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Fair mobility budgets: A concept for achieving climate neutrality and transport equity

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ABSTRACT

Transport justice has two essential dimensions: (1) compensating for inequalities in access to mobility, and (2) mitigating the disproportionately burdensome negative consequences of transport. In light of the urgently needed action regarding climate change especially in the transport sector, measures reducing carbon emissions to mitigate the impact are inevitable. However, policy measures for reaching climate targets should avoid increasing unequal mobility chances. Therefore, there is a need for concepts striving to mitigate both climate impacts and transport injustice.

The paper addresses the potential of introducing individual mobility budgets to achieve transport-related climate goals while reducing inequalities in mobility. The concept proposed in this contribution is based on a combination of qualitative and quantitative impact assessment methods including a stakeholder involvement process and transport modelling based on different data sources. The results provide policy recommendations as well as further research requirements, which are already partly addressed iin follow-up projects.

1. Introduction

Despite the constant efforts to improve transport systems and to make mobility more accessible all over the world, there are still wideranging disparities regarding mobility access for different social groups. The increasing awareness of the variety of reasons leading to the exclusion of certain social groups from using the transport system to its full extent has led to a wider discussion of “transport justice” (Lucas, 2006; Martens, 2012; Gössling, 2016). In many cases, the term “transport justice” stands for the effort to develop policy guidance for mitigating local disparities in transport accessibility (Lucas, 2006). A wider understanding of the term additionally includes the unequal burden disadvantaged social groups have to carry due to their increased exposure to the risks and harmful health consequences of transport. For example, a family with limited financial means can only afford a used car with poorer safety equipment and is at higher risk in the case of an accident. But even passive effects of transport affect social groups suffering from poverty more severely, as housing near streets with heavy traffic is more affordable, but puts the residents under constant distress due to higher noise and emission levels (Gössling, 2016).

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In the light of climate change, this dimension of transport justice also takes on a temporal component, since transport continues to be responsible for a large amount of greenhouse gas emissions (GHGE) and it is not the polluters, but especially future generations that will be affected by the full extent of the consequences (Martens, 2017). In this respect, climate change has become one of the most important challenges transport policy has to address to avoid catastrophic consequences which will add to a further increase in inequalities. However, the urgency with which climate protection measures in transport are now being demanded is sometimes in conflict with efforts to achieve equalisation. Many efforts concentrate on the urban environment to reduce the number of private cars in cities and provide cleaner alternatives, while commuters coming from suburbs or the surrounding countryside are still often using private cars to enter the cities. People prefer to drive to larger shopping centres than to smaller shops nearby, which ultimately results in people becoming even more dependent on their cars, as town centres lose their retail infrastructure. At the same time, carbon taxes are becoming more likely, putting people in poorly accessible areas at a particular disadvantage, although it is not even certain that these measures will have a sufficient impact.

In this paper, we present a concept which aims to provide a valid pathway to reach climate neutrality in transport while at the same time mitigating disadvantages in the everyday mobility of different social groups. The concept is the result of a feasibility study ("mobalance") performed in Austria, which examined the impact and implementation requirements of individual mobility budgets to achieve GHG emission reduction goals. Starting from an introduction into the different dimension of transport (in)justice and the principle of "sufficiency" in mobility, the paper describes the methodological approach taken in the project followed by the discussion of results of an impact analysis of introducing mobility budgets in Austria. Finally, the paper conludes with a decscription of the resulting concept for individual mobilita budgets as well as accompanying recommendations and provides an outlook on a national and a transnational follow-up project, which will further explore and test specific aspects of implementing mobility budgets.

2. Challenges in transport justice and climate mitigation

2.1. Dimensions of transport (in)justice

Reasons for disparities regarding accessibility to transport services and destinations are manifold and reflect structural institutional and political priorities as well as individual circumstances (Martens, 2017). On the policy level, the decades-long priorisation of automobility has led to increasing distances between places to live, work and play, and to a "new street equilibrium based on the supremacy of automobiles" (Norton, 2007, p. 332), with an imbalanced allocation of urban public space to different types of road users in favour of cars. Regarding individual circumstances, Martens (2017) highlights three influence factors explaining disparities in mobilty choices: place of residence, level of income, and individual abilities and skills, all resulting in potential disadvantages due to limited physical or financial access or inability to use a transport service, be it through lack of training or physical disabilities. Exploring more closely the characteristics of persons affected from disparities, Sammer et al. (2012) distinguished between 15 types of transportation disadvantaged groups, which were defined by limitations such as physical and sensory impairments, limited financial, language or learning capabilities, multiple responsibilities to care for others (e.g. children or older relatives), age-related (legal) restrictions (as for youths or the very old), and insufficient access (e.g. rural population, especially with no access to cars). In addition to these barriers due to limited access or abilities, there are also emotional barriers hindering the use of specific transport services under certain circumstances. Grounded in the sociology-based Social Practice Theory (SPT) (Reckwitz, 2002; Shove, 2012), which describes three basic components of everyday routines (material, competence, and meaning) to perform a specific behaviour, Millonig (2019) has introduced a framework for assessing behaviour barriers in the mobility context in relation to "access" barriers (physical or financial access), "ability" barriers (cognitive or training abilities), and furthermore "acceptance" or "ambition" barriers (emotional barriers due to social norms, fear, shame, etc.). These barriers describe circumstances, where a person might have access and also the ability to use a transport service, but avoids doing so out of fear (e.g. for their own safety or to fail using an unfamiliar system, especially in high crime areas; Moreira and Ceccato, 2021) or because a mobility behaviour pattern feels inappropriate for a social group acting within a specific societal norm (e.g. European muslim migrant women riding bicycles; Hanson, 2010; Peters, 2013).

Emotional and ability barriers are however not only relevant when it comes to unequal chances to participate in social life through mobility, but also regarding the injustice of who has to carry the majority of the burden of negative consequences of growing mobility. Poorer families are for example disproportionally more affected by noise and emissions as often only housing near busy traffic arteries is affordable for them (van Schalkwyk and Mindell, 2018). Hence, the unwillingness or inability of changing from motorised and high emission modes to more sustainable modes is also directly contributing to these disparities and addressing behaviour change barriers towards more sustainable behaviour is an essential element of transport justice. However, current approaches to develop frameworks identifying transport justice threshold indexes (e.g. Oswald Beiler and Mohammed, 2016) fall short of including these aspects, as respective data is hardly available and thresholds can merely be assessed based on location data (access to transport options, land use and distances to destinations) and conventional socio-demographic characteristics (e.g. age, gender, household size and income). Still, the importance of considering these types of constraints in decision making is increasingly recognised. Approaches based for example on social milieus and related group-specific social norms, values and experiences can provide improved knowledge in this field to identify and overcome emotional and ability barriers of behaviour change.

2.2. Climate mitigation strategies in transport

Behaviour change towards more sustainable lifestyles is an essential element of transport development goals since environmental concerns became increasingly aware in the early 1990 s. In Austria and Germany, policy strategies were developed based on the "Avoid

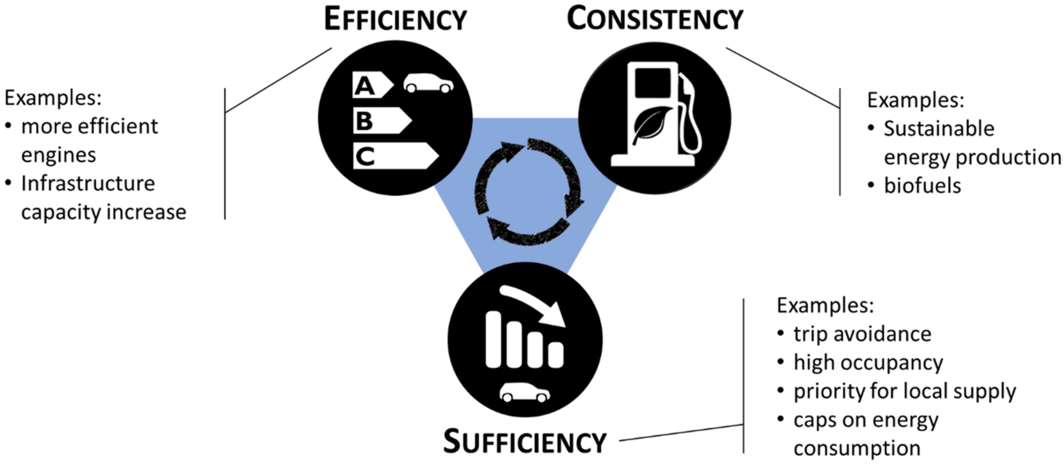

Fig. 1. Efficiency, consistency and sufficiency as complementary strategies for sustainable mobility.

– Shift – Improve" (ASI) approach (BWK, 1991; Bundestag, 1994). Following this strategy, policy measures should aim firstly on avoiding the need to travel, e.g. by improved urban planning, transport management and optimasation and e-communication options (e.g. teleworking), secondly by shifting travel to more efficient and cleaner transport options, especially non-motorized or public transport, and thirdly by improving the environmental impact through technological improvements to make vehicles more energy efficient and fuels less carbon intensive (Bakker et al., 2014). However, although the emphasis in the strategic policy documents was put on reducing environmental impact through avoiding travelling, traffic volumes continued to increase. This means that the transport sector has – contrary to other sectors – even dramatically increased its GHG emissions, even though technological developments have significantly contributed to the improved efficiency of vehicles: Since 1990, the transport sector in Austria has recorded the largest increase in greenhouse gas emissions of 10.1 million tons of CO2 equivalent, or 73.3% (Uba, 2020b). This development includes a clear behavioural component in the form of rebound effects, since, for example, the improved fuel efficiency of cars has led to the purchase of ever larger vehicles (Millonig and Haustein, 2020).

As the primary goal of avoiding traffic has been clearly missed, the effectiveness of strategies to obtain sustainability need to be reassessed to change the current trajectory. In principle, sustainability is based on three main strategic pillars: Efficiency, Consistency, and Sufficiency (Fig. 1) (Korte, 2015). Up to now, many measures designed to promote sustainable transport development have mainly followed the efficiency principle (e.g. by reducing fuel consumption) or the consistency principle (e.g. by replacing fossil fuels with biofuels). The advantage of these strategies is that they act as drivers of innovation and consumers can maintain their accustomed mobility behaviour; even improvements are put on display (e.g. cost savings or higher comfort). However, the disadvantages are becoming more and more apparent: Increased efficiency, for example, is often soon (over-) compensated, as savings achieved through higher efficiency are usually immediately offset again due to rebound effects (Dimitropoulos et al., 2018; Millonig and Haustein, 2020). Rebound effects occur because people tend to assign costs of any kind (e.g. money or time) to relatively stable mental accounts (Ranyard, 2017)- This means that savings in one of the mental accounts are reinvested in the same category, resulting in an increase in demand that compensates for the savings. An example: In the transport system, distances per person have increased each year in recent decades, but at the same time the travel time budget remains more or less at the same level, indicating that the time saved is simply reinvested in longer distances (Cervero, 2011). Another example is the fact that increasing the energy efficiency of cars leads consumers to buy larger cars, thus offsetting the savings (Ajanovic et al., 2012) or that consumers who buy 'green' cars use the car more than a conventional car out of 'good conscience' (Haustein and Jensen, 2018).

For this reason, it is increasingly being argued that efficiency and consistency strategies are not enough to achieve sustainability goals, but must be supplemented by sufficiency (Fischer et al., 2013; Linz, 2015). This, however, demands changes in behaviour, which requires individual consumers to consciously and intentionally forego the consumption of resources or resource-intensive goods. Furthermore, also sufficiency measures may lead to unexpected rebound effects. A study performed during the COVID-19 pandemic in Austria showed for example that the extensive avoidance of commuting due to the surge in teleworking led only marginally to a reduction in emissions. After the elimination of work trips, many more leisure trips were made, and numerous public transport commuters switched to the car, as the annual passes for public transport no longer paid off for a few hours per week in the office (UBA and Mipra, 2020).

In parts of the society, sufficiency as a voluntary self-limitation has already become part of a conscious lifestyle. Movements that propagate a simplification and deceleration of everyday life seem to be the first signs of a cultural change. Fewer young people have a driver's license, cars are losing their status symbol image, and when driving and flying seem unavoidable, various platforms offer the possibility of financially compensating for the CO_2 produced. However, social science research and experiences from comparable civil society movements show that the group of people who are freely willing to make changes (such as the social milieu of the post-materialists) make up little more than about 10 to 15% of the entire population (Markvica et al., 2020). Other social milieus are much more firmly integrated into their social environment and habits (Linz, 2015). Younger milieus show more flexibility (Hunecke et al., 2020), but it is unclear, how their attitudes are changing with growing age and responsibilities. This makes it necessary to take measures to anchor sufficiency in the reality of life for a critical mass of the population in the long term, which also requires the consideration of milieu-based concerns and fears of becoming disadvatanged in comparison to others.

Since such measures clearly interfere with the everyday life of people who are reluctant to change out of such concerns, they easily generate resistance and rejection, which is why the implementation of measures and strategies to increase acceptance must be accompanied. The Lüneburg transdisciplinary research project "Energy system transformation & mobility" is based, for example, on push and pull measures that are already being used in various cities and proposes a mutual combination (Opel and Schomerus, 2015). However, a conscious renunciation of resource-intensive forms of mobility requires more than this, since push-and-pull induced changes in behaviour are primarily the result of extrinsic positive and negative reinforcement, without those affected becoming aware of the effects of their previous and new behaviour patterns; thus, they may not feel in control over their actions. Approaches that make the individual overuse of available resources transparent and offer the possibility of achieving a more environmentally aware use of resources – through targeted behavioral adjustments with only a moderate loss of comfort – have high potential for success in terms of both acceptance and effectiveness.

One major difficulty in establishing sufficiency as a new usage paradigm, though, is, among other things, that those concerned are not adequately aware of the concrete effects of habitual and possible alternative behaviour patterns and are thus unable to develop a sense of control over their actions. Experience from other research disciplines could offer promising approaches here. The principle of goal-setting theory from organizational psychology, which has been developed since the early 1990 s (Locke and Latham, 1990, 2002), states that specific, ambitious goals lead to better task fulfilment than easily attainable or abstract goals (e.g. "doing one's best"). Today, the principle is known in project management in the form of "SMART" targets (Specific, Measurable, Attainable, Relevant, Time-bound). Target-setting approaches are now also being implemented on a large scale in the health sector when it comes to achieving health-promoting behavioral changes through clear, meaningful and easily communicated targets (Strecher et al., 1995; Bailey, 2019). When applied to the mobility sector, individually communicated mobility reduction targets that are tailored to the personal reality of life (e.g. adjusted to the situation of daily goals or the individual socio-economic background) could offer a scope in which the individual persons can set and vary concrete activities for more adequate behaviour patterns in their personal sphere of action. In this way, they retain a sense of control and can also make informed and conscious decisions to set short-term, realistic goals on the way to more sufficient behaviour. In this way, the acceptance and perceived fairness of measures and the motivation to achieve ambitious goals can be increased.

3. Methodology

3.1. Basic conditions and methodological approach

At first glance, the two major goals postulated by the call for transport justice – reducing the barriers to be mobile while at the same time reducing the negative effects of growing mobility – appear to be contradicting each other, and this conflict may indeed be challenging to a certain extent. Therefore, efforts to reduce carbon emissions must balance measures to reduce the amount of especially private motorised transport with interventions to improve transport options for specific disadvantaged groups. This bears the risk of (perceived) unfairness and conflict between different social groups, especially as the individual contribution to climate change is generally poorly understood and the value of individual behaviour change is underestimated. This becomes especially apparent when considering that "sustainable transport" has been a prominent goal in urban and national mobility plans already for decades, but still CO_2 emissions do not seem to get anywhere near the ambitious transport related reduction goals which the Paris Agreement (UN, 2015) implies. Technological developments (e.g. e–mobility, hydrogen propulsion) will only be able to cut down part of the emissions, as models assessing the impact of planned and foreseeable measures in the transport sectors show. Calculations performed for example by the Austrian Federal Environment Agency reveal that the currently most optimistic development path will only be able to achieve half of the required volume of carbon reduction until 2050 (Millonig et al.,2020). Thus, radical changes in mobility behaviour patterns are inevitable.

In the feasibility study "mobalance", the concept of "carbon budgets" was transferred to the mobility context to assess the potential of "mobility budgets" for developing targeted measures and achievieng individual acceptance. Carbon budgets represents the total quantity of CO_2 emissions that is consistent with remaining below a given level of global temperature change. So, for any given temperature target, the total allowable CO2 emissions are finite (Matthews et al., 2018). For the study, the national 2050 reduction target in the transport sector was defined as the amount of total CO_2 allowances, hence the national mobility budget. Although the translation of the global carbon budget to national allocations is not trivial and has sparked many discussions concerning fairness and equity principles based on concepts of responsibility, equality and capability across nations (Matthews et al., 2020), the national targets were chosen as a starting point to asses the translation to the individual level.

As the hypothetical implementation of a radical intervention such as mandatory individual mobility budgets represents an extreme measure to reach carbon emission reduction goals, stakeholder involvement and a sound data base for assessing the impacts was crucial for the project. Therefore, a combination of qualitative-interpretative methods and quantitative-statistical methods was followed to ensure the comprehensive consideration of different stakeholder opinions for defining the main characteristics of individual mobility budgets and their implementation, and to obtain a sound assessment of the feasibility and impact of such a measure. As a first step, average individual mobility budgets were calculated to make the consequences of ambitious targets more tangible on the individual level. This was followed by a qualitative assessment of crucial characteristics of individual budgets achieved by involving stakeholders from different fields during a consensus conference. The concept for mobility budgets developed on the basis of this

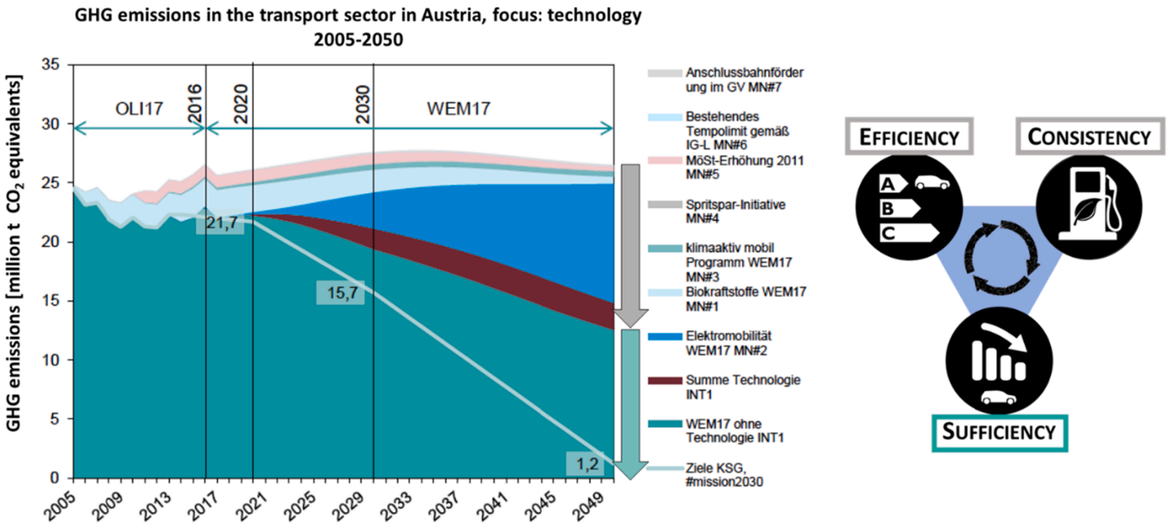

Fig. 2. GHG emission development and targets in the transport sector in Austria (2005–2050): potential savings attributed to technological efficiency and consistency measures (grey arrow) and still unresolved remaining amount of CO_2, which may be reached with additional sufficiency measures (green arrow) (graph on the left: Weiner, 2018). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

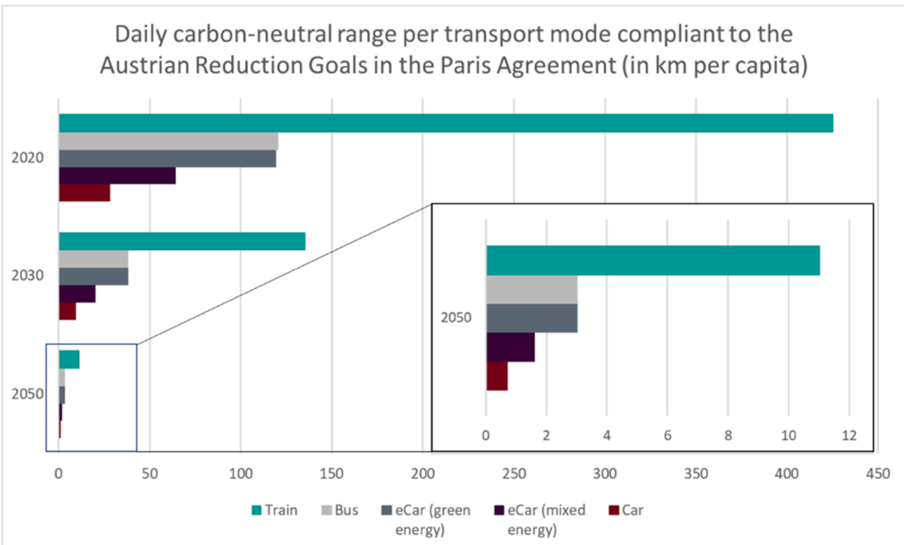

Fig. 3. Daily maximum ranges per person and transport mode (no combination of transport modes) in compliance with the Austrian CO_2 upper limits in the transport sector.

consensus was then tested through impact assessment on the individual level as well as the transport system level.

3.2. Calculation of average individual mobility budgets

In preparation for the stakeholder involvement, variants of basic characteristics of individual mobility budgets for the case of Austria were hypothesised on the basis of literature and practical examples of carbon budget initiatives and the Austrian transport related national carbon reduction goals. Average budgets were calculated on the basis of studies by the Austrian Federal Environment Agency (Weiner, 2018), which show that even under optimal conditions (69% share of e-vehicles by 2050, achieved among other things by increasing the mineral oil tax) only about half of the required CO_2 reduction can be achieved. This approach served as an initial rationale for the stakeholder communication that in addition to efficiency and consistency measures, sufficiency measures to effectively change mobility patterns from the “anytime, anywhere” mantra towards an “as much as necessary, as little as possible” paradigm need to be realized (see Fig. 2).

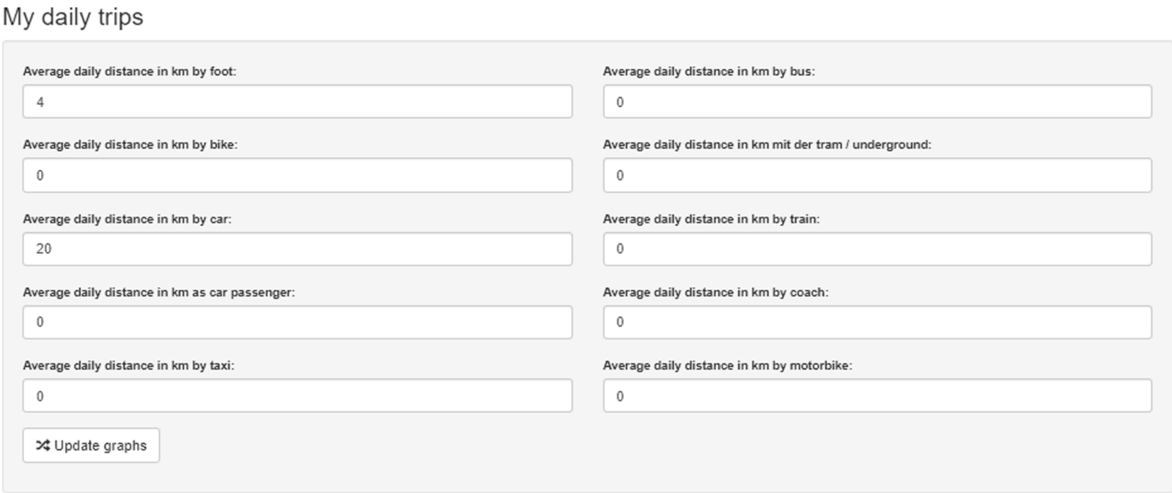

Fig. 4. Input of average daily travel behaviour.

These average individual upper limits could define a sufficiency benchmark ("ceiling") for personal mobility in Austria. The CO_2 footprint of mobility served as an indicator for this definition, as the ecological footprint of different forms of mobility can be described very well in CO_2 equivalents as an approximate value. Likewise, the CO_2 intensity (still) allows a good conclusion to be drawn about the energy intensity of forms of mobility, which in turn provides a picture of the eco-social sustainability of forms of mobility. CO_2 equivalents are also a suitable unit of measurement for integration into existing (international, national and regional) regulations and target functions. These ceilings for the formulation of a mobility budget can be defined by existing CO_2 reduction targets at European, national, regional, or even city level. For the feasibility study, these were:

- Available CO_2 budget for the (hypothetical) achievement of the 2 °C climate target and its allocation in the years until (expected) decarbonization in 2050 (basics from (Meyer and Steininger, 2017).
- Data on reduction targets in traffic and possible reduction contributions of existing and planned measures from the Mobility Status Report of the Austrian Federal Environment Agency (Heinfellner, 2018)
- The climate targets set under the Effort-Sharing Regulation, according to which Austria is to reduce its emissions by 36% until 2030 compared to the reference year 2005.
- For the case of Vienna: existing targets on CO_2 emissions of transport from strategy documents such as the Urban Development Plan STEP2025 (Telepak, 2015) or the Smart City Framework Strategy for Vienna (Homeier, 2014).

The transfer of these upper limits to individual upper limits showed that, from today's perspective, achieving the CO_2 reduction targets in Austria can only be achieved with sufficiency measures (see Fig. 3). Even if technical and regulatory measures foreseeable today are taken into account, mobility habits would have to be significantly restricted, since the climate-compatible "leeway" (or maximum compatible transport performance) per vehicle will be dramatically reduced over the coming years until the target value in 2050 is reached. While a green electric car could still cover 119 km (73.9 mi) per day today if the upper CO_2 limits were retained, only 38 km (23.6) per day would be climate-compatible in 2030. If the limits for 2050 were already in force today, in Austria one could only drive a maximum of 3 km (1,9 mi) per day on average before exceeding the daily amount of climate-compatible CO_2 emissions.

3.3. Qualitative assessment and stakeholder involvement

For involving different stakeholder groups, a Consensus Conference was organised. Consensus conferences are a form of participation, where a panel of citizens question expert witnesses on a particular topic at a public conference. The panel members receive a detailed information pack and are given time to prepare before the actual conference so they can come to the topic as better informed citizens. After questioning the experts to clarify open questions, the panel strives for reaching a consensus regarding specific guiding questions (Joss, 1998). For the "mobalance" study, this concept has been adapted to invite stakeholders to discuss four topics around the concept of individual mobility budgets:

1) Conception of mobility budgets: *Where should the system boundaries for individual mobility budgets be drawn?*
2) Calculation of mobility budgets: *How can mobility consumption (or resource consumption) for the calculation of mobility budgets be measured?*
3) Social aspects of mobility budgets: *Should a person's life circumstances influence the size of their individual mobility budget?*
4) Mobility budgets and trading of mobility credits: *How could the (possible) trade of mobility credits allocated to a mobility budget work?*

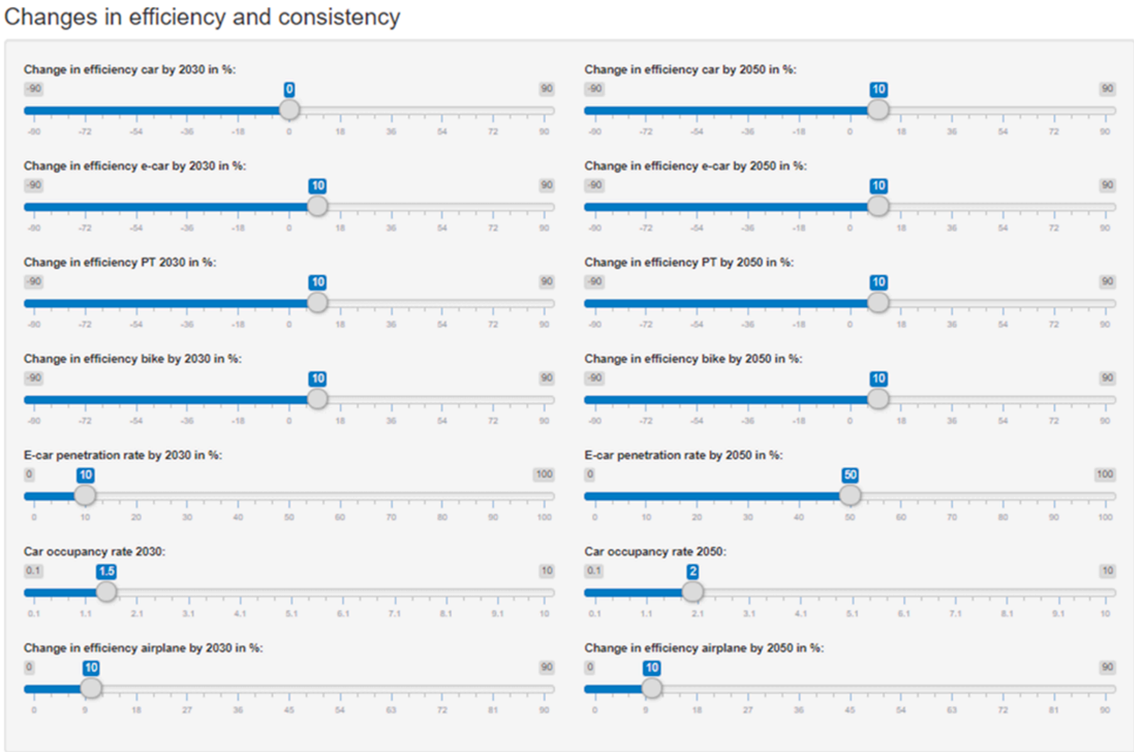

Fig. 5. Input mask for the entry of improvements in efficiency and consistency in the transport system for 2030 and 2050.

20 representatives from different stakeholder groups (administration, private sector, academia, NGOs, interest groups, public enterprises, public institutions) participated in the conference to reach consensus on the definition of mobility budgets on the individual, municipality and national level. Given the complexity and the radical nature of the concept, it was decided not to involve citizens at this stage of the discussion, but the format put a strong emphasis on considering citizen needs. Despite the different perspectives of stakeholders, the format was able to create a strong sense of solidarity in the participants regarding their jointly developed vision of implementing mobility budgets. The results informed the subsequent quantitative impact assessment of mobility budgets.

3.4. Impact assessment on individual level

In order to make visualize the impact of individual mobility decisions, a simple online self-assessment tool was developed to help traffic participants to assess the consequences of their own mobility behaviour under changing conditions. Assumptions regarding technological and social trends can also be individually adapted.

Respondents are asked to provide statistical information on personal mobility behaviour (daily distances per means of transport see Fig. 4). In addition, they are able to provide input for possible scenarios of a development of transportation options, like the improvements of efficiency for different mode of transport or the share of electric vehicles in the fleet for 2030 and 2050 (Fig. 5).

To provide meaningful comparisons of the impact of their current mobility behaviour, the respondents behaviour is set into context to the current mobility behaviour in Austria. To extract mobility data and GHG-Emissions for an average day in Austria, the trips of the first reporting day of each respondent are used. The CO_2 equivalents E_r in g per day are calculated by summing the emissions for the trips t in the set T_r of the trips of respondent r on that day as $\mathrm{E_r} = \sum_{t \in T_r} d_t e_{m_t}$, where d_t is the trip distance of trip t in kilometres and e_{m_t} are the average emissions of the main mode of transport used for trip t in g of CO_2 equivalents per kilometre. The average emissions for each vehicle type in Austria are taken from Emission factors related to passenger/tonne kilometres provided by the Austrian Federal Environment Agency (Uba, 2020a), supplemented emission factors provided by the Swiss mobitool (Frischknecht and Tuchschmid, 2017) where necessary.

3.5. Impact assessment at transport system level

Data sets from two surveys were used to assess the transport impact of individual mobility budgets: “Österreich Unterwegs” Open Government Data (ÖU) (Tomschy et al., 2016), a national mobility survey with data on mobility patterns and socio-geographical influences in the Austrian population (N = 1,162 households), and a preference survey (N = 1,010 individuals), which was carried out as part of the project to analyse how people would replace their journeys if they were no longer able to use high energy modes (especially private cars) due to restrictions. Both data sets were weighted with extrapolation factors to achieve representativeness for

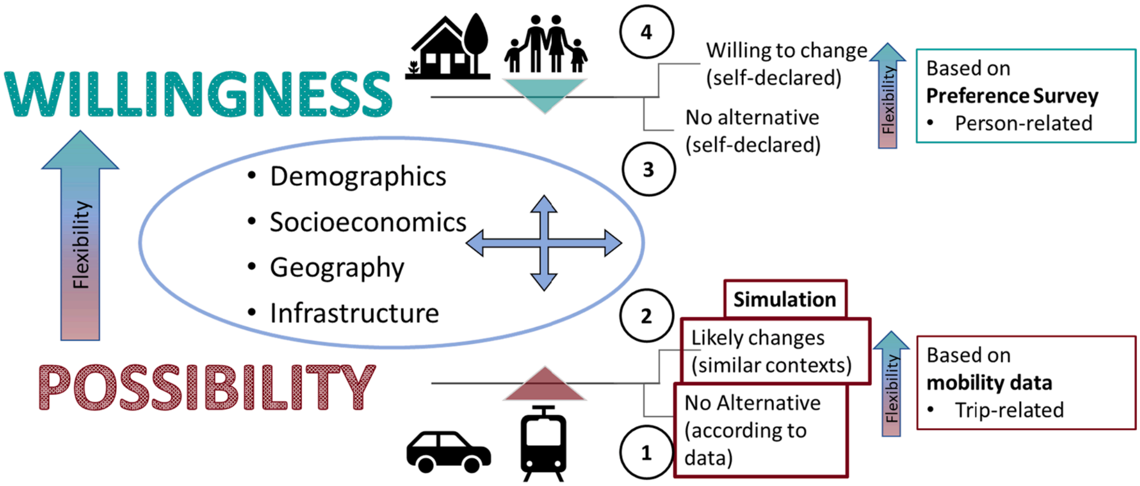

Fig. 6. Diagram showing the estimation of willingness vs. possibility to change the mobility behaviour to a "greener" alternative based on a preference survey for the willingness and on mobility diary data for the possibility to change.

the Austrian population.

The two surveys represent two basic conditions of mobility flexibility: willingness - personal/social (determined from survey data), and possibility - infrastructural/economic (investigated by simulation of mobility data). Both conditions allow estimates of upper and lower limits of the shares of the population that are restricted with regard to their access to mobility alternatives (see Fig. 6). They thus provide an initial indication of those socio-geographical circumstances in which a mobility budget would have particularly serious consequences. In case of missing possibilities due to lack of infrastructure and when the when the lack of will is due to personal limitations, individual mobility budgets should receive a higher allocation of allowances at the beginning in order to compensate for the above-average disadvantage and achieve a "fair" allocation of allowances. At the same time, these circumstances are also those which must be prioritised in the context of the implementation of measures (e.g. improvement of local supply facilities and public transport).

4. Results: Fair budget distribution and impact assessment

4.1. Stakeholder consensus on mobility budgets

The involvement of different groups of actors in the Consensus Conference has above all shown that ceilings can be derived from reduction targets, but that the floors (enough leeway to meet a minimum of basic needs) vary significantly due to the different spatial and social living conditions of the population and therefore exceed the average ceilings in some places. Therefore, the upper limits must also be adjusted according to the individual situation in order to be able to organize mobility within the limits of sufficiency. At the same time, the framework conditions must also be adapted over time so that the lower limits can also manage with smaller budgets; in other words, mobility offers, and accessibility must be improved, especially where individual lower limits are above average.

In general, a central concern discussed in the conference was how to achieve a socially "fair" solution which cannot be misused e.g. by rich or powerful individuals. In this context, it was also agreed to consider a trading option for a limited percentage of "credits" between the owners of mobility budgets. Since rigidly fixed individual mobility accounts cannot react flexibly to changing conditions (e.g. unforeseen urgent journeys), a limited contingent of tradable certificates should be made possible. In practice, this could take the form of each person being able to trade, for example, 10% of their personal mobility account on a certificate exchange, with the price of the certificates being determined by the market. However, the total amount of certificates must always remain below the emission limits; there is no provision for the purchase of additional certificates that would mean that the emission limits would be exceeded during a certain period of validity (e.g. per year in the case of annually adjusted emission limits). The proportion of personally tradable certificates should also be kept at a low level to prevent speculation with certificates.

4.2. Individual self-assessment of mobility behaviour impact

The visualisation tool for assessing the impact of individual mobility patterns in relation to Austria's 2030 and 2050 GHGE reduction goals has been implemented on the project website to provide an interactive environment for comprehensible communication of the consequences of individual behaviour. The tool has been used in the dissemination activities of the project and forms the basis for testing individual mobility budgets in follow-up projects (see Section 6).

For the current scenario, the data is represented as a weighted histogram (weighted by the extrapolation factors provided in ÖU) shown in the first plot of Fig. 7 together with lines indicating the current average in the data (black line), the average planned emissions

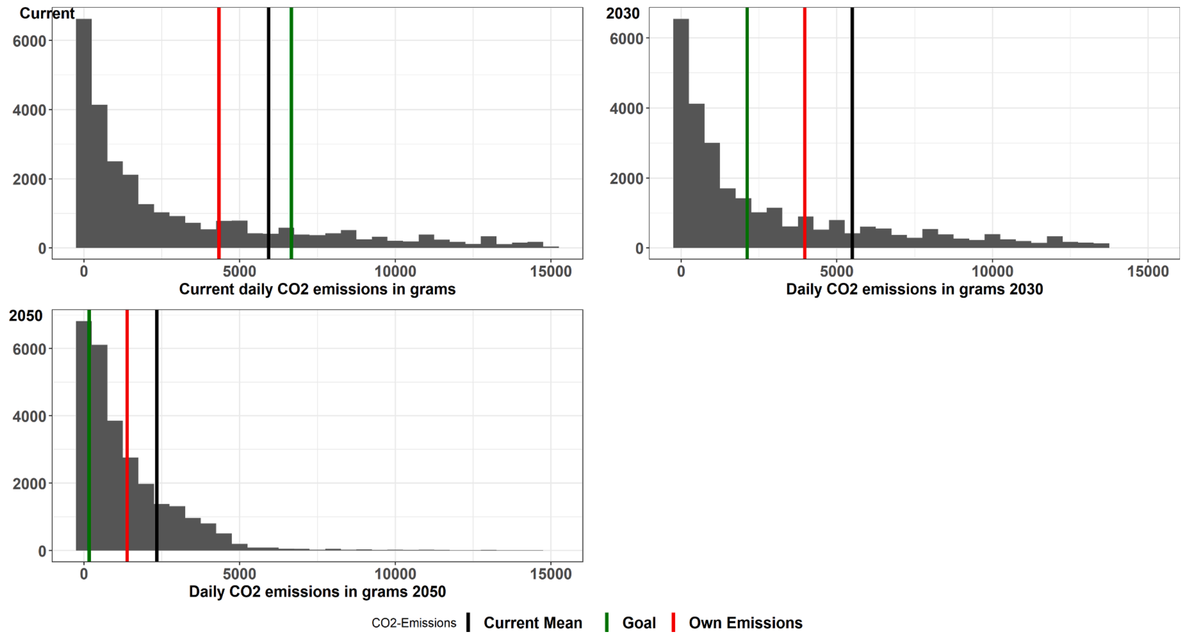

Fig. 7. Histograms of current daily CO2 emissions according to ÖU. The vertical lines show the current mean CO2 Emissions per person day (black), the allowed mean emissions per person day according to the mobility budgets (green) where the current value are the real current emissions and the emissions according to the values filled in the tool for the respondents' current mobility and the efficiency improvement (red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

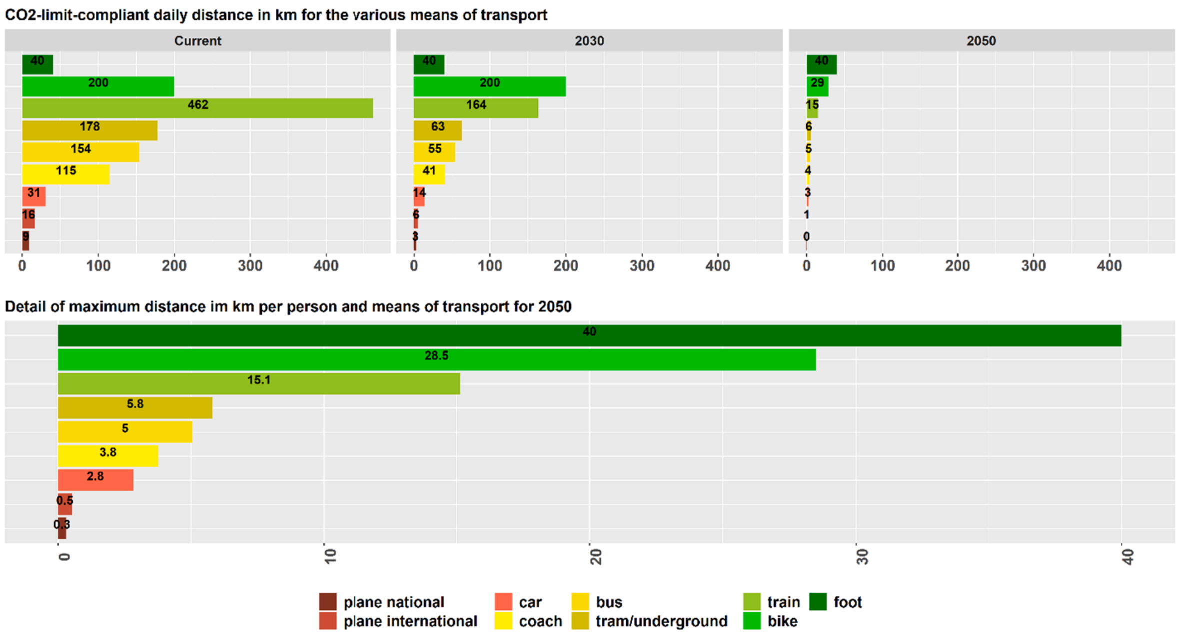

Fig. 8. The figure at the top shows the CO2-budget compliant distances that are possible with each mode if this mode is the only one used for that day for the current scenario, for 2030 and for 2050. The graph in the bottom line shows the situation for 2050 in more detail. Here, even with 50% electric cars and an increase in efficiency for cars and electric cars of 10%, an average car could only travel 2.8 km (1.7 mi) on a day before the daily CO2 budget is reached. The possible distances for walking and cycling were reduced to the distance possible in 8 h (40 km (24.8 mi) for walking and 200 km (124.2 mi) for cycling).

for that year (green line) and the emissions of the respondent according to their given current behaviour (red line). For the other two plots, the emissions factors were adapted according to the efficiency and consistency adaptations. The remaining two graphs show the scenarios for 2030 and 2050 where the black lines are again the mean emissions, the red lines the adapted emissions of the respondent for 2030 and 2050 respectively and the green lines the average emissions per person according to the remaining CO_2 emissions for mobility in Austria in 2030 and 2050. Note that the mobility behaviour is taken as a constant here, i.e. the histograms always represent the behaviour found in ÖU.

To reinforce the significance of the graphs, meaningful examples are displayed ("With your current transport behaviour, you would have to save 1218 g (43.0 oz) CO2 per day in 2050. This corresponds, for example, to 18 km (11.2 mi) by car. You would have no budget for holiday trips"). The current examples in this paper are for a mobility pattern of a daily average of 4 km of walking and 20 km of car journeys per day.

The final representation of necessary behaviour changes due to climate goals is given in Fig. 8. In this figure the bar plots show how far one could travel with one chosen mode of transportation according to the GHG-Emission goals and the efficiency and consistency adaptations provided.

This striking presentation of one's own contribution to traffic emissions and the consequences of maintaining current mobility patterns can easily convey the highly ambitious goals of the internationally agreed greenhouse gas reduction and the urgency of consistent action on an individual level. At the same time, it shows the indispensable contribution that can be made by one's own behaviour and the acceptance of personal responsibility.

4.3. Potential for behaviour change and need of access improvements

Initially, three types of regions were distinguished as an approximation for different framework conditions (urban, *peri*-urban and rural). Based on ÖU, current and future CO_2 emissions were estimated for the various region types, taking into account already foreseeable technological efficiency improvements (Heinfellner et al., 2018). It was found that CO_2 emissions in the three regions are fundamentally different and that the subdivision into these region types is therefore important in order to be able to take different mobility needs into account and to assess the necessary infrastructural developments.

In order to investigate the basic possibility of switching to more climate-friendly mobility offers, a Quick Assessment Tool (QAT) was developed to enable an assessment of local options for switching in different spatial categories. The underlying assumption of this QAT is that travel time and expenditure budgets remain constant over time (see e.g. Mokhtarian and Chen, 2004). This simulation tool was used to reassess mobility patterns collected from the ÖU survey data by changing the cost structure (according to a scenario 2030). To test the impact of future measures to influence mobility behaviour, an adjusted scenario was designed, where car journeys were "made more expensive" by increasing the current monetary expenditure per distance by 20 % while public transport was set to be 5 % cheaper. Additional assumed improvements in infrastructure result in 5 % reduction of time-costs for public transport and cycling (making these modes slightly "faster").

This setup was chosen to imitate the conditions of a limited individual mobility account and tighter high-GHGE restrictions in order to estimate the effects on people with different socio-geographical backgrounds. In a first step, travel time and travel budget histograms were calculated from the ÖU data for both the current cost and travel time situations and for the situation with the adjusted cost structure. From these histograms the respondents in ÖU with the largest changes in their travel time and travel budget were selected. For these respondents, similar trips from ÖU data were chosen to replace the trips with the largest changes in costs to readjust the cost histograms, e.g. car trips of these respondents were replaced by trips in public transport in case there was a "suitably similar" public transport trip within the ÖU data. To do that a similarity measure was developed that indicates the similarity of trips by considering their spatio-temporal and traveler's socio-demographic closeness using logistic likelihood metrics on suiting data types (e.g. euclidean distances for locations, category-level differences for ordered factorials, differences for numeric variables…). Combining those multiple feature likelihoods in a weighted sum (e.g. pronouncing geographical and day-time proximity) allows to define probabilities for all alternative trips of all agents.

From the travel cost histograms it can be seen that with the introduction of a mobility budget almost all mobile persons in Austria find it (not surprisingly) more difficult to stick to their usual preferred means of transport, as it would be more expensive and/or time-consuming for them, and for a small part it becomes even impossible to maintain their usual behaviour.

The replacement algorithm tries to "correct" the agent's travel expenditure increases in the following steps:

1. The 5% of respondents with the largest changes in their travel time and cost budgets are selected.
2. Trips are replaced by the most similar trip with an equal or "greener" mode from ÖU applying the similarity measure described above.

These steps are repeated until it becomes almost impossible to readjust the travel behaviour of affected persons by using alternatives existing within the ÖU mobility diary data.

The results of this Quick Assessment show that in certain types of regions there is limited scope for finding an exemplary mobility substitute in the vicinity. Outside of urban areas, there are fewer alternatives to MIV, although the data indicate that 1.2–2% of the total population have no alternative to their CO_2-intensive mobility behaviour. However, among those who have the possibility to change, according to the survey data, trip-alternatives, which can improve the effects of the changed cost structure in the scenario 2030, can only be found for about 10–20% of the affected agents. For the remainder, the "price increase" of CO_2-intensive means of transport is not burdensome enough to change their behaviour - due to the lack of alternatives or those that are too complicated, they would rather accept the cost increases in the scenario 2030 (the required higher input of money and/or time) than change their behaviour. This was compared to a preference survey where people were asked about their willingness to replace trips that are no longer possible with the chosen mode. As an example, people who are currently choosing their car for work trips were asked to state

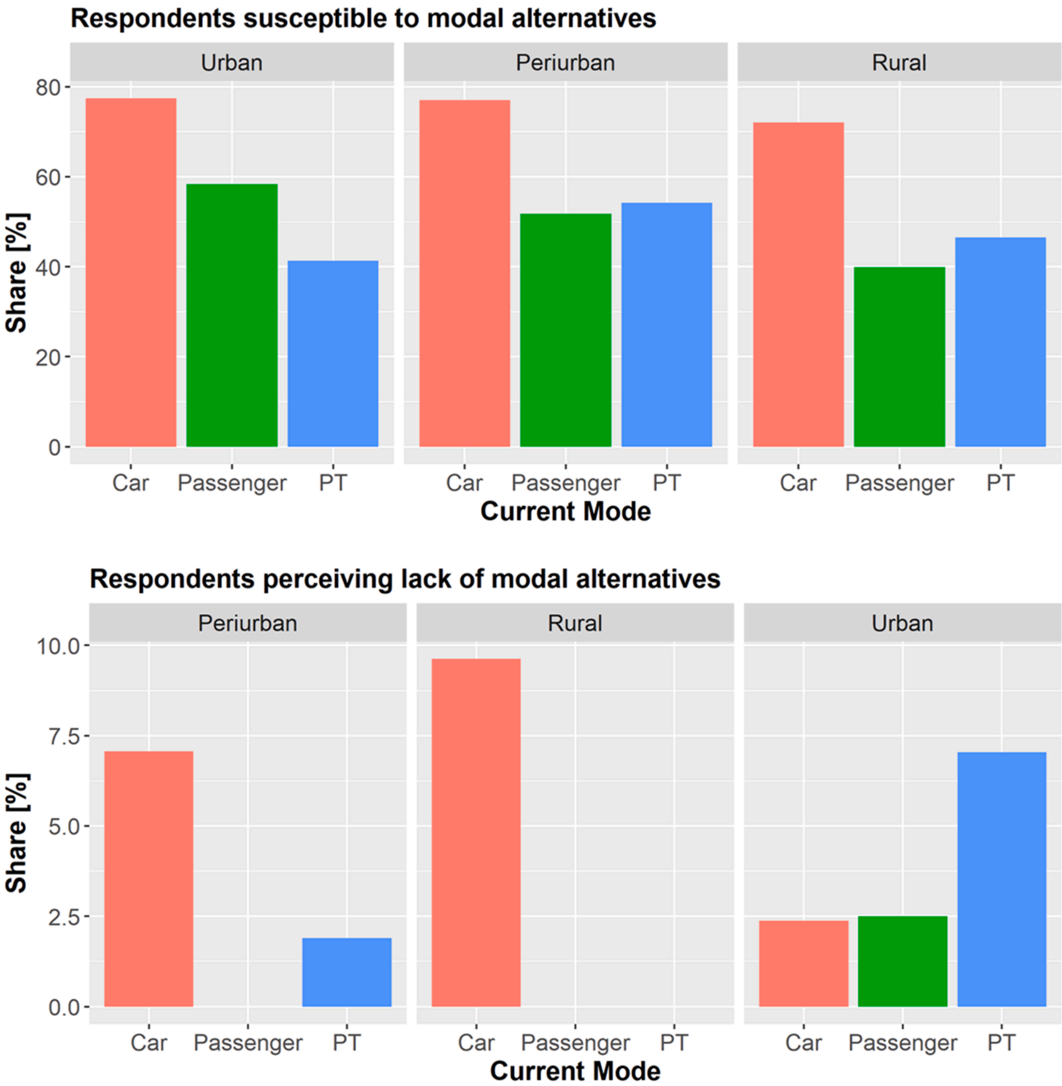

Fig. 9. Share of regular trips in different modes for which respondents in the preference survey would gladly chose an alternative (top) and who would chose a modal alternative under no circumstances (bottom) in case their current mode (given on the x-axis) was no longer available for three geographically different region types.

their likeliness to choose alternatives in a four level Likert scale from "under no circumstances" to "very gladly". Modal alternatives for trips were carpooling with others, public transport, (e-)bike, on foot, where the alternative currently taken was not available anymore.

To estimate the likelihood that trips in certain modes could be replaced, for each of the activity types (work, education, shopping, visits, leisure, accompaniment of others and errands) respondents who carry out this activity regularly (At least several times a week) were selected. Subsequently, the proportion of these respondents who would gladly or very gladly accept at least one alternative was calculated. From this the proportion of regular trips for which an alternative was imaginable was calculated for different regions (see Fig. 9). Similarly, the number of respondents with no modal alternative to their current mode was calculated as the number of respondents who stated "under no circumstances" for all modal alternatives.

The results show, that 40–80% (based on activity type and current mode) of the respondents who were asked to change their mobility behaviour under the conditions of the survey consider their mobility behaviour to be changeable, while 1%-7% of the respondents experience it as lacking an alternative; subjectively, therefore, the lack of alternatives is assumed somewhat more often than would be the case in real terms on the basis of the mobility survey data. This means that here, too, without infrastructure adaptation in certain geographical or social areas, there is a lack of alternative mobility options. The noticeable difference between the declared willingness to change (up to 80%) and the possibility of change within environmental similarity (at a maximum of 20%), as shown by the data, requires measures to create mobility alternatives and local supply facilities to improve accessibility in the predominantly rural regions. In connection with the discussed steering instruments, it is necessary to strategically identify and foresee those affected strongly, in advance.

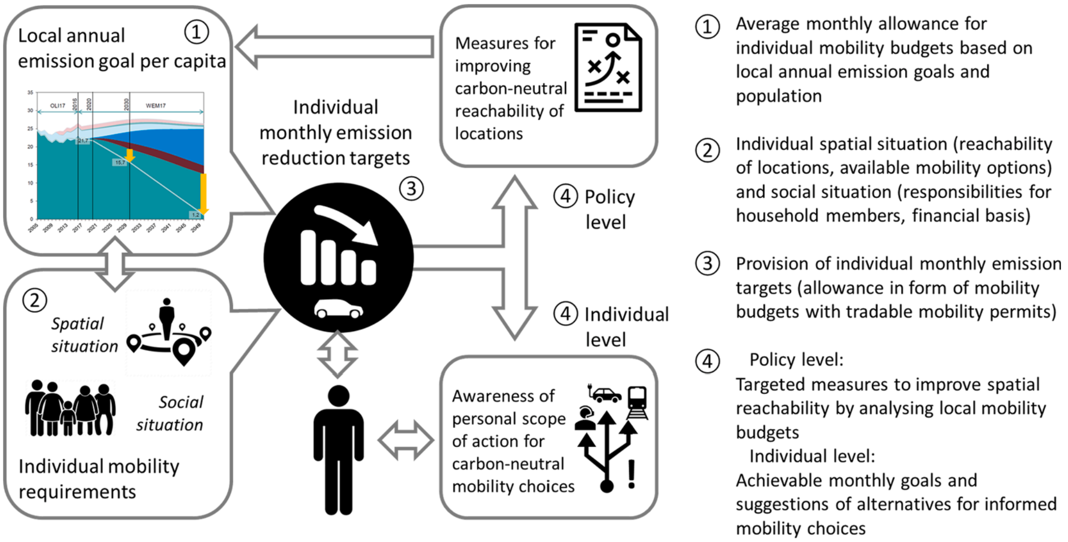

Fig. 10. Mobility budget concept resulting from the mobalance project.

5. Proposed concept of fair mobility budgets and recommendations

As a final result the mobalance project can offer insight into various possible approaches to the introduction of personal mobility accounts. Based on the inputs gained from the intensive stakeholder process (consensus conference and focus groups), from an extensive literature analysis as well as from simulations of traffic impacts and trading options, the following aims for the conception of individual mobility budgets were defined:

- **Compensation of spatial-social disparities (fairness)**: by considering the scope of action of individual persons (socio-spatial situation, existing alternatives)
- **Increasing willingness to change behaviour**: through informed decisions and individually achievable short-term goals
- **Improvement of possibilities**: through systematically relieving local accumulations of high certificate requirements due to lack of accessibility by intensifying local supply and public transport services

Under these conditions, the concept of mobility budgets was further specified as following for the case of Austria:

- **System boundaries**: passenger transport in Austria
- **Structure**: Persons and companies (for business trips) in Austria receive a certain number of certificates per time unit (e.g. for one week or one month). The number of certificates is adapted to the climate targets and may not be exceeded. There is a trading exchange where parts of the certificates can be traded on the free market.
- **Monitoring and target function**: For reasons of data protection and acceptance, personalized tracking should be avoided as far as possible (alternative: chip cards for refuelling, etc.). The target function therefore results from the actual expenditure on mobility in the form of fuel and ticket purchases.
- **Initial distribution of the certificates** (e.g. on national level) is based on 2 factors in order to achieve the fairest possible distribution: (1) accessibility of destinations, (2) socio-economic situation and mobility barriers.

Fig. 10 shows the annual determination of individual mobility budgets and the possibilities at individual and political level to ease the burden on individual budgets. First, the national emission targets for the respective year are calculated on the basis of emission measurements and calculations for the previous period (only individual transport without business trips). The resulting annual certificate for climate-friendly CO2 emissions is divided by the population to achieve the average number of certificates per person:

1) In order to obtain a fair distribution of certificates taking into account socio-geographically disadvantaged people, the individual mobility needs ("floors") are determined.
2) Each citizen will then receive individual monthly emission caps (allowances/certificates/permits) in the form of a mobility budget (which could also be used as currency for the purchase of transport), which will also include the possibility of trading a certain proportion of their allowances in order to achieve greater flexibility (e.g. for unexpected necessary travel).
3) During the course of the year, individual budgets can be managed by citizens through informed mobility decisions based on the known emission levels of the available means of transport, while at the same time, at the policy level, areas or groups with above-average demand for allowances can be identified in order to prioritise targeted measures to relieve the respective budgets.

4) At the end of the annual cycle, the success of the planned emission reduction is evaluated and new - harder or milder - reduction targets for the next period are calculated to stay on the long-term reduction path.

6. Conclusion

The COVID-19 crisis has shown that radical measures are possible and even widely acceptable, if the urgency and responsibility needed connect to personal lives. However, carbon reduction goals are far too vast and unspecific and too distant in the future for the average citizen's perceived context to stir a sense of personal responsibility, even though the climate crisis is equally urgent (CED, 2020). So, despite an increasing general awareness of climate protection needs and a wide range of literature regarding mobility behaviour and potential nudges to motivate behaviour changes (Millonig and Mitgutsch, 2014; Markvica et al., 2020), there is a high discrepancy between reported environmental awareness and actual mobility practices. A stronger focus should be put on the individual contributions through behaviour change, which is indispensable for complementing efforts on the service side (e.g. technological improvements). This, however, can only be achieved by offering the individual traveller a tangible and worthwhile chance to contribute, which again is only possible if individuals comprehend the impact of their own everyday mobility choices. To break down the complexity of nationally determined contributions to the global climate action, schemes like monthly personal or household carbon quotas or tradable permits (Hillman, 1998; Starkey and Anderson, 2005) can translate general long-term goals into achievable individual short-term targets, similar to solutions supporting other behavioral changes like dietary or fitness goals (Locke and Latham, 2002).

The feasibility study "mobalance" explored a radical concept for reducing transport related GHG emissions using the case of Austria and its national carbon reduction goals for 2030 and 2050. Several tools and methods were used to assess the effects of this concept of mobility budgets; in addition, intermediate findings were discussed with various stakeholders in focus groups and workshops. It was shown that a strong change in the behaviour of all actors is necessary to meet the reduction targets of mobility budgets, especially requiring major planning and organizational efforts and investments to achieve compliance with the strict GHG targets in the long term. Incorporating individual socio-geographical contexts is essential, as stakeholders emphasized that individuals need to perceive the distribution as fair, and therefore efforts to level out disparities need to be developed, e.g. in rural areas (expansion of local supply and services, expansion of public transport offers). Equally important are activities to change the current transport growth paradigm into a sufficiency perspective, which presupposes a reorientation of the population and decision makers. Under these conditions, mobility budgets and more general GHG budgets require a certain lead time, which must be cushioned by the introduction of GHG taxes to accelerate the transformation. Regarding the further development of the concept developed in mobalance, the following preparatory work, among other things, still needs to be carried out before mobility budgets can be realized:

1) Awareness building:

Convincing decision-makers and the population of the effectiveness and necessity of measures (e.g. by means of information and impact assessments, based on learnings from popular explanations of pandemic infection models during the COVID-19 crisis to achieve awareness and comprehension)

2) Technical implementation:

- Development and implementation of technical components (e.g. communication tool, GHG tracking tool)
- Models for fine tuning mobility budgets for different groups of people (fair distribution)
- Coordination of different stakeholders to set targets for GHG emissions (e.g. social targets vs. economic targets)
- Extension of the tools for the identification of rebound and side effects (e.g. increased energy demand due to GHG tracking and virtual mobility, rebound into other consumption areas)

As this preparatory work takes time and there are only 10 (until 2030) and 30 (until 2050) years left to meet the reduction targets, immediate measures must be taken, and clear development paths need to be defined at the policy level. The following recommendations for action at the policy level were therefore formulated from the mobalance project:

- The necessary immediacy of measures requires the earliest possible initial implementation, therefore an immediate introduction of GHG taxation is recommended.
- The continuous annual reduction of transport related GHG emissions (according to nationally agreed targets based on the Paris Climate Convention) is recommended by applying the instrument of individual mobility budgets in order to achieve a targeted relief of social impacts.
- It is recommended to embed mobility budgets in an extended and comprehensive climate/consumption/social resource budget in order to compensate spill-over effects into other sectors and to prevent the compensation of savings.

In addition to these recommendations, suggestions for specific measures for essential areas defined at the beginning of the project (legal measures, planning measures, economic instruments, persuasion and information measures) were specified (see Table 1).

Due to the limited resources of the study several important aspects have been identified but remain insufficiently explored, hence, they must be clarified for experimental trials of mobility budget applications (especially compared to carbon taxes). This includes for example approaches to implement accurate and fair monitoring with relatively little time and technical complexity, removing data protection concerns, experimental environments for testing real implementation and enforcement, the affordability for the regulatory level (less tax income is generated), the acceptance by the population, low transaction costs and only minor fluctuation of certificate

Table 1
Mobility budget recommendations.

Categories of implementation	Potential measures (selected)	Recommendations
Laws (regulatory law)	• Install upper limits for motor vehicles, (e.g. concerning CO_2 emissions, mass or energy consumption) • Complement Environmental Impact Assessments (EIAs) with tools regarding resource budgets	• Check possibilities for conversions • Discuss RTI potentials
Planning	• 15-minutes-City • Stop construction of car infrastructure • City designs based on CO_2 footprints	• Check or initiate conversions • Exploit/realize RTI potentials
Economic instruments	• CO_2 tax • Kerosene tax • Abolish fossil subsidies	• Initiate tax arrangements • FTI potential: underpinning CO_2 sufficiency as a driver for innovation
Nudging	• Provide easy sustainable alternatives • Social references/examples • Marketing for sufficient behaviour	• Examine possibilities for conversions. • Discuss RTI potentials
Information	• Communicate best practices • Valorise living standards • Create awareness of the positive effects of sustainable mobility	• Examine possibilities for conversions. • Discuss RTI potentials

prices.

To further the design and realization of individual mobility budgets, two follow-up projects started in the spring of 2021. On the European level, a three-year transnational research project to develop tools and instruments for defining individual mobility budgets is initiated (MyFairShare”). The project includes six Living Labs in different European countries exploring various application options of mobility budgets, e.g. offering mobility budgets as a local community project, adapting mobility budgets for “congestion charging 2.0”, etc. A two-year national implementation project (“CARBON DIET”) focuses on the development of tools for limiting CO_2 emissions of business travels in companies and research institutes.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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