decrease. These results were expected, as mobility, travel modes and local travel emissions are closely connected.

We found no significant relationships between AS characteristics and national or international leisure travel emissions in our regression models. This indicates that there might be some underlying causes for people's leisure travel behaviour, most likely related to attitudes or possibly linked to life satisfaction. When comparing the spatial distributions of international travel emissions and AS sizes, the focus was on identifying areas where high emissions are situated, since the overall aim for climate mitigation should be to reduce the high emissions from travel. Spatial analysis revealed small AS sizes and high national leisure travel emissions in Hafnarfjörður (central area and Ásland), lower Kópavogur (Lindir and Kórar) and Grafarvogur (Foldir), but also close to Suðurhlíðar/Fossvogur and in scattered spots in 108. One likely explanation is the compensation hypothesis (e.g. Næss, 2006; Czepkiewicz et al., 2018b; Holz-Rau et al., 2014), where people living in denser central areas wish to compensate for their poor quality urban environment by travelling into nature. Another explanation could be related to personal attitudes (Czepkiewicz et al., 2018b). In addition, we found small AS but high international leisure travel emissions in 101, 107, 104, Seltjarnarnes, Suðurhlíðar/Fossvogur, Grafarvogur (Foldir). This is similar to what has been found previously by Czepkiewicz et al. (2019).

The likelihood of having a small AS (under 6.77 sqkm) was increased by proximity to blue spaces and distance to the city center. Small AS were heavily concentrated in the city center and around it (101, 107, 104, 103, 108). Two noticeable hotspots emerged, one in the very center of 101 and the other by the Kringlan shopping mall. Better access to public transport did not seem to go hand in hand with small AS sizes, despite such indications from prior studies (Harding, Patterson & Miranda-Moreno, 2013; Chen & Akar, 2016). What is more, not driving a car increases one's likelihood of having a small AS 1.8 times, which could then indicate that active travel modes in particular are connected to small AS sizes, since public transport access seemed to have the opposite effect. It should be noted that this relationship could also be vice versa - having a small AS through residential selection contributes to not having to drive a car (Raudsepp et al., 2021; Czepkiewicz et al., 2018b).

The patterns above also describe a complex urban planning problem in Reykjavik. Firstly, the location of jobs and other key activity points close to the city center versus other areas is a big driver for mobility. Although it could be tricky to move workplaces, the traffic flow to the center could be alleviated by enabling more people to work from home, or establishing local (that is within 15-20-minutes walking from residential areas) workspaces where people can rent a desk for remote working. Also, the diversity of leisure activities further from the center could be improved, which is an issue also highlighted in prior studies (Raudsepp et al., 2021). Secondly, public transport accessibility and lack of frequency is evident, particularly near residential areas and key points of interest. This is illustrated well by the examples from Garðabær and lower Kópavogur, where small AS sizes were matched with high local travel emissions, suggesting that people living there travel short distances by car. In addition, there was a clear relationship between small AS, active travel and lower GHG emissions from local travel. Although public transportation access did not seem to be connected to having a small AS, there are still benefits to using public transit instead of a car due to lower emissions. Transport planning should encourage walkability and using public transport because these have a lower environmental impact than commuting frequent daily travel distances by car (Ewing et al., 2006). Thirdly, the geography of the capital area introduces its own challenges to transport planning. The central area, as it sits on a peninsula, is accessible through one side only, creating a traffic funnel to the center. We hope the latter two issues will be somewhat alleviated by Borgarlinan, as its plans include connecting the center to Kopavogur via bridge. However, we believe that public transport could be improved in the meantime, particularly related to frequency. The poor reputation of the public transport system in Reykjavik has been noted in several studies (i.e. Raudsepp et al., 2021; Heinonen et al., 2021), raising concern that if the reputation does not begin to improve before the launch of Borgarlinan, people will not adapt to it quick enough to reduce transport-related emissions in the city by a significant amount.

4.1 Strengths and limitations

The project achieved the goal of studying AS in Reykjavik for the first time and providing first indications of possible connections between AS and travel-related GHG emissions. We have shown the relevance of this method in studying mobility and have identified areas which need further investigation.

One of the limitations of the study was the small sample size and personal bias of respondents when answering the softGIS survey. We had to rely on people’s memory and best estimates of their trips and trip frequency. More accurate data sources, such as GPS data collected by an opt-in surveying method, or mobile positioning data, which places no burdens on a respondent, could improve the results (i.e. Järv et al., 2014; Hasanzadeh, 2021). However, we recognize the challenges related to obtaining those types of data (Hasanzadeh, 2021). Secondly, the AS model used is based on a convex polygon method, which on one hand enables one to gauge the scale of one’s urban mobility patterns, but on the other hand does not consider the underlying road infrastructure and possible pathways between destinations. This limitation could be improved on by using the individualised residential exposure model as described by Hasanzadeh et al (2018).

4.2 Next steps

There are several research directions to study further. Firstly, studying exposure to different types of land use could provide better insight into what really matters for people from an urban design perspective. A detailed land use typology should be applied, and possibly developed into a typology to characterise neighbourhoods. This could be done using the residential exposure model (Hasanzadeh et al., 2019). Secondly, we suggest developing a mobility typology for the respondents, which would include AS characteristics and travel habits. Both above mentioned typologies could be used to study connections to GHG emissions in better detail. Thirdly, many studies have previously indicated a strong link between mobility and wellbeing, and connections with AS characteristics and health and wellbeing have been made in health science studies. As a next step, we would like to study the associations between wellbeing and AS characteristics, as well as conducting a spatial study of wellbeing in Reykjavik. Then, neighbourhoods with clusters of small AS could be studied further to determine any similarities between the neighbourhoods or between the people living in them. Lastly, a more thorough analysis of routes and frequency of certain routes through the residential exposure model (Hasanzadeh et al., 2019) could provide better insight for transport and road planners as to which areas need to improve in public transport connectivity to reduce the environmental burden from car-heavy local travel in Reykjavik.

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Appendix A

Model Coefficients – Annual local travel GHG emissions (kgCO2eq, use phase, LN transformation)

Predictor	Estimate	SE	t	p	Stand. Estimate
Intercept [a]	5.06411	0.58373	8.6754	< .001	
age	-0.00282	0.01066	-0.2646	0.791	-0.00994
gender:					
Female – Male	0.02909	0.09646	0.3016	0.763	0.02231
education:					
Lower tertiary – Basic & secondary	0.07101	0.12368	0.5742	0.566	0.05447
Higher tertiary – Basic & secondary	0.05541	0.12733	0.4351	0.664	0.04250
income:					
Medium – Low	0.17921	0.16555	1.0825	0.280	0.13746
High – Low	0.01194	0.15091	0.0791	0.937	0.00916
Very high – Low	0.07824	0.14491	0.5399	0.589	0.06001
Hours worked per week:					
30 to 35 – less than 30	-0.02069	0.21713	-0.0953	0.924	-0.01587
35 to 40 – less than 30	0.23612	0.18327	1.2884	0.198	0.18111
40 to 45 – less than 30	0.43923	0.16800	2.6145	0.009	0.33689
more than 45 – less than 30	0.58359	0.17746	3.2885	0.001	0.44762
Access to private yard:					
No – Yes	-0.04656	0.09822	-0.4740	0.636	-0.03571
Bedroom number:					
1 – 4+	-0.09409	0.17580	-0.5352	0.593	-0.07217
2 – 4+	0.00600	0.14903	0.0403	0.968	0.00460
3 – 4+	0.14235	0.13702	1.0389	0.299	0.10918
Inhabitants number:					
1 – 6+	-0.21966	0.24180	-0.9084	0.364	-0.16848
2 – 6+	-0.09472	0.18671	-0.5073	0.612	-0.07265
3 – 6+	-0.10805	0.18593	-0.5811	0.561	-0.08287
4 – 6+	-0.11871	0.17561	-0.6760	0.499	-0.09106
5 – 6+	0.08646	0.18829	0.4592	0.646	0.06631
population density 1km	-0.00720	0.00664	-1.0840	0.279	-0.05613
green spaces 1km	0.11778	0.45176	0.2607	0.794	0.01176
blue spaces 1km	0.21822	0.45401	0.4806	0.631	0.02211
Distance to city center:					
1-3 km – Less than 1km	-0.19812	0.21598	-0.9173	0.359	-0.15196
3-7 km – Less than 1km	-0.18718	0.23553	-0.7947	0.427	-0.14357
7-12 km – Less than 1km	0.00452	0.24611	0.0184	0.985	0.00347

Model Coefficients – Annual local travel GHG emissions (kgCO2eq, use phase, LN transformation)

Predictor	Estimate	SE	t	p	Stand. Estimate
12+ km – Less than 1km	-0.12252	0.30161	-0.4062	0.685	-0.09397
Public transport zone:					
2 – 1	-0.21613	0.20816	-1.0383	0.300	-0.16578
3 – 1	-0.22517	0.21853	-1.0304	0.303	-0.17271
4 – 1	-0.15407	0.22221	-0.6934	0.488	-0.11817
Main travel mode:					
bus – car	-0.67330	0.25946	-2.5950	0.010	-0.51642
on foot – car	-1.10558	0.14347	-7.7057	< .001	-0.84799
bike – car	-2.02590	0.31585	-6.4142	< .001	-1.55389
AS size in sqkm	0.01741	0.00319	5.4520	< .001	0.21652
AS Centricity 15min:					
Polycentric – Not polycentric	0.94204	0.12283	7.6692	< .001	0.72255
AS elongation	0.10487	0.02657	3.9464	< .001	0.15064

[a] Represents reference level

Model Fit Measures

				Overall Model Test			
Model	R	R^2	Adjusted R^2	F	df1	df2	p
1	0.649	0.421	0.380	10.4	36	513	< .001

Appendix B

Model Coefficients - Annual national travel GHG emissions (kgCO2eq, use phase, LN transformation)

Predictor	Estimate	SE	t	p	Stand. Estimate
Intercept [a]	6.75565	0.70412	9.5944	< .001	
age	-0.01485	0.01271	-1.1683	0.243	-0.05803
gender:					
Female – Male	-0.02498	0.11836	-0.2111	0.833	-0.02141
education:					
Lower tertiary – Basic & secondary	0.24020	0.15178	1.5826	0.114	0.20588
Higher tertiary – Basic & secondary	0.19041	0.15758	1.2084	0.228	0.16320
income:					
Medium – Low	0.11561	0.19868	0.5819	0.561	0.09908
High – Low	-0.00750	0.17801	-0.0421	0.966	-0.00643
Very high – Low	0.30255	0.17544	1.7245	0.085	0.25931
Hours worked per week:					
30 to 35 – less than 30	0.09628	0.25508	0.3774	0.706	0.08252
35 to 40 – less than 30	0.02813	0.21317	0.1320	0.895	0.02411
40 to 45 – less than 30	0.07800	0.19426	0.4015	0.688	0.06685
more than 45 – less than 30	0.19098	0.20480	0.9325	0.352	0.16369
Access to private yard:					
Yes – No	-0.03422	0.11960	-0.2861	0.775	-0.02933
Bedroom number:					
1 – 4+	0.11199	0.21170	0.5290	0.597	0.09598
2 – 4+	0.15578	0.18152	0.8582	0.391	0.13352
3 – 4+	0.13256	0.16924	0.7833	0.434	0.11361
Inhabitants number:					
1 – 6+	0.42411	0.29016	1.4616	0.145	0.36350
2 – 6+	0.22585	0.21974	1.0278	0.305	0.19358
3 – 6+	-0.05515	0.21839	-0.2525	0.801	-0.04727
4 – 6+	-0.11625	0.20671	-0.5624	0.574	-0.09964
5 – 6+	-0.13149	0.22538	-0.5834	0.560	-0.11270
population density 1km	-0.02387	0.00803	-2.9712	0.003	-0.21180
green spaces 1km	-0.17413	0.55581	-0.3133	0.754	-0.01963
blue spaces 1km	-0.71193	0.55736	-1.2773	0.202	-0.07941
Distance to city center:					
1-3 km – Less than 1km	-0.38646	0.25421	-1.5202	0.129	-0.33123
3-7 km – Less than 1km	-0.83556	0.28665	-2.9149	0.004	-0.71616
7-12 km – Less than 1km	-0.98991	0.29994	-3.3003	0.001	-0.84845

Model Coefficients - Annual national travel GHG emissions (kgCO2eq, use phase, LN transformation)

Predictor	Estimate	SE	t	p	Stand. Estimate
12+ km – Less than 1km	-1.23820	0.37242	-3.3247	< .001	-1.06125
Public transport zone:					
2 – 1	0.00402	0.24618	0.0163	0.987	0.00345
3 – 1	-0.01657	0.25743	-0.0644	0.949	-0.01420
4 – 1	-0.20838	0.26150	-0.7969	0.426	-0.17860
Main travel mode:					
bus – car	-0.29237	0.32778	-0.8920	0.373	-0.25058
on foot – car	-0.28886	0.17634	-1.6380	0.102	-0.24758
bike – car	-0.21715	0.32928	-0.6595	0.510	-0.18612
AS size in sqkm	0.00375	0.00369	1.0153	0.311	0.05430
AS Centricity 15min:					
Polycentric – Not polycentric	0.12501	0.15186	0.8232	0.411	0.10714
AS elongation	-0.03701	0.03695	-1.0017	0.317	-0.04999

[a] Represents reference level

Model Fit Measures

				Overall Model Test			
Model	R	R^2	Adjusted R^2	F	df1	df2	p
1	0.340	0.115	0.0432	1.60	36	441	0.017

Appendix C

Model Coefficients - Annual international travel GHG emissions (kgCO2eq, use phase, LN transformation)

Predictor	Estimate	SE	t	p	Stand. Estimate
Intercept [a]	7.96133	0.51951	15.325	< .001	
age	0.00463	0.00932	0.496	0.620	0.0270
gender:					
Female – Male	-0.03853	0.08487	-0.454	0.650	-0.0493
education:					
Lower tertiary – Basic & secondary	0.12538	0.11373	1.102	0.271	0.1605
Higher tertiary – Basic & secondary	0.16448	0.11644	1.413	0.159	0.2106
income:					
Medium – Low	-0.08975	0.14722	-0.610	0.542	-0.1149
High – Low	-0.06249	0.13648	-0.458	0.647	-0.0800
Very high – Low	-0.01950	0.13251	-0.147	0.883	-0.0250
Hours worked per week:					
30 to 35 – less than 30	-0.03723	0.19782	-0.188	0.851	-0.0477
35 to 40 – less than 30	0.12376	0.16525	0.749	0.454	0.1585
40 to 45 – less than 30	0.08621	0.15398	0.560	0.576	0.1104
more than 45 – less than 30	0.13286	0.16431	0.809	0.419	0.1701
Access to private yard:					
Yes – No	-0.07121	0.08598	-0.828	0.408	-0.0912
Bedroom number:					
1 – 4+	-0.14483	0.15408	-0.940	0.348	-0.1854
2 – 4+	-0.08086	0.13136	-0.616	0.539	-0.1035
3 – 4+	-0.05343	0.12435	-0.430	0.668	-0.0684
Inhabitants number:					
1 – 6+	0.24684	0.21085	1.171	0.242	0.3161
2 – 6+	0.27117	0.16945	1.600	0.110	0.3472
3 – 6+	0.02422	0.16675	0.145	0.885	0.0310
4 – 6+	-0.08501	0.16070	-0.529	0.597	-0.1089
5 – 6+	-0.06355	0.16981	-0.374	0.708	-0.0814
population density 1km	-0.00339	0.00582	-0.582	0.561	-0.0448
blue spaces 1km	0.26717	0.39892	0.670	0.503	0.0456
green spaces 1km	-0.16753	0.40876	-0.410	0.682	-0.0276
Distance to city center:					
1-3 km – Less than 1km	-0.20545	0.17281	-1.189	0.235	-0.2631
3-7 km – Less than 1km	-0.35240	0.19776	-1.782	0.076	-0.4512

Model Coefficients - Annual international travel GHG emissions (kgCO2eq, use phase, LN transformation)

Predictor	Estimate	SE	t	p	Stand. Estimate
7-12 km – Less than 1km	-0.20648	0.20893	-0.988	0.324	-0.2644
12+ km – Less than 1km	-0.46207	0.26564	-1.739	0.083	-0.5916
Public transport zone:					
2 – 1	0.04381	0.17621	0.249	0.804	0.0561
3 – 1	-0.01976	0.18389	-0.107	0.914	-0.0253
4 – 1	8.18e-5	0.18236	4.48e-4	1.000	1.05e-4
Main travel mode:					
bus – car	0.12951	0.27821	0.466	0.642	0.1658
on foot – car	-0.09182	0.12345	-0.744	0.457	-0.1176
bike – car	0.04474	0.23788	0.188	0.851	0.0573
AS size in sqkm	-9.95e−4	0.00296	-0.336	0.737	-0.0199
AS Centricity 15min:					
Polycentric – Not polycentric	0.10472	0.10939	0.957	0.339	0.1341
AS elongation	-0.01349	0.02466	-0.547	0.585	-0.0297

[a] Represents reference level

Model Fit Measures

				Overall Model Test			
Model	R	R^2	Adjusted R^2	F	df1	df2	p
1	0.279	0.0779	-0.00748	0.912	36	389	0.617

Appendix D

Model Coefficients - AS size (smallest vs other)

Predictor	Estimate	95% Confidence Interval Lower	Upper	SE	Z	p	Odds ratio
Intercept	1.88637	-1.82390	5.5966	1.8930	0.996	0.319	6.5954
age	0.05894	-0.00572	0.1236	0.0330	1.786	0.074	1.0607
gender:							
Female – Male	0.24803	-0.29877	0.7948	0.2790	0.889	0.374	1.2815
education:							
Lower tertiary – Basic & secondary	0.16859	-0.56430	0.9015	0.3739	0.451	0.652	1.1836
Higher tertiary – Basic & secondary	-0.08877	-0.82566	0.6481	0.3760	-0.236	0.813	0.9151
income:							
Medium – Low	-0.39933	-1.34433	0.5457	0.4822	-0.828	0.408	0.6708
High – Low	-0.44700	-1.29400	0.4000	0.4322	-1.034	0.301	0.6395
Very high – Low	-0.18851	-1.03055	0.6535	0.4296	-0.439	0.661	0.8282
Hours worked per week:							
30 to 35 – less than 30	-0.44014	-1.57250	0.6922	0.5777	-0.762	0.446	0.6439
35 to 40 – less than 30	-0.74604	-1.74613	0.2541	0.5103	-1.462	0.144	0.4742
40 to 45 – less than 30	0.05275	-0.83664	0.9421	0.4538	0.116	0.907	1.0542
more than 45 – less than 30	-0.49623	-1.47943	0.4870	0.5016	-0.989	0.323	0.6088
Access to private yard:							
No – Yes	0.29263	-0.26392	0.8492	0.2840	1.031	0.303	1.3400
Bedroom number:							
1 – 4+	0.23360	-0.75814	1.2253	0.5060	0.462	0.644	1.2631
2 – 4+	-0.39780	-1.25927	0.4637	0.4395	-0.905	0.365	0.6718
3 – 4+	-0.29522	-1.08665	0.4962	0.4038	-0.731	0.465	0.7444
Inhabitants number:							
1 – 6+	0.27105	-1.26627	1.8084	0.7844	0.346	0.730	1.3113

Model Coefficients - AS size (smallest vs other)

Predictor	Estimate	95% Confidence Interval Lower	95% Confidence Interval Upper	SE	Z	p	Odds ratio
2 – 6+	1.06323	-0.14662	2.2731	0.6173	1.722	0.085	2.8957
3 – 6+	0.89330	-0.23011	2.0167	0.5732	1.559	0.119	2.4432
4 – 6+	1.08384	0.01812	2.1496	0.5437	1.993	0.046	2.9560
5 – 6+	1.09339	-0.03647	2.2232	0.5765	1.897	0.058	2.9844
Household type:							
Single – Household with kids	0.05402	-0.84120	0.9492	0.4568	0.118	0.906	1.0555
Couple – Household with kids	-0.43109	-1.29705	0.4349	0.4418	-0.976	0.329	0.6498
Public transport zone:							
2 – 1	0.43822	-0.88073	1.7572	0.6729	0.651	0.515	1.5499
3 – 1	0.40190	-0.93128	1.7351	0.6802	0.591	0.555	1.4947
4 – 1	0.69376	-0.60944	1.9970	0.6649	1.043	0.297	2.0012
population density 1km	-0.01593	-0.05433	0.0225	0.0196	-0.813	0.416	0.9842
blue spaces 1km	-4.58557	-7.58564	-1.5855	1.5307	-2.996	0.003	0.0102
open_sb1km	1.60125	-1.57278	4.7753	1.6194	0.989	0.323	4.9592
Distance to city center:							
1-3 km – Less than 1km	0.13817	-0.99877	1.2751	0.5801	0.238	0.812	1.1482
3-7 km – Less than 1km	-0.76320	-2.00652	0.4801	0.6344	-1.203	0.229	0.4662
7-12 km – Less than 1km	-2.55846	-3.93037	-1.1866	0.7000	-3.655	< .001	0.0774
12+ km – Less than 1km	-3.63039	-5.56856	-1.6922	0.9889	-3.671	< .001	0.0265
AS Centricity 15min:							
Polycentric – Not polycentric	-3.58956	-4.35646	-2.8227	0.3913	-9.174	< .001	0.0276
Main travel mode:							
bus – car	-0.92329	-2.57560	0.7290	0.8430	-1.095	0.273	0.3972
on foot – car	-0.04257	-0.80119	0.7161	0.3871	-0.110	0.912	0.9583
bike – car	-1.25607	-2.94874	0.4366	0.8636	-1.454	0.146	0.2848
National travel emissions (annual, kgCO2eq)	-3.90e−4	-0.00118	4.01e-4	4.03e-4	-0.966	0.334	0.9996

Model Coefficients - AS size (smallest vs other)

Predictor	Estimate	95% Confidence Interval Lower	95% Confidence Interval Upper	SE	Z	p	Odds ratio
International travel emissions (annual, kgCO2eq)	-1.04e−5	-9.04e−5	6.97e-5	4.09e-5	-0.254	0.800	1.0000
Local travel emissions (annual, kgCO2eq)	-0.00120	-0.00178	-6.12e−4	2.99e-4	-4.008	< .001	0.9988

Note. Estimates represent the log odds of "AS size (smallest vs other) = < 6.77 sqkm" vs. "AS size (smallest vs other) = 6.77+ sqkm"

Model Fit Measures

Model	Deviance	AIC	BIC	R^2_{McF}	R^2_N
1	422	502	674	0.429	0.591