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Municipal Transport Route Planning Based on Fair Mobility Budget

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Abstract. A series of initiatives have been adopted in the European Union to address greenhouse gas emissions and establish a society that is resilient to climate change. In response to these initiatives, the implementation of mobility budgets offers a more precise strategy for addressing carbon footprints associated with travel. Prioritizing localized carbon footprint control, mobility budgets are calculated and customized according to distinct regions, goals, and target demographics. When prioritizing the mobility budget as the central objective in municipal transport route planning, the focus should encompass principles of fairness and equity in travel. This entails considering factors such as accessibility, variety of mobility choices, inclusivity of transportation modes, and social justice. Therefore, this article aims to formulate an enhanced activity modelling methodology that would aid data-driven decision-making in municipal transport route planning, while upholding the principles of travel fairness and equity. The results obtained from scrutinizing data related to public bus services and mobile networks are presented. The evaluation of Jelgava's city transportation network to facilitate mobility budget reduction is undertaken, and this assessment is based on an analysis of data derived from a survey on public transport use coupled with an examination of the city's mobility budget. The research presents the communication challenges that municipalities will face in planning and implementing changes that are needed to meet the greenhouse gas emission targets and outlines the possible use of visualization tools for modelling, explanation and communication of scenarios.

Key words: mobility budget, public transportation, mobile phone activity.

Introduction

To tackle greenhouse gas (GHG) emissions, the European Commission of the European Union (EU) has embraced a set of proposals aimed at establishing a climate-resilient society (European Commission, 2023). By implementing technologies and strategies that are in line with these proposals, the EU has already witnessed a noteworthy reduction in overall GHG emissions. While economic growth offers undeniable advantages, it comes with a trade-off in the form of increased overall GHG emissions (International Energy Agency, 2023). This situation highlights the challenge of striking a balance between the benefits of technological advancements and their associated environmental costs.

Carbon footprint management typically involves the implementation of carbon budgets that are applied on regional, national, and industry levels. However, ongoing debates persist about the fairness of allocating these budgets, though there is a common consensus that equity should be prioritized (Hänsel et al., 2022; Pan et al., 2023, Williges et al., 2022). By equity in this paper context understanding fair accessibility to the public transport what means accessible, fast, secure, reliable and CO_2 neutral transportation. While government regulations can be used to manage the carbon footprints of countries and industries through stakeholders' involvement, individual carbon footprints cannot be strictly enforced (Bocken & Allwood, 2012; Khanam et al., 2022). Research suggests that the most significant contributor to the carbon footprint per capita is the chosen mode of travel. A more specific approach to managing travel-related carbon footprints is the application of mobility

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budgets. Scholars have highlighted that the mode of transportation has the most substantial impact on the per capita carbon footprint (Bhoyar et al., 2014; Li et al., 2021). To tackle this concern, adopting mobility budgets offers a more focused strategy for addressing carbon footprints associated with travel. By placing an emphasis on localized carbon footprint management, mobility budgets are calculated and customized based on specific regions, objectives, and target demographics.

At its essence, mobility budgets establish the maximum allowable CO_2 emissions per individual on a daily, weekly, or monthly basis, contingent upon the chosen mode of travel and distance covered. However, despite numerous efforts to define them, standardized parameters for individual mobility budgets have not been established yet. The primary difficulties lie in addressing diverse aspects of impartiality and fairness. For instance, Millonig et al. (Millonig et al., 2022) have presented different approaches to characterize mobility budgets, including employing average upper limits like the daily distance travelled by a specific mode of transportation, and devising customized mobility budgets tailored to specific regions such as Austria.

The findings suggest that while implementing constraints on mobility budgets is viable, it necessitates a region-specific approach that considers an intricate examination of the socio-geographic requisites of each area. This intricate nature makes a uniform approach unworkable, even within the EU. Furthermore, the ongoing challenge of defining equity in the context of transportation policies persists (Randal et al., 2020). When treating the mobility budget as a primary goal for municipal transport route planning, the purpose should encompass fairness and equity principles of travel, including factors like accessibility, mobility options, diversity of transportation types, and social equity. At the same time, it should consider both mobility-related aspects and overall GHG emissions. The outcome of this approach is the determination of a monthly mobility budget that satisfies the specified criteria of fairness, equity, and environmental sustainability.

In addition to personal mobility budgets, in (Millonig, 2023), a minimum mobility budget was introduced, which is defined by how much CO_2 emissions have to be accepted for a person to reach the nearest everyday functionalities. In (Krajzewicz, 2023) the functionalities of an accessibility tool based on minimum mobility budgets are described and the application of the tool to 15 Minute City scenarios in different cities is given. In previous urban equity studies, accessibility is usually defined by reachability of points of interest (POI) by different modes (Kelobonye et al., 2019; Tahmasbi et al., 2019; Yu & Cui, 2023) or by general travel time (Benevenuto & Caulfield, 2020). The approach used in this paper is based on a multimodal approach minimizing CO_2 emissions while guaranteeing accessibility.

Our research focuses on identifying appropriate data analysis methods and analytical algorithms to model and analyses events and data streams in the planning of municipal transport routes, leveraging real-time data. The proposed model prototype aims to expand functionality and establish unified control of the urban environment. This approach will enhance the availability, durability, and maintainability of services, while also enabling the use of the same system for statistical data collection and resource optimization. Hence, the objective of this article is to develop an improved activity modelling approach that supports data-driven decision-making in the planning of municipal transport routes that considers the principles of fairness and equity in travel, using a monthly mobility budget as the basis.

The subsequent sections of this article are organized as follows: the second section delineates the methodologies used for gathering and analyzing public transport data and mobile phone data for the public transport route planning task. It is recognized that the primary objective of planning transportation routes is to find a solution that effectively corresponds to passengers' needs while upholding principles of fairness. The fairness concept, incorporated in the fair mobility budget, is regarded as the rectification of spatial-social disparities by considering the range of choices available to individuals. Subsequently, we highlight the results derived from data analysis concerning public bus services and mobile networks. In the third section we establish the benchmarks for the planning process and evaluating Jelgava's city transport network for mobility budget reduction. This is succeeded by exploring mobility equity, wherein we establish the benchmarks for the planning process. This evaluation of the transport network is based on the analysis of the results of a survey on public transport usage and the examination of the mobility budget of the city of Jelgava, Latvia. The mobility budget is considered the objective of the municipal transport route planning problem and within this framework, the proposed visualization tool acts as a guide for estimating the mobile budget. The initial analysis of GHG budgets and travel times by different transport modes was made, as well as planning scenario for the city of Jelgava involves limiting the use of private cars within the city limits and reducing the average travel time via public transport is considering. Finally, the fourth section presents the discussion and conclusions of the study.

Materials and Methods

To illustrate the impact of individual mobility decisions, a straightforward online self-assessment tool was created (Millonig et al., 2022). This tool helps traffic participants evaluate the consequences of their mobility behavior under varying conditions. Moreover, users can personally customize the tool by adjusting assumptions that are related to technological and social trends, and are requested to furnish statistical data on their personal mobility behavior, including daily distances travelled per mode of transport. Additionally, they can contribute input for potential scenarios related to the evolution of transportation options. To offer meaningful comparisons of the impact of respondents' current mobility behavior, we contextualize their behavior in relation to the prevailing mobility patterns in Jelgava. This approach allows for a more insightful understanding of the individual impact on the overall mobility landscape in the country. To evaluate the transportation implications of individual mobility budgets, data regarding public transportation was sourced from Jelgavas Autobusu Parks Ltd. This dataset covers two comparable timeframes, February 2017 and February 2022, allowing for a demonstration of the impact of COVID-19 restrictions on the use of public transportation services.

During the COVID-19 pandemic, a desire for reduced exposure to public spaces prompted significant changes in the population's behavior. More individuals shifted from using public transport to relying on personal vehicles for commuting. This shift was influenced by factors such as the implementation of stay-at-home measures, including remote work, and the reduction of leisure events. Even with improved protective measures in place, personal transport has proven to be a safer and less restrictive mode of travel during COVID-19. However, this transition has led to an increase in the personal carbon footprint in mobility, impacting individual mobility budgets. To address this issue, the application of mobility budgets offers a more targeted approach to managing the travel-related carbon footprint. Various methods can be employed to specify mobility budgets, one of which involves gathering data from the survey on the mobility modes of individuals traveling to points of interest. This data can then be utilized to estimate greenhouse gas emissions for subsequent analysis, aiming to determine how municipal transport route planning can effectively contribute to the reduction of GHG emissions (Arhipova et al., 2023).

The provided dataset encompasses the following details:

- Percentage and count of entries and exits at specific bus stops in relation to the overall total;
- Discrepancy between entries and exits at specific bus stops (count);
- Distance travelled per trip and day, measured in kilometers;
- Distance travelled categorized by passenger types, presented as percentages and counts;
- Travel duration per trip and day, measured in minutes;
- Average weekly travel duration in minutes.

Data about mobile activity was sourced from Latvijas Mobilais Telefons Ltd (LMT), a telecommunications operator, covering the same timeframes as the public transportation data. This mobile activity dataset consists of call data records (CDR), generated as mobile operator network events within Jelgava. The data was aggregated in 15-minute intervals, preventing the identification of movements of specific individuals. Consequently, privacy concerns did not necessitate additional regulations. The obtained data encompasses the count of unique subscribers in Jelgava for the years 2017 and 2022, as well as the count of unique subscribers per mobile base station per day of the week and per hour of the day (Arhipova et al., 2023). The data was analyzed with the use of R (R Core Team, 2023) and Python Software Foundation, version 3.10.4.

Public Transport Data Set Decription

As mentioned earlier, to obtain a statistical assessment of the influence of COVID-19 on the use of public transportation vehicles, a comparison was made between data from 2017 and 2022. February was taken as the month for analysis based on the availability of data for the year 2022. In total, there were 215,863 passenger trips registered in February 2017, where 183,139 (85%) of those were made on 20 weekdays and 32,724 (15%) on eight weekends. On average, 9,157 trips were made in a single weekday, and 4,091 – on weekends. This shows a significant difference between trip counts on weekdays and weekends. The average number of trips on weekdays was higher by 2.24.

In total, there were 80,028 passenger trips registered in February 2022, where 66,859 (83.5%) of those were made on 20 weekdays and 13,169 (16.5%) on eight weekends. On average, 3,343 trips were made in a single weekday, and 1,646 – on weekends. On average, there was an increase of 2.03 trips on weekdays. This indicates that despite a substantial decrease in the number of trips (by 62.9%), the overall pattern between weekdays and weekends remained consistent. Concerning the distance travelled per trip or per day, the following data was collected. In February 2017, there were 630 bus trips covering a distance of 6,393.2 km total. The mean distance covered per trip stood at 11.5 km, ranging from a minimum of 0.96 km to a maximum of 25.83 km. The results reveal that during February 2017, there was no noteworthy contrast in travel distance between weekdays and weekends, with the average distance per passenger trip amounting to 4.61 km. In February 2022, 157 bus journeys were undertaken, encompassing a distance of 1,677.1 kilometers total. The mean distance travelled per trip stood at 11.7 km, with a range spanning from a minimum of 0.96 km to a maximum of 25.83 km. The outcomes disclose that in February 2022, there was no noteworthy disparity in travel distance between weekdays and weekends, averaging 4.73 km per passenger trip. Nevertheless, a divergent trend emerges between weekdays and holidays/weekends. The shifts in behavioral patterns induced by COVID-19 have yielded significant alterations. In 2022, travel distance diminished on weekends, while in 2017, it increased during weekends.

Another aspect that could have been influenced by COVID-19 is the duration of trips. In both 2017 and 2022, the average recorded trip duration was approximately 13 minutes, and there were no significant differences in trip duration between these two years. Similarly, trip duration did not exhibit significant variations between weekdays and weekends. Nevertheless, a connection between the time of day and trip duration was noticeable – peak hours tended to correspond with longer travel times.

The residents of Jelgava enjoy multiple benefits based on their social status. Children and schoolchildren receive free travel passes. This is required in order to assess the composition of passengers. The following data was obtained for February 2017 and February 2022 (Table 1). On average, the holders of a free travel pass (children) took 138 trips per weekend, 303 trips per weekday and there were 256 total passenger trips in February 2017. These results show that passenger category has no significant impact on passenger trip count, as there were 5.5 times more passenger trips on weekdays regardless of category. In February 2022, an average of 72 passenger trips using free travel passes (children) were recorded per weekend, 140 per weekday, and there were a total of 121 trips in all passenger trips. Likewise, in 2022, the passenger category did not have a significant impact on the passenger trip count, with five more passenger trips on weekdays compared to other days.

Considering the COVID-19 restrictions, it was anticipated that there would be a decrease in residents' use of public transport. Consequently, passenger turnover was analyzed. In February 2017, the total turnover was 994,910.2 passenger kilometers (pkm), with an average of 160,000 pkm on weekdays, 87,570 pkm on Saturdays, and 63,944 pkm on Sundays. In comparison, in February 2022, these figures were as follows: a total turnover of 379,744.8 pkm, with averages of 63,551 pkm on weekdays, 34,580 pkm on Saturdays and 27,325 pkm on Sundays. In aggregate, the turnover for February 2022 was 2.6 times lower than that of February 2017.

Mobile Phone Data Set Description

This dataset encompasses various parameters characterizing mobile activity, including the location of residents and their movements. It includes data on mobile calls, user density within an area, mobile internet usage, mapping of mobile base stations across municipal areas, GPS coordinates for these stations, and the mapping of stations within a spatial grid measuring 1 km x 1 km (the same grid is applied in the GHG modelling tool described later). Generally, this data is to be used in conjunction with other data types to discern elements like the proximity of residents' commute routes to public transport stations and the categorization of districts based on commuting hours (e.g. business or residential areas). It is important to note that the specific location of individual subscribers at the initiation of a conversation was determined by a single base station, with each station serving as an infrastructure element that facilitates mobile connectivity (Arhipova et al., 2023).

The observation of individual base stations in February 2017 showed that certain districts experienced increased mobile call activity on Fridays and Sundays, accompanied by decreased activity on

Table 1

Distribution of passenger trips based on ticket type for 8 weekends and 20 weekdays in February 2017 and February 2022

Type of day / year	Children 2017 / 2022	Other 2017 / 2022
Weekend	1 101 (15%) / 575 (17%)	31 623 (15%) / 12 643 (16%)
Weekday	6 065 (85%) / 2 806 (83%)	177 074 (85%) / 64 246 (84%)
Total	7 166 (100%) / 3 381 (100%)	208 697 (100%) / 76 889 (100%)

other days. As a result, a hypothesis was formulated suggesting that these particular city districts are predominantly residential areas, while the remaining districts are more aligned with commercial zones. Upon analyzing the data for February 2022, a significant alteration in district classification emerged. This transformation was primarily driven by the impetus of COVID-19 restrictions and the adoption of remote work arrangements. Rather than adhering to a rigid classification of districts solely as residential or commercial zones, a more nuanced approach was adopted, designating each district as partly mixed. Consequently, two discernible categories of districts were defined: mixed business districts and mixed residential districts.

To summarize, these findings suggest that the initial categorization of districts as a factor for pinpointing the POI in future mobility budget planning may exhibit variations based on specific situations or circumstances. Regarding the classification of base stations, it was noted that significant shifts in behavior could lead to inadequate initial parameter settings. This underscores the potential for alterations in public transport usage patterns when planning the transportation network based on classification. Nonetheless, to discern the impact of COVID-19 on district behaviors accurately, mobile phone activity data presents ample information. It also provides tangible insights into the necessary re-evaluation measures for the placement of public transport stops.

Public Transport Route Planning Task

The central aim of the transport route planning is to devise a solution that effectively caters to passengers' needs while upholding the principles of equity. This entails considerations such as opting for public transportation as the preferred mode of travel, ensuring the presence of public transport vehicles on city routes, and enhancing the accessibility of public transport stops. Within the domain of transportation policy and implementation, the principles of equity and fairness are regularly employed. The equity concept addresses the queries about the funding of transport infrastructure and services, examining how much various users and non-users should contribute. Simultaneously, the concept of fairness, embodied in the fair mobility budget, is considered as the compensation of spatial-social disparities by taking into account the array of choices accessible to individual persons. While mobility budgets may not be the primary goal in transportation network planning, many tasks within this field frequently depended on principles of fairness and equity (Millonig, 2023). Incorporating the mobility budget into passenger requisites involves identifying a suitable public transport route, aligned with district classifications.

The solutions to this planning task are defined as monthly mobility budgets, offering a decision framework where individuals can select from diverse options to curtail emissions while adhering to their budgetary constraints. This provides an informative gauge for authorities and transportation providers, spotlighting areas that need improvements in accessibility and transportation alternatives to alleviate the limitations imposed by budget constraints. Hence, the overarching objective for planning the transportation network can be defined as follows: minimize the time required for accessing points of interest by using diverse modes of transport or multiple public transport vehicles within pre-established parameters. These constraints encompass:

- Meeting decarbonization goals tailored to specific regions (e.g., a city), with a targeted 10% reduction compared to the previous year, distributed among all resident;
- Considering local factors, such as the availability and accessibility of alternative transport choices;
- Incorporating societal considerations, encompassing caregiving responsibilities, financial circumstances, and other social dynamics;
- Addressing fundamental daily necessities, including employment, education, and everyday essentials;
- Adhering to constants in human mobility, such as daily travel time budget ranging from 60 to 90 minutes, irrespective of the mode of transport or location, alongside a daily average of 3 to 4 trips;
- Enabling the exchange of a limited portion of emission allowances per capita (e.g., 10%) through a trading mechanism.

As the modes of mobility have shifted towards an increased use of private vehicles, primarily cars, government institutions may need to take proactive steps to encourage transition from extensive private vehicle use to more sustainable alternatives, such as public transport or private transport with lower CO_2 emissions. This can be achieved through awareness campaigns, improved public transport routes and schedules, availability of free travel passes, and exploring other innovative approaches. By establishing a sustainable public transportation network that residents would actively use, government authorities can foster a positive shift towards more eco-friendly transport options and meet its decarbonization goals. Therefore, the purpose of public transportation route planning is to meet certain requirements like resident behavior changes, CO_2 quota, mobility budget, and mechanisms (Park & Ride, free rides, personalized discounts) that would improve location accessibility (time and distance) by planning public transport and other CO_2-neutral transport infrastructure. Primarily, planning modelling is based on the configuration of the public transport network, the actual time of use, inhabitant location, and dispersion of POI. The task outcome is to prepare proposals based on data to improve the transportation network depending on conditional options. An evaluation of accessibility (both time and distance) is to be conducted by using a mobility budget calculation application and modelling. This approach involves aligning initial data inputs (such as population density and location use intensity) with mobile phone data for calibration. The structure of a standard data model will cover three levels:

- Mobile activity data and tracking data to identify and analyze mobility patterns;
- Mobility patterns linked to other second-level data that includes static data (socio-economic statistics and survey data);
- Public transport (bus) data (routes, distance, time, number of passengers).

Attention will be paid to transferability of mobile phone data to all available living labs. The following data will be prepared as input parameters for the mobility budget calculation model:

- Adjusted population density with unique mobile activity data. More accurate national data about population and unique mobile activity data per km² will be used to adjust actual population density data per km²;
- Parameters for POI (like m² of working or shopping space);
- Transport route data and possible Park & Ride locations.

The strategic design of the public transportation network can potentially offer almost the same accessibility to POI as private transport. This approach contributes to fulfilling essential mobility budget requirements (including CO_2 emission targets) and holds the promise of boosting the use of public transport and diminishing reliance on private vehicles. The research question revolves around understanding the potential impact of implementing voluntary support mechanisms aimed at fostering change.

Results

1. Evaluating Jelgava City Transport Network for Mobility Budget Reduction

In 2018, CO_2 emissions in Jelgava were 109,012 tons distributed across various sectors: private and commercial transport accounted for 32%, residential buildings – for 29%, industry – 27%, commercial buildings and equipment – for 6%, municipal buildings and equipment – for 3%, public transport for 2%, municipal fleet for 1%, and public lighting for 0.4%. In order to reduce global warming and promote climate neutrality, the city of Jelgava should reduce CO_2 and related GHG emissions. According to the goals set by the sustainable energy and climate action plan for Jelgava (Sustainable energy, 2023) by 2030, it is necessary to reduce GHG emissions by 40% compared to the base year of 2005 and to adapt to climate change. The most significant reduction of GHG can be achieved by replacing private transport with public transport. In the future, the GHG footprint of public transport will decrease even more, reaching almost 0% by deploying electrical busses. The current transport network in Jelgava is adjusted to those residents who can reach the public transport network on foot. To reach the stated GHG emission goals, Jelgava will need to introduce a new Park & Ride strategy to reduce the use of private cars in the city significantly. Adequate data-driven scenario modelling of Park & Ride capabilities is described later in this research.

1.1. Analysis of Public Transport Use Based on Survey Results in Jelgava

Drawing from the outcomes of the survey, an examination of public transport use was carried out. The survey was directed at Jelgava residents aged 16 and above. The sample was comprised of 1,500 residents, selected randomly from a database. The survey was conducted by the market and public opinion research center SKDS (SKDS, 2023) using the CATI (Computer-assisted telephone interviewing) method and carried out between 27 September 2022 and 31 October 2022. The study had a participation rate of 46% for male respondents and 54% for female respondents, where Figure 1 presents the sampling statistics results by age and educational level.

All socio-economic groups represented in the survey were divided by the income parameter to help link mobility behavior and attitude to income level. As expected, higher-income respondents more than others used private cars and were less motivated to use public transport. The survey also covers patterns for the accessibility of different POIs and understanding of POI access needs on daily, weekly, and monthly levels. On weekdays, “shopping” (50% of respondents do it a couple of days a week) and “work” (55% do it daily) are the most popular reasons for moving around. On holidays and weekends, “shopping” (43% of respondents do it once during the weekend), “visiting friends” (23% do it a couple of times a month), and “relaxing” (20% do it once a month)

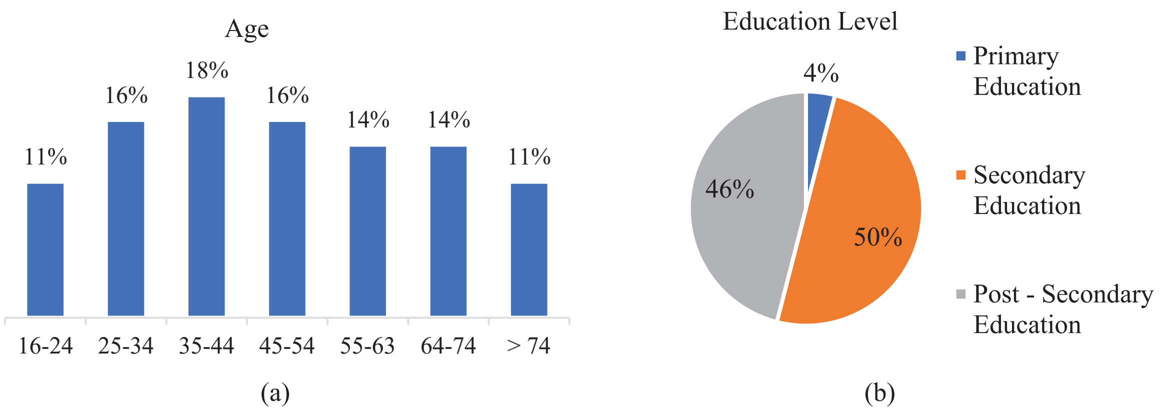


Figure 1. Jelgava city residents sampling statistics in 2022:
(a) Sampling distribution by age; (b) Sampling distribution by education level.

are popular reasons for moving around. Responding to the question: "Do you use Jelgava's city public transport on a daily basis?" the majority of residents (54%) indicated that they rarely use public transport. In response to the subsequent question: "What factors would encourage you to start using or increase your use of Jelgava's public transport services?" approximately 33% of respondents indicated that they had no motivating factors (Figure 2).

Figure 3 illustrates the factors that contribute to the residents' reluctance to use the city's public transport services. The most common responses include "personal comfort preferences" (25% of residents) and "time saving and faster movement by other transportation modes" (27%).

We see that responses related to personal comfort during commutes as the reason for not using public transport services constitute altogether 52%. Only 23% of respondents admitted that their reasons for not using public transport were directly related to the quality or availability of public transport. 11% of respondents replied that "there is no suitable public transport timetable on the required route", 6% admitted, "the coverage of public transport stops does not meet the needs" and another 6% responded, "There is no public transport available on the required route". Therefore, this indicates crucial input data for a GHG reduction strategy and scenario planning for the optimization of the public transport system. Most probably, improvements in public transport alone will not lead to change of behavior among car owners, and, subsequently, progress in GHG reductions. The municipality should consider different strategies for reducing the use of private cars in the city.

Almost half (46%) of respondents admitted that they spend up to 45 minutes daily to travel between various destinations on weekdays. Conversely, 50% of residents spend up to 1 hour to travel between destinations on weekends (Figure 4).

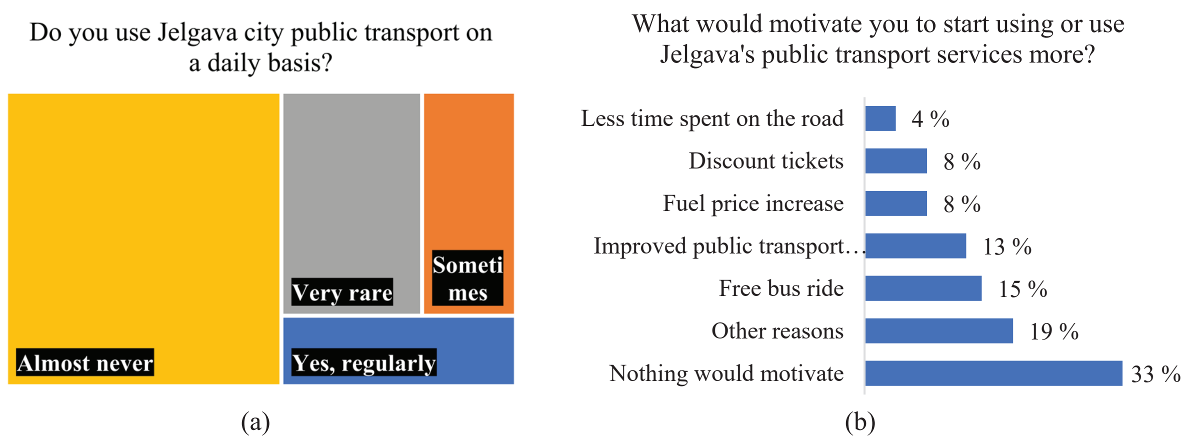


Figure 2. Factors that influence the willingness of Jelgava residents to use public transport:
(a) Frequency of using public transport; (b) Motivation factors.

The survey data suggests (Figure 4) that in Jelgava, the average travel time on weekdays is around 60 to 90 minutes and the median travel time is 31 to 45 min – it makes sense if one travels by car. The same situation can be observed on weekends when average travel time is 90 to 120 minutes and median travel time is 46 to 60 min. Travel time on weekends is longer, probably because the residents combine walking with the use of public transport. The local residents' travel time and distance covered by car sets expectations on not just time but also travel distance and POI that people could access in the city of Jelgava. This information provides important input data for calculating accessibility using GHG mobile budgets. To reduce the use of private cars in Jelgava, the city needs to ensure that similar distances can be covered and the same number of POI can be reached in the same amount of time (in 45 to 90 minutes a day) by public transport. For Jelgava, this means improving its public transport network in combination with Park & Ride infrastructure. The transportation data reveals that when travel time exceeds 15 minutes, 44% of the residents opt for a private car, and only 13% rely on public transport. Additionally, 32% of the population use private transport on a daily basis (Figure 5). According to mobility studies, average daily travel time is around 90 minutes – a reasonable amount of time to spend for commute and travel to POI. It also correlates with the available modes of transport in the area because faster means of transport cover longer distances in the same time period.

The examination of incentives that drive residents to use public transport revealed that merely 39% of respondents think that reducing the use of private transport is important. In contrast, 52% do not perceive the reduction of private transport use as important, and 9% encountered difficulty providing a response to this question. The relationship between

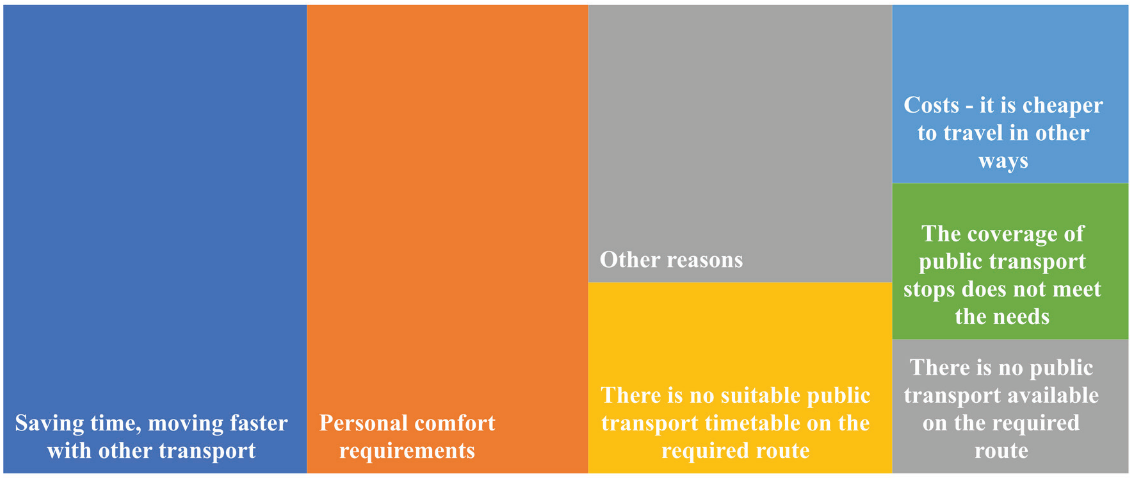


Figure 3. Factors that contribute to the residents' reluctance to use the city's public transport services.

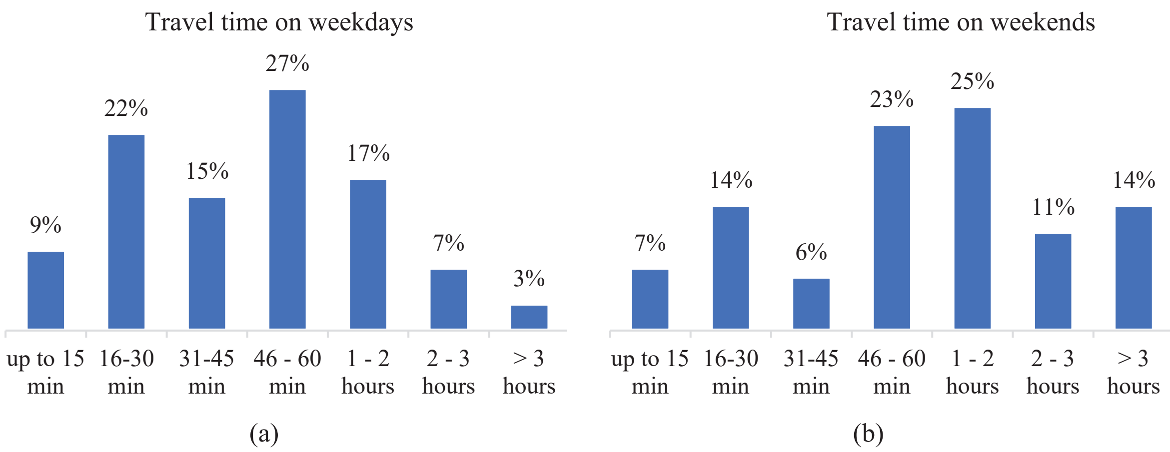
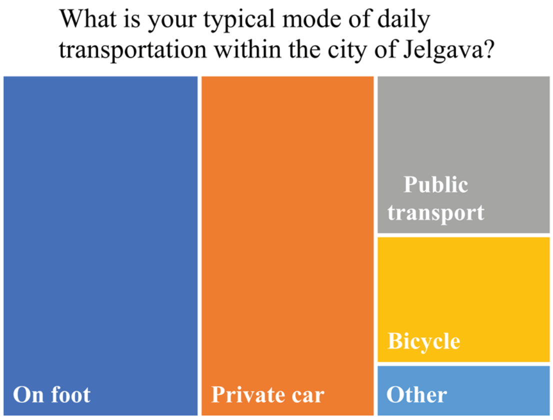
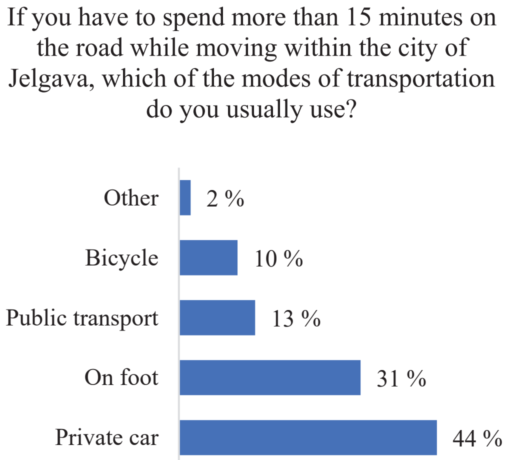


Figure 4. Travel time spend by Jelgava residents: (a) On weekdays; (b) On weekends.



(a)

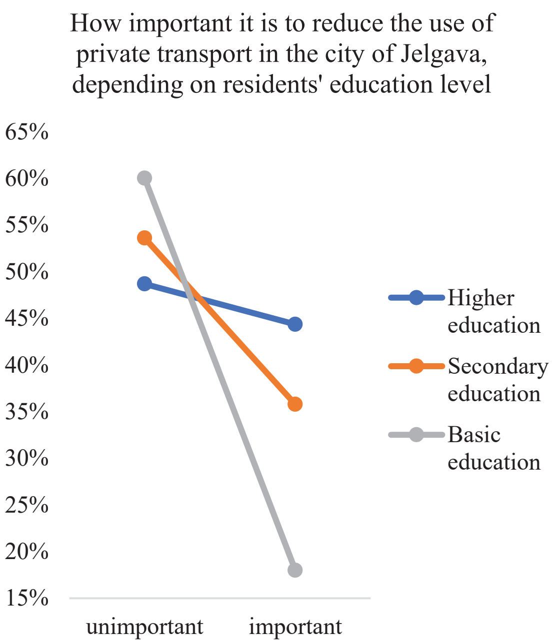


(b)

Figure 5. Modes of transport used by Jelgava residents:
(a) Typical mode of transportation; (b) More than 15 minutes transportation.

respondents' opinion regarding the reduction of private transport use and their level of education and income was analyzed. Respondents with a lower level of education and income usually gave the response "not important", whereas those with higher education and income levels most frequently indicated "is important" (Figure 6). Among respondents with a household income of up to EUR 350 per member, the majority do not think that reducing the use of private cars is important. For those earning between EUR 351 and EUR 500, opinions remain relatively consistent. However, among households with an income of EUR 501 or more per member, the majority sees the need to limit the use of private transport (Figure 6).

Overall, the survey shows that for short distances (travel time of up to 15 min) respondents prefer walking or cycling. The main reasons for not using public transport for short distances are bicycle-friendly infrastructure, unavailability of public transport, and walking being a healthy activity. If travel time exceeds 15 minutes, respondents use private cars for personal comfort and time saving reasons. On a daily basis,



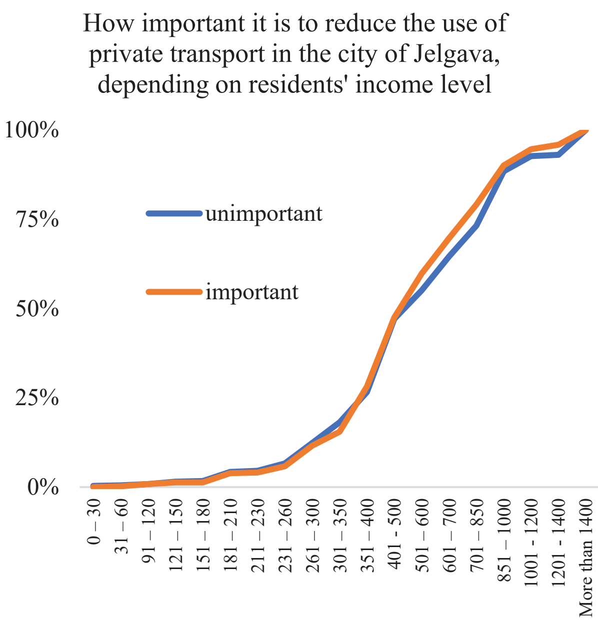


Figure 6. Relationship between the choice to reduce the use of private transport and type of Jelgava residents' group: (a) Depending on education level; (b) Depending on income level (EUR per household member).

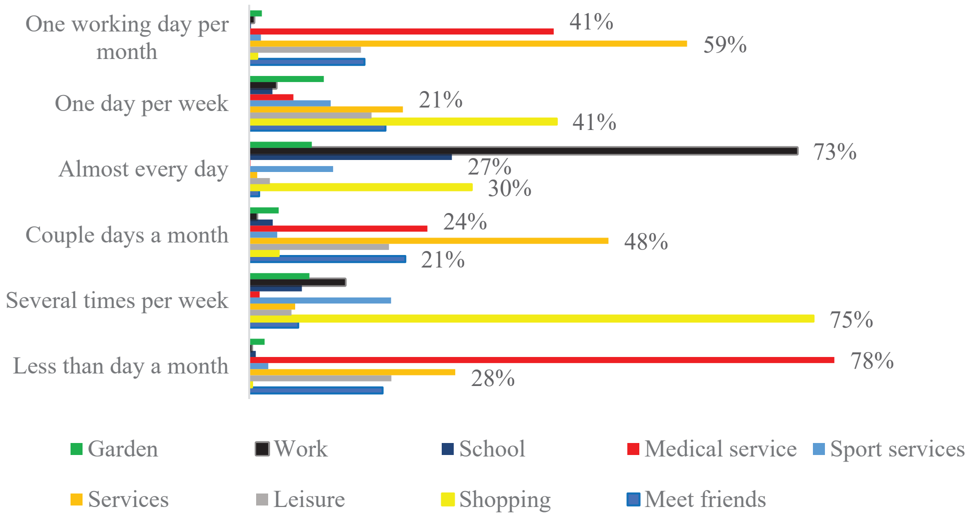


Figure 7. Frequency of POI visits by Jelgava residents.

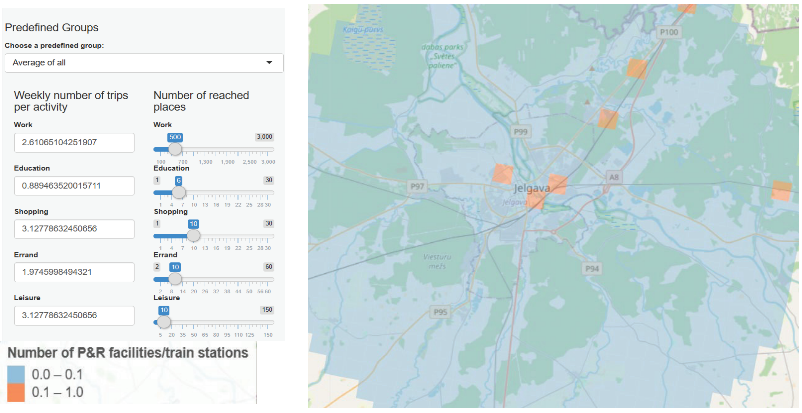
the primary POIs most commonly identified by the residents of Jelgava are workplaces (73%) and schools (27%). Furthermore, shopping (75%) is consistently highlighted as a prominent POI several times a week, but various service providers as POIs being attended on a weekday once a month has been mentioned by 59% (Figure 7).

It can be concluded that in Jelgava, numerous facilities are conveniently situated within a short walking or cycling distance. Public transport is not widely favored for commuting, and individuals who use cars are less inclined to use public transport willingly. The mobility parameters discussed earlier further validate that the preferred travel duration falls within the range of 30 to 60 minutes. This underscores the need for improved route planning to motivate individuals to make a shift towards public transport.

1.2. Study of Jelgava City Mobility Budget Analysis

The visualization tool is based on minimum mobility budgets (Millonig, 2023), originally developed to assess the impact of individual mobility patterns on Austria's GHG emission reduction targets for 2030 and 2050. Based on these budgets, a tool for visualizing the accessibility for different activities (work, education, shopping, errands, and leisure) was developed (Krajzewicz et al., 2023), based on UrMoAC (Krajzewicz, Heinrichs & Cyganski, 2017), a tool for calculating urban accessibility. The visualization tool has been adapted to analyze the Jelgava mobility budget. This tool provides an interactive platform aimed at transparently conveying the consequences of individual behaviors. The information displayed on the map is defined by the following parameters: minimal GHG budget, travel time, population within clusters, workplaces within clusters, schools within clusters, errand facilities within clusters, shopping amenities within clusters, recreational facilities within clusters, Park & Ride facilities, and train stations. The available transportation modes encompass walking, cycling, public transport, Bike & Ride, Park & Ride, and driving a car. It is possible to adjust the average travel time to selected groups, as well as predefine maximum travel times, for example, 15 min by foot, 20 min by bike and 45 min by public transport, uniform 20 min or uniform 30 min. The maximum time allowed per activity (work, education, shopping, errand, and leisure) in each mode in minutes is calculated. According to the previous survey results and statistical information, the predefined groups are chosen on average of all residents, number of work-related POI as 500, education – 6 POI, shopping – 10 POI, errands – 10 POI and leisure – 10 POI. In Figure 8, the number of Park & Ride facilities and train stations is shown, using a visualization tool.

For all of POI placement calculations, a 1 km x 1 km grid was used. All data was gathered from open data sources: POIs came from OpenStreetMap geospatial services. OSM was also used for the calculation of distances, and transportation data came from GTFS (General Transit Feed Specification) and locally provided data was supplied by Jelgava transportation operators. It is possible to add additional data points for modelling purposes. Additional data for calculation is used as classifications from different sources, like CO_2 per mode of transport, average speed per mode of transport, etc. Calculations are between centroids of grid cells considering the number of points of interest in each grid cell. Therefore, analysis of results is also done on the grid cell level. Some of the POI data for



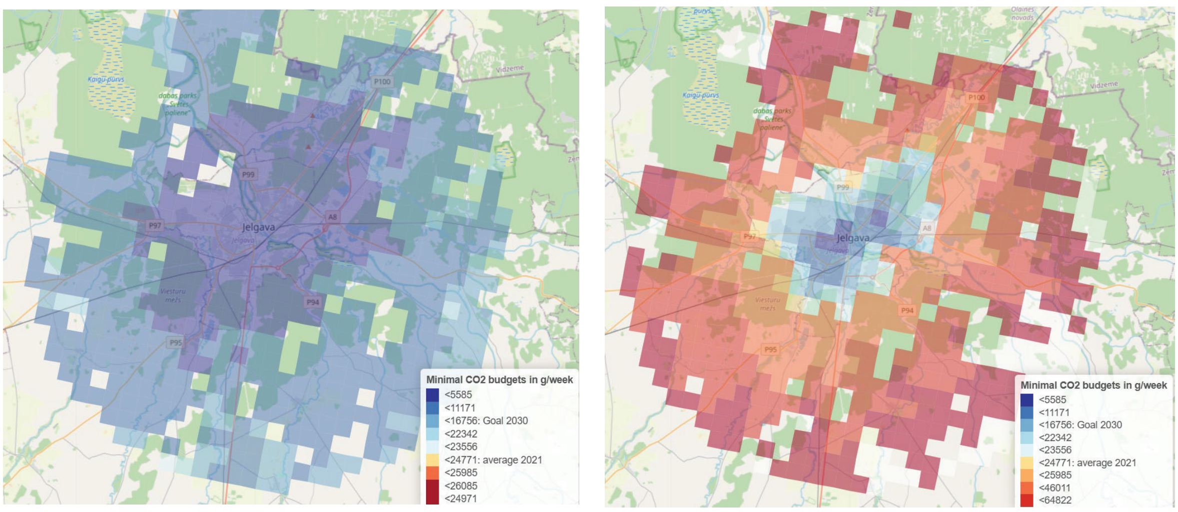
(a) (b)

Figure 8. Mobility budget visualization tool:
(a) Predefined groups; (b) Park & Ride POI selected.

the model could be calibrated and cross-validated using other data sources like mobile activity data. The tool is built as fully interactive modelling software that permits changing input parameters and using output results for visual analysis. All detailed data could be visible on the grid cell level as well as calculation results based on the selected output view; it could be a minimal GHG budget or travel time (Millonig et al., 2022). Therefore, the tool could be used for scenario-planning sessions with municipality experts.

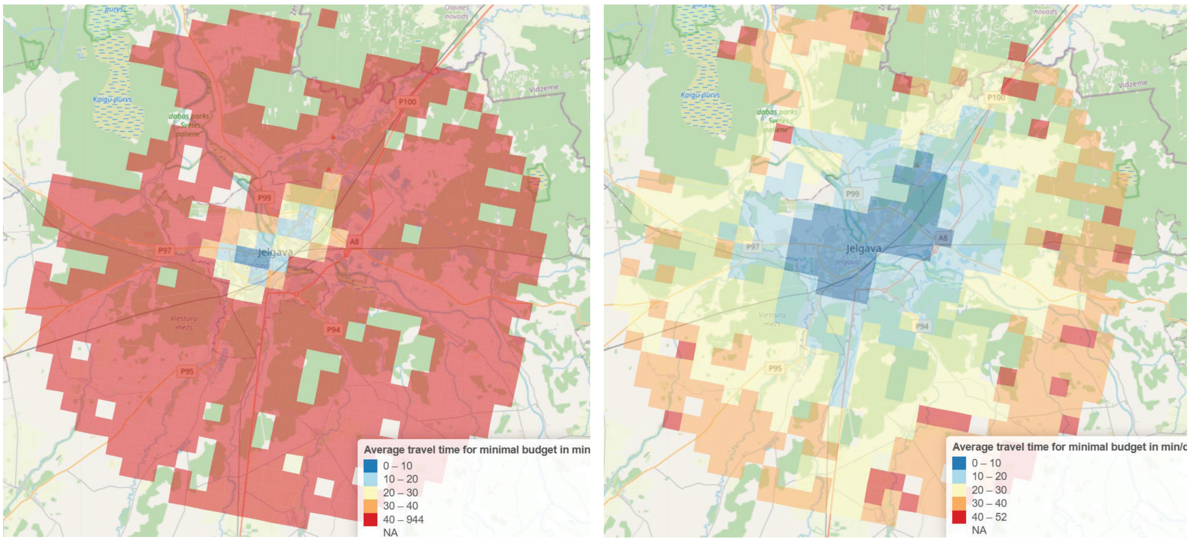
The evaluation of Jelgava based on the mobility budget criterion of "Minimal CO_2 budget in g/week by foot, bike, and public transport" shows that the city is a climate-neutral urban center. However, it does not meet the criteria of a climate-neutral urban center based on the "Minimal CO_2 budget in g/week by private car" mobility budget criterion (Figure 9). This clearly shows that by maintaining the current level of private car use, reaching GHG budget 2030 targets in Jelgava is impossible. A scenario of replacing private cars with GHG-neutral transportation modes like bicycles, walking, and public transport must be developed. To adhere to the CO_2 mobility budget, it becomes imperative to establish a demarcation that restricts private transport from entering the city.

Examining the average daily travel time (in minutes) for the minimal budget across different modes of transportation, the findings reveal that in the case of Jelgava, the use of public transport does not comply with the 15-minute city concept. However, this criterion is satisfied when using a private car to reach the city center. The visualizations (Figure 10)



(a) (b)

Figure 9. Minimal CO2 budget in g/week by transportation mode:
(a) Transportation on foot, by bicycle, and public transport; (b) Transportation by private car.



(a) (b)

Figure 10. Average travel time (min/day) for minimal budget:
(a) Transportation on foot, by bicycle, and public transport; (b) Transportation by private car.

show that the average travel time on foot, by bicycle, and public transport is 10 to 30 minutes in the very central part of the city but reaches 40 to 60 minutes in the rest of the city. The average travel time by car to most of the city's territory is 20 to 30 minutes. This also explains why locals prefer private cars and have little motivation to change to public transport services.

The challenge of developing an optimized transportation system is focused on improving public transportation by minimizing costs and maximizing the number of trips. When considering the mobility budget as the goal of an optimization problem, the objective function should encompass fairness and equity principles related to travel. Constraints in this scenario should address both mobility considerations and overall greenhouse gas emissions. In this context, the proposed visualization tool serves as a guide for estimating the mobile budget. This tool can be used by government institutions to encourage a shift from the extensive use of private vehicles to more sustainable options, whether for public vehicles or environmentally friendly private vehicles that produce less CO_2. This approach aims to find a balance, for instance, between achieving decarbonization goals and establishing a sustainable public transportation network that is widely used by citizens.

Considering previous findings, the initial analysis of GHG budgets, and travel times by different transport modes, one of the planning scenarios for Jelgava is to restrict the use of private cars in city territory and decrease average travel time by public transport. By using the proposed approach and the developed tool, one can model various scenarios by changing public transport timetables and improve the average travel time by public transport. In the scenario of restricting city access by car, possible Park & Ride locations could be added to the accessibility model and GHG budgets. Therefore, one of the key optimizations or planning principles must be minimization of the distance between the no-entry boundary line (Park & Ride) and the city center. The solution entails a planned route that enhances accessibility.

Presented in this paper, the visualization and analysis tool can explain different scenarios and planning tasks. However, in this paper's context, we are focusing on scenarios for planning the municipal transportation system in order to provide accessibility and fairness. Innovation of the proposed visualization method is in the possibility to provide input data on a special level, a 1 km x 1 km grid, in order to calculate accessibility of the population from each grid cell to POI using different transportation modes. For planning the municipal transportation system, public transportation routes and travel times are used. As a result, the tool allows modeling and what-if analysis based on different input data and input parameters for travel frequency and travel mode. Different input data could be used not just to model future situations but also to model exceptional situations like special events and extreme behavior of people. To illustrate this, we are using data collected during and after the COVID-19 pandemic. As current model transportation data is taken from a general transit feed specification (GTFS, 2023) open data source, if needed, this data could be replaced with more accurate data from Jelgava's municipal bus company or adjusted data created for modelling purposes. Currently this scenario with public transport data as input and travel time by all transport modes except private car is the main optimization scenario and changes in public transport frequency and position of bus stations correlating with travel time by all transport modes except private car.

Discussion and Conclusions

Research findings indicate that the choice of transportation significantly influences the per capita carbon footprint. Moreover, an examination of people's behavior reveals that private cars emerged as the preferred mode of mobility during the COVID-19 pandemic.

Concerning the categorization of mobile phone base stations, it was noted that significant shifts in behavior could result in insufficient initial parameterization. This also implies that planning the transportation network based on the intended class could potentially induce alterations in the use of public transport. Nonetheless, mobile activity data offers sample insights to assess the impact of COVID-19 on district behaviors precisely, offering tangible insights for required re-planning actions concerning the locations of public transport stations.

In the wake of the COVID-19 pandemic, mobility patterns have shown a notable inclination towards private modes of transport, particularly cars. In response, government bodies might find it imperative to encourage a transition from heavy reliance on cars to either eco-friendly means of private transport or public vehicles. This transformation can be facilitated through awareness campaigns, the provision of optimized public transport routes and timetables, free ticket initiatives, and other means. In doing so, a delicate balance can be achieved between meeting the decarbonization objectives and establishing a sustainable public transport network that caters to the needs of the citizens.

In order to achieve the set GHG goals, municipalities will need to deploy specific strategies that will require restrictions on the use of some transport modes, most probably private car access to the city center. At the same time, new accessibility to social infrastructure, working places, and other POI will need to be increased by optimization and planning of the public transport network. The decision-making process and decision explanation to the professionals and the public will require data-driven and visual tools that can be used for modelling and presentation. The tool used in this research is well-suited for planning and modelling on the municipal level, for planning and transportation professionals, and to some extent for public presentation.

The survey data reveals current expectations regarding accessibility in Jelgava, where the most popular transportation mode is a private car. It means that in modelling future scenarios, the municipality will need to improve the public transportation system and accessibility of POI so that the travel time and distance covered by public transport meets those by car as closely as possible.

To successfully model, implement, monitor and communicate changes on the municipal level concerning restrictions and other GHG-related changes and mobility budgets, municipalities could use the data-driven approach and tool presented in this research. Not only municipal teams, and planning and transportation experts, but also the media and general public can benefit from the use of the mobility budget calculator and visualization tool, which, together with different data, can improve modelling and communication. It is obvious that in order to meet its GHG goals, the Jelgava municipality will need to introduce restrictions to change the behavior of inhabitants. It will require very coordinated communication that is based on solid data. Here, the presented tool can play a major role as it can be accessed online by the public.

The task of municipal transport route planning revolves around improving public transportation efficiency by minimizing costs and maximizing the number of trips. When focusing on the mobility budget as the main point of a planning problem, the objective function should embrace the principles of fairness and equity related to travel. Constraints in this scenario should address both mobility considerations and overall greenhouse gas emissions. In this context, the suggested visualization tool acts as a guide for estimating the mobility budget.

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