SWICE Working Paper on DLS Mobility

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1. Executive Summary - SWICE Working Paper on DLS Mobility

What is the minimum final energy needed to ensure wellbeing for all in Switzerland? What level, type, organization, and approach of mobility could be a basis for such wellbeing?

Reducing the negative impacts of Swiss mobility has been an intractable problem for decades. Despite numerous initiatives, transport energy and GHG emissions have been basically unchanged over the 1990-2020 period, and are almost entirely caused by cars and trucks. Some aspects have changed: public transport is improving, but urban sprawl is getting worse.

Wellbeing is complex and multidimensional, but requires minimum material prerequisites, which are defined and quantified in the Decent Living Standards (DLS) framework, originally developed to inform policies to close the gaps in living standards in the Global South.

In this paper, we **make a methodology contribution to DLS by developing an activity-based bottom-up mobility model for Switzerland**, a rich country with very high levels of consumption. It is based on a scenario to solve issues of mobility and the built environment together, developed in "*Systems perspectives on transforming Swiss housing by 2040: wellbeing, shared spaces, sufficiency, and de-sprawl*".

While following the DLS philosophy, which combines basic needs with central capabilities at the household, community, and national level, we aim to contribute to DLS literature, where mobility until now remained a "black box". Our bottom-up model keeps today's daily number of trips for work, leisure, etc. from the 2015 Swiss Microcensus, but adapts the distances and transport modes to optimized use of spaces from the scenario described above. It is both ambitious (much better use of spaces) and conservative (same number of trips, EP2050+ efficiency factors), making further improvement possible.

The main cause of the failure to reduce the negative impacts of cars has been a largely technical approach to what fundamentally and primarily is not a technical problem. From a human needs perspective, mobility is not a need, but a satisfier for several needs. In other words, it is generally a means to an end, not an end in itself; when it is an 'end', it is typically done via non-motorised means. Demand for mobility is mainly driven by culture (specifically the material nature of needs satisfiers covering a single need), and a sprawled built environment. This leads to more and longer trips. This is the result of a socially constructed "car lock-in", in the context of the political economy of car dependence, where interlocking elements of car manufacturing, infrastructure, urban sprawl, public transport, and culture reinforce each other – and can only be solved together.

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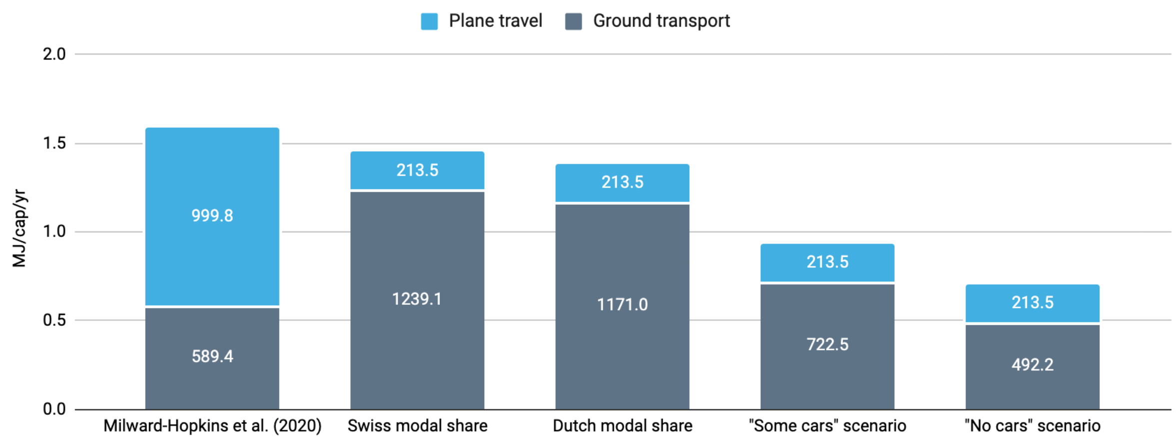
Our model works by defining **four zones of daily interaction**, with frequency based on today's mobility patterns, but distance based on space optimization: **local** (1 km, most daily services), **extended local** (3 km, work, remaining daily services, social/cultural events), **regional** (15 km, public administration, hospitals, visiting friends), and **extra-regional** (100 km, nature, friends/relatives, international). As leisure is the biggest driver of mobility, we do a detailed analysis by motive and type. The resulting trips are combined with transport modes based on distance, adapted from the current Swiss and Dutch modal split. Two modal splits are explored: "some cars" and "no cars", without considering all required societal arrangements, beyond neighborhood transformation. For the sake of simplicity, we do not consider health conditions, occupational needs, or other factors that currently make cars necessary for some people. Nonetheless, minimizing car journeys may be more feasible than it first appears, due to the density of neighborhoods we assume in the space-optimized scenario, and the fact that, in principle, and putting aside temporal considerations, total public transport requirements remain well below today's nationally averaged capacities.

Table ES1: Overview of results by method, showing total distance and modal split, in pkm/cap/yr

Method used or population considered		Annual mobility excluding air travel	Annual car transport	Annual public transport
Swiss population, 2015 Microcensus		13'754	7'611	3'372
Based on DLS best practice (Japan)		4'829	716	2'862
Interaction-based approach	Swiss modal share	3'241	1'717	495
	Dutch modal share	3'241	1'708	233
	"Some cars" scenario	3'241	587	1'143
	"No cars" scenario	3'241	0	1'704

In terms of final energy used, all scenarios significantly reduce today's transport energy of 31.55 GJ/cap/yr (277 PJ/yr/8.78M), by approximately 95-97%, as shown in the figure below:



Finally, an additional allowance of 1500 km per year is added for Swiss residents with strong links to other countries, given their high share of the resident population. This adds another 107 MJ/cap/year, for a total at or below 1 GJ/cap/year, still a **97% final energy reduction** (vs. 2015).

This illustrates the significant potential of re-thinking mobility and the built environment together, specifically the accessibility of services and access to shared spaces.

2. Introduction to mobility and wellbeing

For decades, reducing the negative impacts of Swiss mobility has been an intractable problem, despite many initiatives by the confederation, cantons, communes, companies, universities, schools, and other organizations.

Specifically, passenger transport in Switzerland is currently dominated by cars and air travel in terms of distance, inducing a large amount of negative effects such as air pollution, noise, accidents and greenhouse gas emissions. While technical efficiency parameters, such as air pollution, final energy, and GHG emissions per kg of car (and sometime per whole car) have been improving, the main aggregate impacts have been either stagnating (final energy and GHG emissions) (BAFU 2023), or worsening, sometimes at an accelerating rate (urban sprawl, landscape fragmentation) (Jaeger et al. 2010; Jaeger et al. 2007).

In summary, the main cause of the failure to reduce the negative impacts of cars has been a largely technical approach to what is only partially a technical problem. Most action has focused on electrification, road-building, or improving public transport. This has led to some improvement (excellent public transport) and some degradation (new roads inducing more traffic and more urban sprawl), as well as overall growing car transport volume (BFS, 2024). Creutzig et al. (2022) have shown there is a potential of reducing motorized mobility needs while maintaining high levels of well-being. This report focuses on ground transport in Switzerland, approaching it from the perspective of human needs and satisfiers. Aviation is considered in terms of limits for climate neutrality, as it is a major aspect of Swiss mobility today. From a human needs perspective, mobility is not a need, but usually considered a second-order satisfier for several needs (Max-Neef 1991). For example, a job may be a primary satisfier for subsistence, and meeting friends a primary satisfier for identity; in both cases transport would be an enabler of primary satisfiers, or a secondary satisfier with respect to meeting those needs. This can be applied to all needs and satisfiers. Generally, singular satisfiers (those meeting a single need) and a dispersed built environment will lead to increased transportation, as more primary satisfiers are required across a greater number of distinct locations. To a large extent, this induced directed travel will not satisfy any needs in itself, it will only allow people to engage in activities and interactions which do satisfy needs. Only the undirected travel - for its own sake where the destination is ancillary - can be considered as a primary satisfier of physical and mental health needs, but this is mainly done with non-motorised modes (Hook et al., 2023).

Today's main driver of unsustainable mobility, excessive car use, has not developed by accident, and cannot be solved without understanding the "car lock-in", or the political economy of car dependence, which is based on five interlocked and mutually reinforcing elements: car manufacturing, car infrastructure (roads, parking etc.), urban sprawl, public transport, and a culture built around the car (Mattioli et al. 2020). Changing only one element, for example by electrifying cars will not solve the problem, and may even reinforce the lock-in.

If all cars are electric, does it matter? Regardless of whether all cars can be electrified rapidly to avert multiple environmental crises, is the car lock-in desirable or acceptable? There are many non-energy adverse effects of cars, such as biodiversity loss, landscape fragmentation, chemical pollution, accidents, social exclusion, contribution to concentration of power and inequality, etc.

Based on the interconnection of needs satisfiers, culture, the spatial organization of the built environment, and mobility practices and especially its car dependence, these dimensions can only be changed together. One such scenario to solve mobility and the built environment together is developed in Nick (2024), combining a new building moratorium, rapid building renovation towards high efficiency, shared spaces, and compact functional neighborhoods, and a simultaneous de-sprawl and reuse of materials from no longer needed buildings. Nick (2024) model floor space, building energy efficiency, final energy use, construction workers, worker productivity, and renovation rates. However the resulting mobility is not modeled: this is the focus of the present paper. In terms of transport, the focus of the approach is less mobility, more accessibility (Ferreira et al. 2012).

Decent Living Standards (DLS) were originally developed (Rao and Baer, 2012) to define and quantify the material prerequisites for decent living, i.e. the minimum needed for wellbeing in a complex society (hunter-gatherer societies, in contrast, can achieve very high wellbeing with very little material consumption; Galbraith et al. 2024). The required final energy for providing DLS is referred to as Decent Living Energy, and is the focus of this paper. The original purpose of DLS was to provide a multidimensional, needs-based way to assess deprivation, particularly in the Global South: it was first calculated for India, South Africa, and Brazil. It thus provides a far more meaningful measure of living standards than the various income poverty lines that exist.

So what is the meaning of DLS for rich-countries, where a large majority of the population already has access to material resources far in excess of those required for DLS? To answer this question, consider the concept of consumption corridors (Di Giulio and Fuchs 2014), which propose that consumption across a given population should vary between a minimum that guarantees one's basic needs can be met, and a maximum that ensures no one's consumption prevents others from meeting their needs. DLS can represent the bottom of such a corridor. Therefore, a rich-country DLS can serve several important distinct purposes, as it defines:

1. A minimum floor every individual should be entitled to, regardless of their ability to pay
2. A basis to define the ceiling of a sustainable consumption corridor
3. An objective basis for defining building or equipment standards
4. Via the consumption corridor, a basis for multiple public policies
5. A basis for economic incentives, in aggregate or separately for housing, mobility, etc., with subsidies for people below DLS, and highly progressive taxes above the ceiling
6. A set of practices which can become basis for cultural norms

2.1 Wellbeing and energy use

Global energy consumption has been rising rapidly and consistently for well over half a century (Global Energy Assessment Writing Team, 2012) despite multiple financial crises and pandemics. Today's unsustainable level of energy use is at the roots of ecological crises, resource scarcity, and the regional conflicts these can generate. The negative externalities also tend to primarily harm the most marginalized or least well-off (Haberl et al., 2011). While improvements in energy efficiency have occurred continuously since the industrial revolution, these have not reduced energy use, but instead catalyzed further energy and economic growth (Sakai et al., 2019). Within this context, some countries achieve high social outcomes with far lower environmental impacts than others, but no country currently manages to achieve high social outcomes while remaining within planetary boundaries (Fanning *et al.*, 2022). Modeling the lowest energy necessary for decent living is therefore a crucial question.

One might ask what it means to say decent living, and what its relationship to wellbeing is. The topic is vast, but ecological research has generally revolved around two types of wellbeing: hedonic and eudaimonic.

Hedonic wellbeing has roots in Epicurean philosophy and Bentham's utilitarianism, and relates to questions of happiness and subjective wellbeing. Eudaimonic wellbeing on the other hand, broadly focuses on providing people with the capabilities required for flourishing. These can include physical health and safety; clean air and water and adequate nutrition; social and political participation; autonomy cultivated through education and cognitive understanding; time and space for imagination and social play (Doyal and Gough, 1991; Lamb and Steinberger, 2017).

Studies attempting to understand what low energy demand means and how to achieve decent living with low energy are not new, and have for the most part focused on the eudaimonic understanding of wellbeing. In the rest of this report, wellbeing will exclusively be used to mean eudaimonic wellbeing.

Already in 1985, a study was published estimating 1000 watts of energy per person per year would be sufficient to meet basic needs and more (Goldemberg *et al.*, 1985). Focusing on economically developing countries, this landmark study argued that economic growth is a poor way to measure the wellbeing of a country, and that the focus should instead be on basic human needs like nutrition, shelter, clothing, health, and education, with particular attention devoted to the poorest. This approach was developed so as to describe a list of necessary activity levels and their corresponding energy intensities according to broad categories: *Residential, Commercial, Transportation, Manufacturing, Agriculture, Mining and Construction*. The results allowed Goldemberg *et al.* to imagine a world where emerging countries could live better with low energy use. While the energy intensities are outdated, some of the study's assumptions remain usable today.

Studies on the energy requirements of an economically developed country also exist, like the 2000-Watt Society which is an objective set out by the Board of the Swiss Federal Institutes of Technology in 1998 for the year 2050. Used as a political framework, the goal of the 2000-Watt Society is, as the name suggests, to reach a Swiss energy system with a yearly per-capita primary energy consumption of 2000 watts. This idea has led to much research on energy, as well as government-backed guidelines to ensure sustainability through reduced energy consumption. The idea of wellbeing isn't centrally defined when considering energy reductions, however, and the solutions are heavily focused on energy efficiency improvements and renewable energy systems contrasting with the needs-based approach of Goldenberg et al. (1985).

2.2 Decent living standards and Decent Living Energy

In their 2012 paper (Rao and Baer, 2012) *"'Decent Living' Emissions: A Conceptual Framework"*, Rao and Baer elaborate a conceptual framework for quantifying wellbeing from a eudaimonic perspective, using a set of basic goods for each household that it suggests are universal prerequisites of wellbeing. In contrast to well known *outcome* indicators of wellbeing, they define the physical *means* that enable wellbeing. The universality of the approach rests on the theoretical distinction between *needs* and *need satisfiers*, whereby needs are universally shared by every human (*hunger, sleep*), and need satisfiers are culturally specific (*types of food, types of shelter*) (Doyal and Gough, 1991).

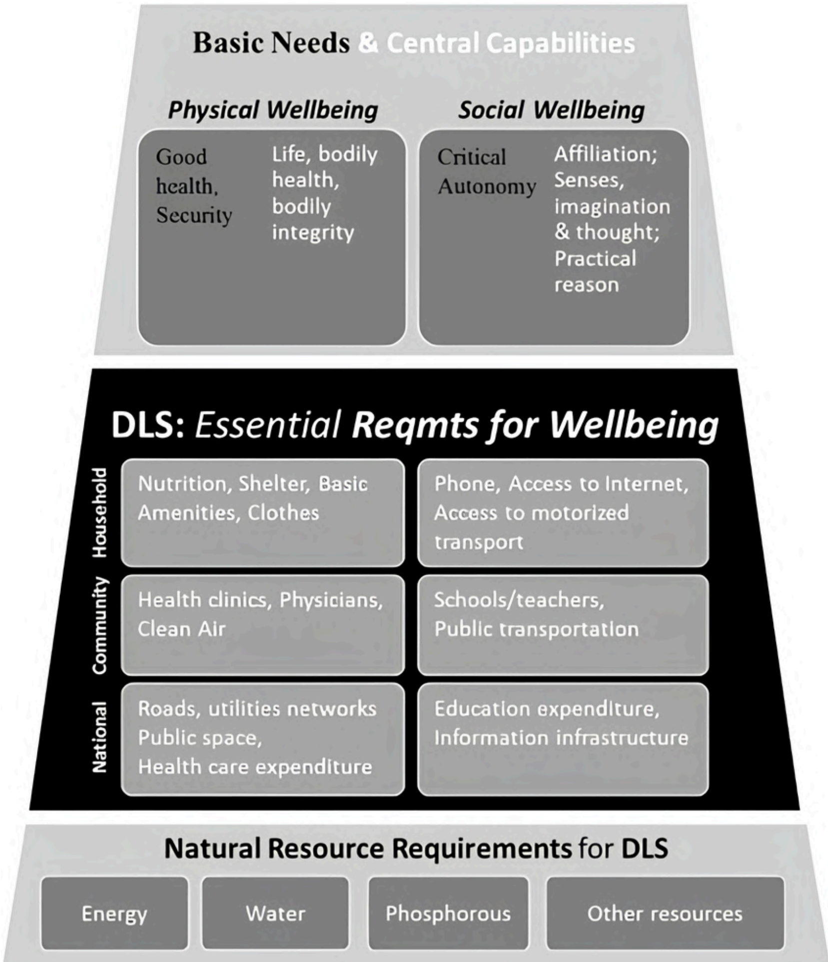


Figure 1: Decent living standards (DLS): hierarchy of material requirements and their derivation (Rao and Min, 2018)

This framework was later expanded upon in Rao & Min (2018), which defined *Decent Living Standards (DLS)* as a list of *material prerequisites for wellbeing*, with suggested levels of each requirement. Combining basic needs from Doyal & Gough with Nussbaum's central capabilities (Doyal and Gough, 1991; Nussbaum, 2000), DLS defines essential requirements at the household, community, and country level, and considers these to be prerequisites for physical health, social affiliation, and political participation. Goods and services are defined broadly enough that they are considered appropriate for the majority of modern, industrial societies, via a theoretical framework where each *satisfier* has to follow these rules (Rao and Baer, 2012):

- *Satisfy at least one basic need*
- *Not impede others' fulfilling their needs*
- *Either be the only satisfier of a particular need, or currently be overwhelmingly preferred by people (globally) among competing satisfiers.*

The list of material requirement indicators is listed in appendix #1, and the structure of the framework is in Figure 1. Due to the quantified (or quantifiable) structure of DLS, environmental sciences and development literature has embraced this concept to answer various questions.

First, DLS has been used to evaluate where in the world needs remain unmet. The *DLS gap* is a measure of the difference between a country's current provision of resources and the DLS inventory. A seminal 2021 study concludes that more people today are deprived of DLS than are income-poor (Kikstra *et al.*, 2021), even using the threshold of \$5.50 d^{-1} usually defined for upper-middle income countries. This highlights how DLS is a measure of living standards that go well beyond poverty, as it is conventionally understood.

Second, various studies have studied *Decent Living Energy*, which is simply the energy required to provide DLS. A study of India, Brazil and South Africa (Rao, Min and Mastrucci, 2019) combined analysis of DLS gaps with first estimates of DLE, while also considering mitigation efforts and technology transfer arrangements. Using a similar method, Millward-Hopkins et al. (2020) expanded DLE work to make the first global estimate, based on calculations for 120 countries that considered regional and demographic variations such as climate and population age structures. In contrast to Rao, Min and Mastrucci (2019), it focused on a single year (2050), and estimated minimum global energy requirements for DLS by considering universal access to state-of-the-art technologies. Results suggest the final energy requirements of providing universal DLS in 2050 could be 60% lower than global energy use in 2019, despite a larger global population. In today's highest-consuming countries, cuts in energy use of ~95% were suggested to be possible while still providing DLS for all.

However, the studies above only identify minimum values for energy use, and they do not consider the influence of inequality. Focusing on energy, Millward-Hopkins (2022) found that a scenario where the lowest consumers lived at DLS, and inequalities beyond that matched levels broadly considered 'fair' today, could increase the total energy required to secure universal decent living in 2050 by ~40%. With population growth at the low end of projections, this still implies that a 50% reduction on today's energy use would be possible.

2.3 Energy use in Switzerland

Our project concerns Switzerland, where energy use is 10-15 times larger than existing DLE estimates (Millward-Hopkins 2020), and the country's broader environmental impacts exceed multiple planetary boundaries (Dao *et al.*, 2015).

As an important basis for Swiss energy policy since the 1970s, the energy outlooks give an insight into where the country is heading. The latest published report, Energy Perspectives 2050+ (BFE, 2020), develops scenarios for energy supply and demand in Switzerland up to 2060 which meet the target of zero net emissions and guarantee a secure, clean, affordable energy supply based primarily on indigenous production. To this end, the scenarios show potential technological developments and calculate the direct additional costs of transforming the Swiss energy system to meet the net-zero emissions target.

The solutions for net-zero carbon emissions in 2050 considered by the report are a mixture of technological efficiency improvements, imports, and technologies built to decouple energy from carbon emissions. However, EP2050+ does not consider wellbeing, today or in the future, and assumes increased levels of consumption in 2050. This raises the difficulty of reaching net-zero, since the major energy reductions sufficiency behaviors can offer aren't considered. Solutions thus come from a combination of established technologies, such as heat pumps and PV, and immature technologies such as hydrogen-fueled freight, electricity-based hydrocarbons, and carbon-capture and negative emission technologies (See Figure 2).

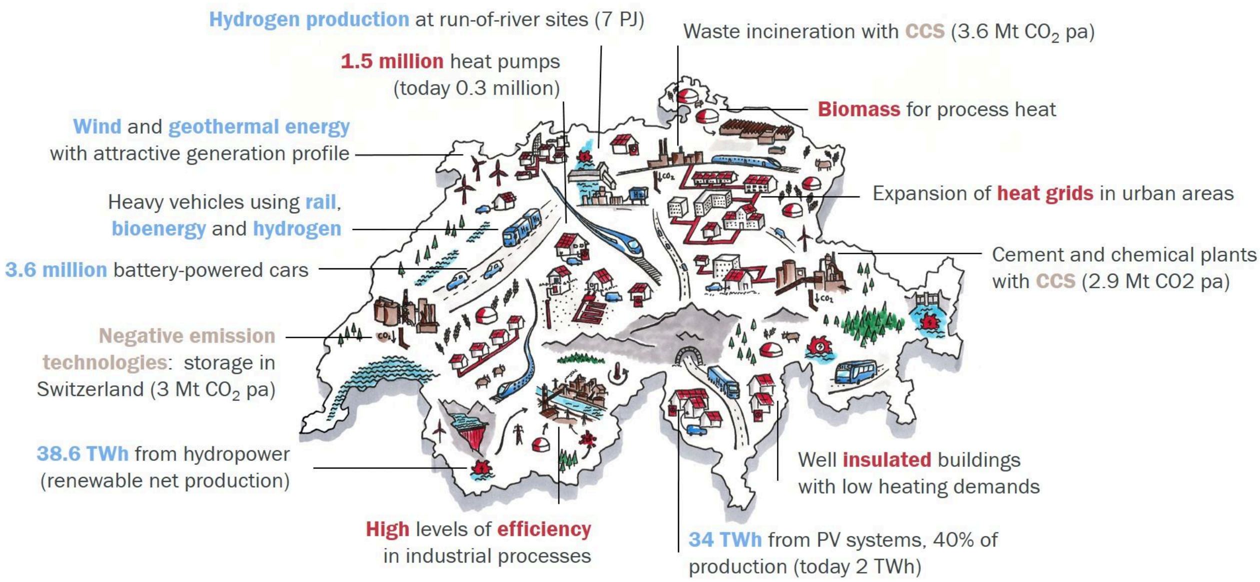


Figure 2: Objectives for a climate-neutral Switzerland by 2050 as stated in the EP2050+ report (BFE, 2020)

2.4 Energy use, mobility, and wellbeing

Mobility's importance for wellbeing cannot be understated since it is what allows people to fulfill their needs by providing access to the many services that are key for both social and physical wellbeing. Mobility in DLS is one of the basic dimensions of social wellbeing, with its universal satisfier defined as "Access to adequate mobility options" (Rao and Min, 2018). This requires satisfiers at different scales, wherein each household must have some sort of access to vehicles, each community must provide services that are reachable by said vehicles, and the transport infrastructure needs to be maintained by some responsible entity. Rao and Min stress that some motorized mobility needs to be available to avoid potential social exclusion and provide opportunities to participate in society.

Switzerland is empirically a very mobile country, with average travel distances above the European average, due to significant national and international travel (Biedermann, 2023). However, large inequalities in mobility are observable within the population in terms of distance, energy use, and greenhouse gas emissions exist (Fisch-Romito & Steinberger, 2024; Bruderer & Diekmann, 2019).

Energy use can be understood as the outcome of energy intensities and activity levels combined, and reductions can be achieved by reducing one of both of these:

The former involves largely technological changes. Many energy intensity projections exist in the literature, often as inputs for a larger energy model. For Switzerland, the EP2050+ report (BFE, 2020) serves as a good benchmark, and defines energy and emissions for different modes of transport. Other Swiss studies (Panos *et al.*, 2023) complement those values with more vehicle and technology-specific efficiencies.

The latter can be reduced through sufficiency practices, often in conjunction with changes in the infrastructure. This approach is less widely studied, but is our main focus. We can look at studies of the transport habits of European cities with economies and geographies close to that of Switzerland, but reduced mobility, for some insights. This has its drawbacks, as the research on low-mobility cities is by definition urban. As our analysis assumes repurposed neighborhoods, which function like urban neighborhoods, the comparison is meaningful, accounting for all but the food-producing population.

A study on different EU cities shows that they have wildly varying historical and societal reasons for their current transport infrastructure and that "*without taking these different contexts into account, it is [...] illusory to try to develop or take a single example as a model*" (Paul *et al.*, 2020). The conclusions of the study still help us get a sense of the requirements of low-mobility in these cities:

- *"Optimizing both the supply and infrastructure of public transport, to make it more accessible, efficient and affordable in the city's urban area;*

- *Raising people's awareness of the benefits of soft mobility, in particular by working on facilities that promote safety and priority;*
- *Encouraging intermodality, bearing in mind that a balanced mix of the three main urban travel modes (car, public transport, bike) is the most efficient.*" (Paul *et al.*, 2020)

Looking at a different scale, studies showed that individuals lived decently with low mobility in car-free neighborhoods, or eco-villages. For example, car-free neighborhood residents in Germany and Switzerland were found to prioritize proximity in their everyday life as well as for holidays, staying in their country or at most Western Europe (Baehler and Rérat, 2022). Also, yearly household distance traveled in motorized transport in car-free houses were found to be smaller (14 '000 km compared to 18' 000 km) than reference households in Vienna (Ornetzeder *et al.*, 2008). The reason for lower mobility there seems to be two-fold :

- First, individuals living in active communities tend to spend a lot of their leisure time within their community, reducing the distances for leisure which currently accounts for half of the distances traveled by Swiss residents (Biedermann, 2023).
- Secondly, the lack of a private motorized vehicle and its replacement by public transport, car-sharing or car-pooling systems (Scarinci, Rast and Bierlaire, 2017) push residents to optimize their motorized travel and reduce unnecessary kilometers, often facilitated by mobile communication and information technologies (Baehler and Rérat, 2022).

Once again, the difficulties of expanding the lifestyle of no more than a thousand residents to the entire Swiss population proves too uncertain to consider, but it outlines how a strong reduction of cars (or maybe even a disappearance of private cars altogether) doesn't inevitably lead to indecent living conditions. It also reinforces the co-benefits of increased social participation in inter-dependent communities, which costs very little energy to maintain.

3. Methodology

3.1 General project methodology

We aim to describe mobility in an ‘idealized’ Swiss society operating at sufficiency and quantify the associated final energy consumption. The calculations involve combining activity-levels (in our case, passenger or tonne kilometers by transport mode) and associated energy intensities (energy required per kilometer for each mode). We do not discuss the affordability of technologies used, nor the political feasibility of the radical changes it generates – we simply assume that the necessary infrastructural, social, and behavioral challenges are overcome. The model can thus be described as a quantified thought experiment on how low Switzerland’s final mobility energy could be without compromising decent living standards.

3.2 Calculations and data

We calculate the energy requirement of passenger mobility by combining estimated **passenger-kilometers** (*which represents the transport of one person for one kilometer*) per mode of transport with their average **energy efficiencies** (*in J/pkm*). We look at *direct* energy consumption only, and we make no assumptions to change occupancy rates from current values.

For i representing each mean of passenger transport:

$$energy\ demand_i = average\ energy\ efficiency_i \times passenger\ kilometers_i$$

There are multiple ways to gather passenger-kilometer data, which we’ll discuss further in the next section, but our main source is the 2015 Swiss Microcensus. This is a national database gathered by the federal office of statistics (OFS) every 5 years, with the latest version published in 2023 about Swiss mobility in 2021 (Biedermann, 2023). We use the 2015 data, since the 2021 report shows a clear reduction in mobility from COVID-19. The 2015 data was obtained through a telephone questionnaire given to 57'090 participants, and is assumed to be representative of the Swiss population. The questionnaire asks each participant to describe in detail their travels of the day before the call, including precise origins, paths, destination, time, means of transport (*including multimodal travel*), motive of traveling and socio-economic data on each participant to name a few (ARE and BFS, 2023). The individual trip descriptions are then aggregated by the federal office into the data we use in the report.

However, when describing the energy requirements of sufficient mobility, the main difficulty we face is quantitatively defining a decent level of mobility. One approach could simply be to think of decent mobility as the mobility of people living decently today. A summary of mobility in Switzerland by purpose and segment is shown in Appendix 2.

3.2.2 Interaction-based mobility: A bottom-up approach

We conceptualize mobility as the enabling of individuals to connect to points of interests, or to achieve certain interactions, which satisfy their needs (*for example: going to the market to buy food, going to the medical center to access healthcare, or going out to see friends and engage socially*). Our starting assumption is that today's very mobile Swiss population travels in a manner which satisfies its needs, but that their mobility choices can be changed, and distances traveled reduced, without compromising wellbeing. So any system that keeps the same type and number of interactions as today could guarantee a similar level of wellbeing. The first steps would then be to define where each interaction takes place, what the distances to these are, and what modes of transport are utilized.

The number of daily interactions of the Swiss population are provided by the 2015 Swiss Microcencus survey in its aggregation of the "Average number of trips in Switzerland per person per day in 2015" (BFS, 2023). The Microcensus data allows us to extrapolate the types of daily interactions of Swiss residents through the categorisation of trip motives, into 7 main categories: (1) Work, (2) Training or school, (3) Shopping, (4) Leisure (with extra categories asked subsequently), (5) Work and service travel, (6) Services and accompanying others (services like going to the doctor), and (6) Other (incl. don't know/no indication) (ARE and BFS, 2023).

In this dataset, trips are defined as traveling between two locations using any means of transport (walking included) with a different motive than the one at the start location. For example, going from home to a place of work counts as one trip. Going from that place of work to a place of shopping is counted as another trip, but any subsequent direct trips from one shop to another wouldn't count as an extra trip. Trips back home are attributed the motive of the activity that took the longest time while people were out. We gather average trip numbers for each travel purpose according to age, as different age groups have different interactions, and the age structure of the Swiss population will change in the future. Interestingly, our data reveals little variation in the number of trips taken by individuals with different degrees of urbanization of households (see appendix #2).

In order to account for distances and modes of transport to reach facilities, we use a novel approach to DLS mobility. We define multiple zones of increasing distance to each household, then locate particular facilities and points of interests within these zones. By assuming facilities can be closer to where people live, we therefore reduce both distances traveled and the share of motorized transport used to travel.

Similar zone-based methodologies have previously been used to model the accessibility of facilities in the EU by sorting between local, subregional and regional facilities (Kompil *et al.*, 2019), each with their radius of service as seen in Table 1.

Table 1: Type of services with the corresponding population and distance criteria (Kompil et al., 2019)

Type of facilities	Examples	Ideal service area population	Ideal service area distance	Minimum service area population	Maximum service area distance
Local (neighborhood)	(Schools, small health facilities, childcare services, sport facilities, small markets etc.)	10'000 people	2.5 km	5'000 people	5 km
Subregional (municipal)	(High schools, hospitals, theaters, cultural facilities, supermarkets, hobby markets etc.)	100'000 people	10 km	50'000 people	25 km
Regional	(Specialized centers for education and health, large facilities for sports and cultural activities, governmental organizations, other high-tech services etc.)	1'000'000 people	50 km	500'000 people	100 km

We draw inspiration from this previous work to distinguish four Swiss zones: local, extended local, regional and extra-regional (see Figure 3). In a rural context, the local zone might be the village, and the extended local might be the next village over, while for more urban landscapes we might talk about neighborhood and city-wide zones. The regional level refers to cantonal travel, and extra-regional for travel outside of the household's canton or Switzerland. Each is defined by an average distance that people must travel to get to a facility within that zone. For the current model, we assume that average distances do not change between rural and urban communities and hence that the mobility in urban, peri-urban, and rural areas will be similar. While agricultural communities will probably require more mobility we consider these to be a small enough percentage of the population to be omitted from the model. There is, however, no reason that the current method could not be extended to consider urban, rural, and peri-urban areas separately.

Table 2: Sizes and definitions of the 4 zones assumed for Switzerland in the current work

Zone	Average distance from household	Reasoning
Local	1 km	A rough estimate of the width and height of urban communes in Switzerland is 2 km. This would mean that people on the edge of town would only travel 1 km to get to the center, with the center being more densely populated. We also assume that the communities should strive to be as tightly knit as possible so that people can walk around their local community in a reasonable amount of time. We thus settle on an average distance of 1 km.
Extended -local	3 km	Calculated average distance to the nearest town in Switzerland using a dataset of 160 municipalities of more than 1'500 people, excluding canton capitals (data detailed in Appendix #4).
Regional	15 km	Population-weighted average distance of each commune to the canton's administrative capital using the same dataset as for the extended local calculations (data detailed in Appendix #4).
Extra -regional	100 km	A majority of extra-regional travel people do is to other cantons that are rather close (for leisure or work-travel), but trips outside of Switzerland can have a very large influence on the average distance. We assume that trips around the world are few and far between in a DLS society, and that trips outside of Switzerland tend to be in Europe, which is relatively close. As a compromise between international and intercantonal travel, we take an estimate of 100 km, which corresponds to the radius of Switzerland if the country were circular.

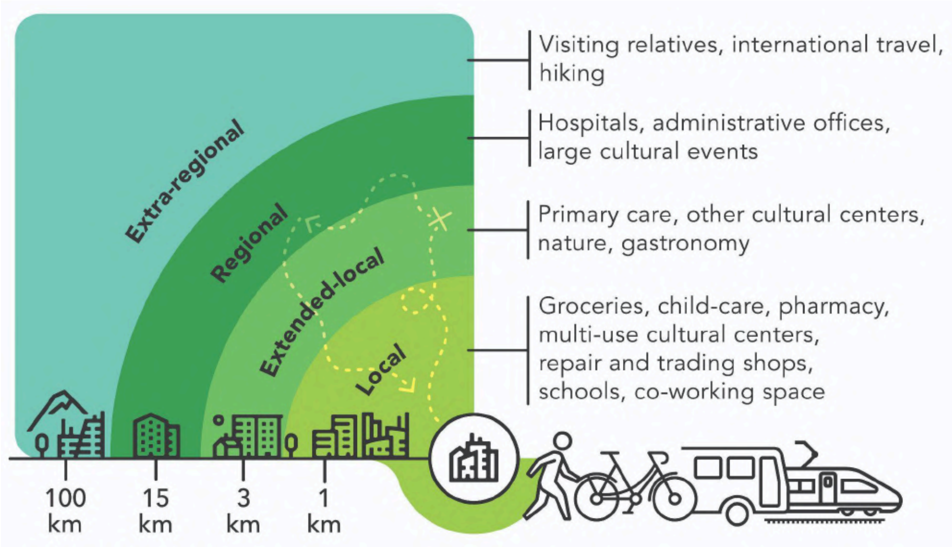


Figure 3: Our framework of zones of interest in the model, with examples of facilities and activities done in each one

Once we have zones of interest defining the general surroundings of each individual, we can start placing the daily interactions of our DLS citizens in each zone of interest. The interactions here are once again classified by the motives of the 2015 Microcensus survey (work, schooling, shopping, etc…). This framework lets us draft an equation to calculate yearly energy consumption in a slightly different way than defined previously.

For m, z representing respectively each motive of mobility from the Microcensus (ARE and BFS, 2023) and each zone of interest as defined in Figure 3:

$$Yearly\ energy\ consumption\ =\ \sum_{m}^{7\ motives} number\ of\ trips_{m} \times \left(\sum_{z}^{4\ zones} zonal\ trip\ energy_{z} \times zonal\ distribution_{m,z} \right)$$

$zonal\ trip\ energy_{z}$ *is a set of values defining how much energy is used on average when people move within a zone. This is based on energy efficiency numbers, modal split and other factors which are described later.*

$zonal\ distribution_{m,z}$ *is a matrix defining the share of transport that is done in each zone for a set motive of transport. It can be seen in* Figure 4.

The exact split of the locations of interactions into zones (defined as $zonal\ distribution_{m,z}$) seen in Figure 4 is mostly derived not from literature but from a combination of current day territorial distribution of local services in Switzerland (BFS, 2018b) and our own reasoning which is explained in Table 3 and details our understanding of a low-mobility DLS society.

Table 3: Travel zones for each main motive of travel

Motives of travel	Average location of travel motive split in zones	Reasoning
Work	60% local 40% ext-local	There is a push to move closer to workplaces and therefore people never need to travel regional distances to get to work. Factory workers close to their factories, but jobs that can be done entirely or somewhat remotely are done in co-working spaces available and managed locally in every community.
Training or school	60% local 40% ext-local	Small primary schools are open in every village or neighborhood, middle schools and high schools are generally shared between villages or between a city and its neighborhood and thus account for some of the extended-local travel. Specialized universities are still few and concentrated in major regional cities, for which we assume that students move closer to campuses to reduce unnecessary mobility. Adults generally still learn, even if they don't go to specialized universities thanks to community knowledge being shared using the primary, middle, and high-school facilities. Remote learning also enables more specialized knowledge to be dispensed without the need for extra-regional travel of teachers.
Shopping	85% local 15% ext-local	Grocery shopping and first necessities are entirely local and constitute most of the shopping trips. Durability and repairability are central to the creation of goods with a move away from a consumption society, and general repair shops are available in every local zone. A sharing economy is put into place, with many tools and objects being shared within communities, lent or traded. Travel to extended- local zones are only done for more specialized goods and repairs, but constitute a minority of trips.
Leisure	65% local 28% ext-local 5% regional 1.8% extra-regional	Leisure in the survey has its own separate subcategories which we placed into zones then averaged to get our distribution (see Figure 5)
Work and service travel	30% local 50 % ext-local 20% regional	Traveling for work includes traveling to clients in the extended-local area and occasionally traveling regionally.
Services and accompanying others	70% local 30% ext-local	This assumes that services are mainly provided within one's community such as primary care, and care work in general, with some services being only available in extended-local. The drastic reduction in cars reduces the possibility of people to drive others to specific places, which reduces extended-local or regional driving of others.
Other (incl. "don't know" and "no indication")	62% local 34 % ext-local 4% regional 0.3% extra-regional	Since this category is very opaque, we assume other activities to be spread amongst zones in a way that is the average spread of all other motives.

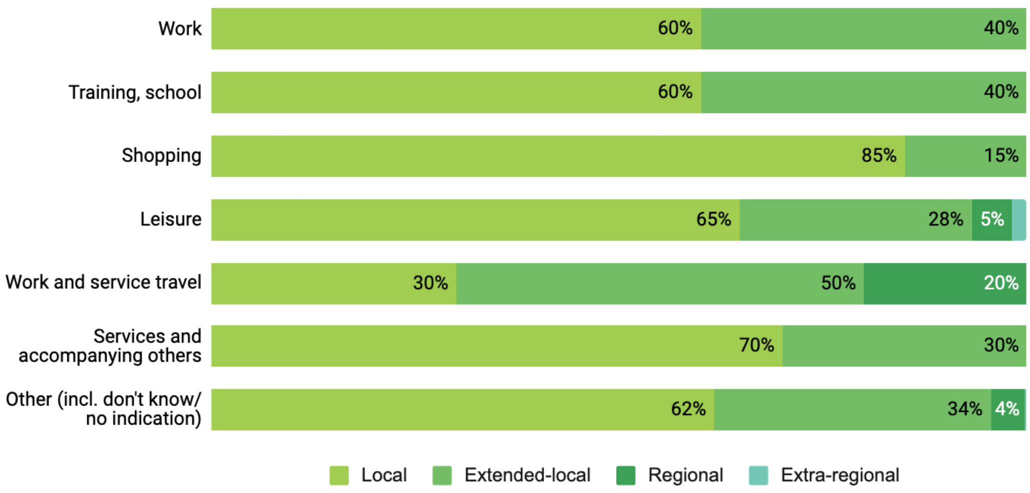


Figure 4: Average location of each interaction/motive split between zones of interest

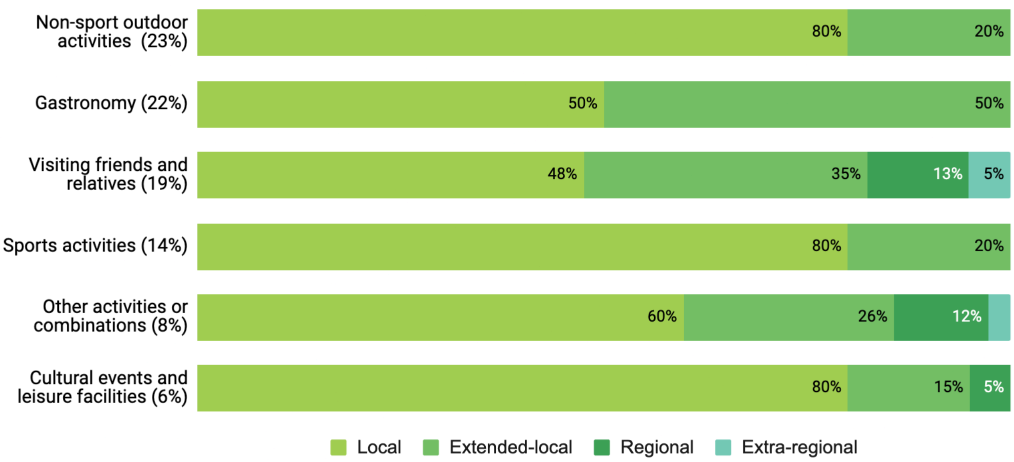


Figure 5: Average location of the top motive of leisure travel split between zones of interest. Each category name also displays the category's importance as a percentage of leisure trips, six categories of 2% or less each were excluded. "Other activities or combinations" is simply an average of all motives.

As we can see, the drastic reduction in what we call regional and extra-regional is a strong conjecture which we justify through the hypothesis that individuals will not travel long distances to access services which are already available locally. Local travel being so prevalent is also only possible by assuming that all the necessary services for wellbeing are available locally, in adequate quantity, quality and are close to every moderately dense community. We believe it is achievable through relying less on economies of scale, but more on small local shops and services, enhanced by taking advantage of digitalisation, a sharing economy and community building.

All of the assumptions we just listed are very clearly no easy feat and require significant changes in both citizen behavior and infrastructure. Further assumptions are developed below in constructing a new modal split.

Now that we understand how we move services and interactions closer to every household, we are still left with the difficult task of estimating the average $zonal\ trip\ energy_z$, which we define in the equation below:

For i representing each mean of passenger transport:

$$Zonal\ trip\ energy_z = \sum_{i}^{6\ means} energy\ efficiency_i \times modal\ share_{i,z} \times avg.\ distance\ traveled_z$$

$modal\ share_{i,z}$ is a matrix defining the share of transport method in each zone described below.

$avg.\ distance\ traveled_z$ is already defined in Figure 3.

$energy\ efficiency_i$ values are the same as used in (Millward-Hopkins et al., 2020).

At this point, we can get a more cohesive picture of how the framework works, which we visualize in Figure 6. We can see that each component of the approach (some of which we'll explain later) work together based on both values from the literature and datasets that we use, but also based on assumptions which we make, and data developed in our framework.

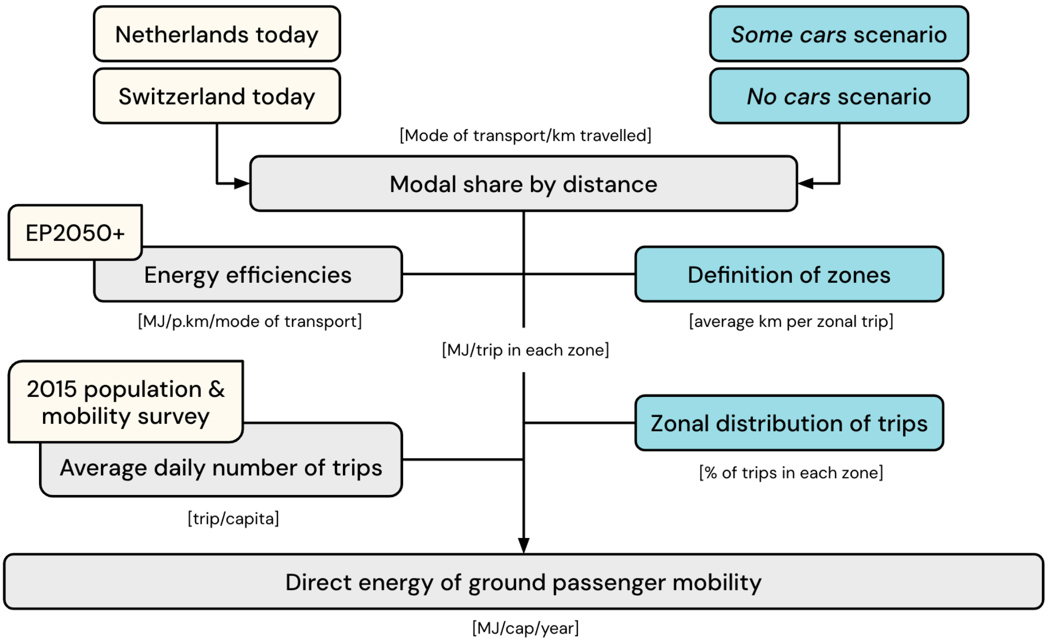


Figure 6: How the interaction-based approach works. Beige boxes represent data gathered from the literature while light-blue boxes are values which we develop in this report (some of which might still include data from literature)

Taking a step back, our approach tries to reduce the mobility energy by doing two things: moving services closer, and making people use their car less. If things are closer, people will objectively travel less because they cover shorter distances for the same trips. However, we also understand that precisely *because* distances are shorter, people will choose to use the car less. Why take the time to get out of your garage, drive, find a parking spot and for the parking to go somewhere you could easily walk to in a few minutes? This rationale is validated thanks to data on modal split, which we expand upon in the next sections.

3.2.2.1 Swiss modal share

Our first scenario involves using the current Swiss modal shift according to distance. While Switzerland is a car-centric country (70% of passenger-kilometers are done with a private motorized vehicle in 2021 (Biedermann, 2023)), due both to habits and car-centric infrastructure, if we look at trips of 1-2 km the car is not predominant. We consequently look at groupings of trips in the 2015 micro-survey according to distance of travel and look into each group for the share of each means of transportation. We used the aggregation made by Citec Ingénieurs SA which provides us with the modal share ($modal\ share_i$) in percentage over varying distances (0 to 0.5, 0.5 to 1, 1 to 2, 6 to 8, 90 to 125, etc…), which we then try to group to get the average modal share in each zone (Citec Ingénieurs SA, 2021).

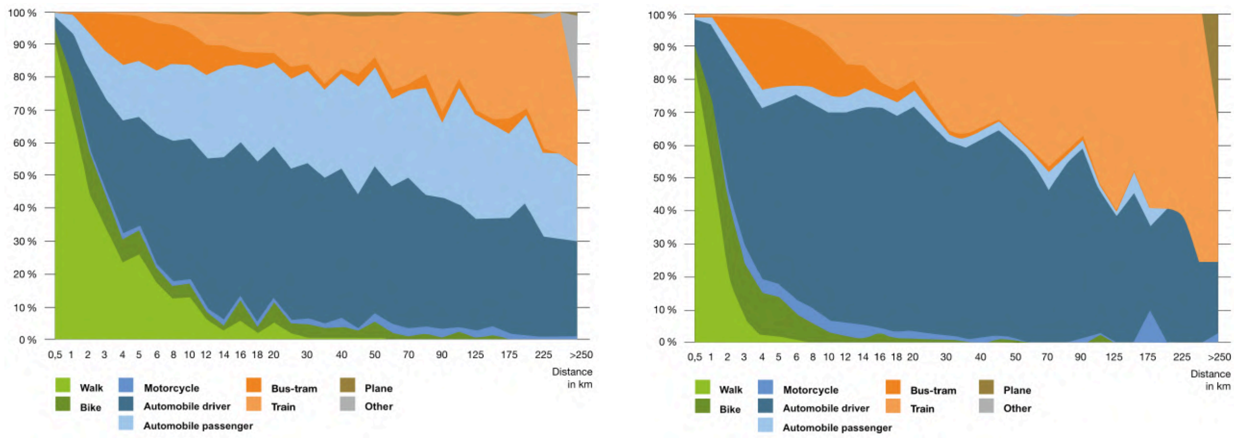


Figure 7: Share of average means of transport used in trip of different distances in Switzerland in 2021, adapted up from (Citec Ingénieurs SA, 2021). The trips were only available filtered to be only leisure trips (left) or trips related to work (right). An example of how you should read the graphs is for example on the left-side graph that 90% of Swiss trips spanning 0 to 0.5 km are done by walking.

It should be noted that the Citec report doesn't give a total modal share but only describes it for work and leisure (see Figure 7). As a way to deal with this, we assume that all the other motives excluding leisure follow a similar modal distribution to that of work travel (which is the more car-centric of the two distributions we have), as a way to get a conservative estimate of the total modal share.

Going back to the Microcensus nomenclature, a single trip can require multiple means of transport (steps), such as walking to your car, driving, then walking out of a parking lot to your office. For our use-case, we consider that walking is still part of the trip to the office and therefore in our data, walking constitutes a certain percentage of long-distance trips.

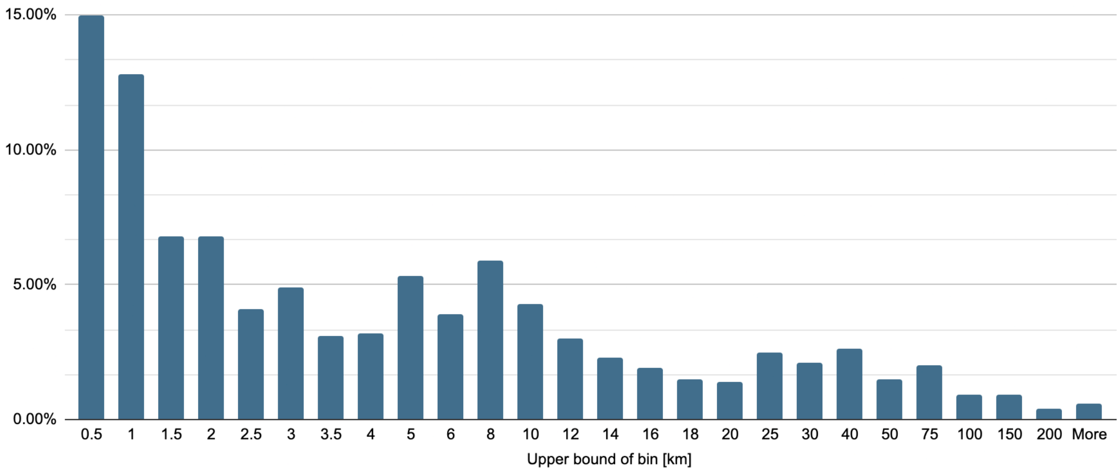


Figure 8: Distribution of trips according to its total distance [in km], (n=193'880). The reason why this doesn't look more like a negative exponential curve is mostly due to the fact that the bin sizes differ from bar to bar.

Grouping the modal share by zone presents some difficulties, as while the average distance to a facility in an extended local zone is 3 km, we can't just take the modal split of people traveling 3 km exactly. Many trips can be shorter, and some longer, and we know that shorter trips involve more walking. In order then to get accurate zone-specific modal split we gather all the total trips from the Microcensus data and sort them in bins of similar sizes as the modal split graph (Figure 8). This gives us *weights* which let us then have a more accurate average modal share.

When we take the weighted average trip distance between 0 and 3 km, we get around 1 km. This is useful to us, as it allows us to assume that all local zone trips would consist of trips of distances between 0 and 3 km. We can then pair this information with the $modal\ share_i$ for each means of transport at each distance from the household to create our $modal\ share_{i,z}$ for each zone, shown in Figure 9.

By playing around with intervals we can reach analogous conclusions for the extended-local zone (where all trips are between 1 and 6 km from the household), and the regional zone (between 3.5 and 75 km). For extra-regional trips, we assume that the modal share of trips 150 km long is representative of the modal choice of Swiss citizens for extra-regional travel.

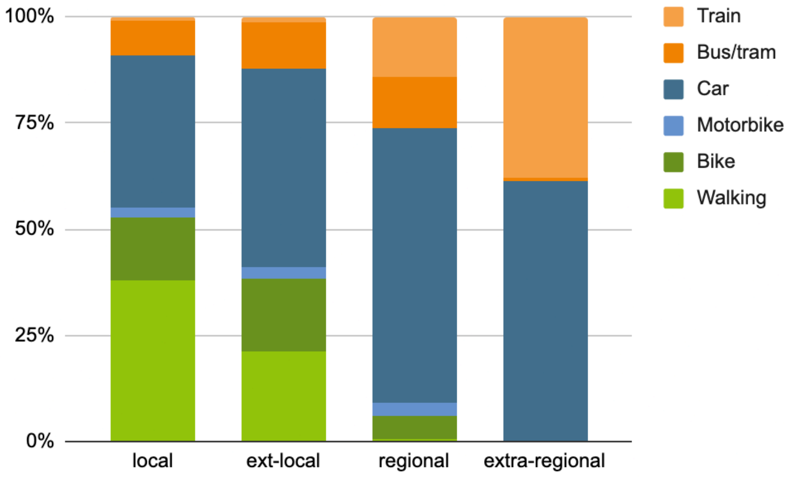


Figure 9: Average use of each means of transport per zone, using data from the Swiss Microcensus for work-related travel.

3.2.2.2 European modal share

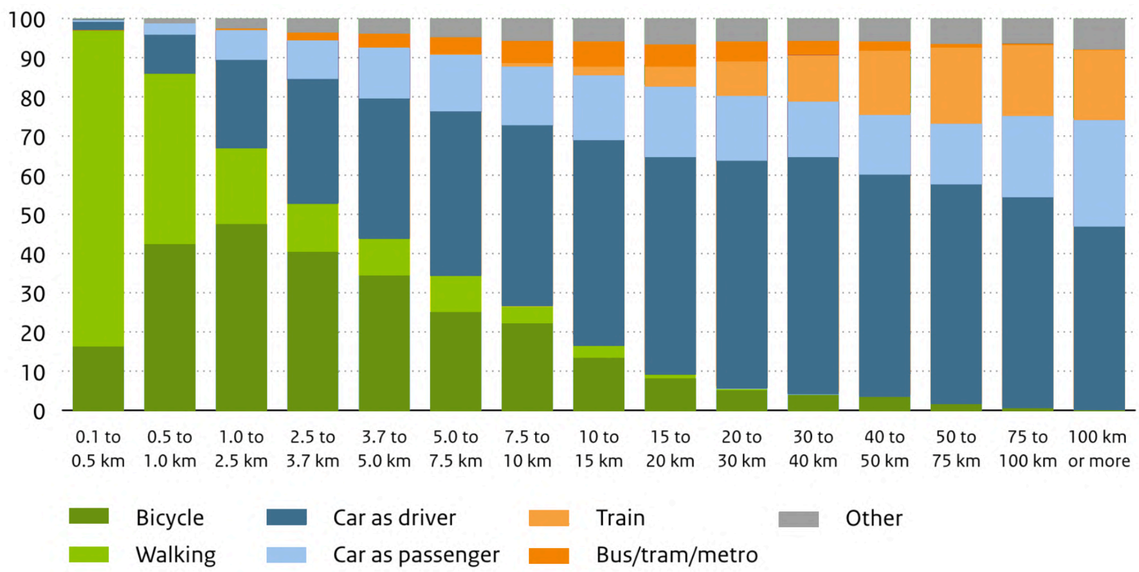


Figure 10: Modal share of transport modes per distance category in the Netherlands in 2019 (de Haas and Hamersma, 2020). Colors have been changed for consistency.

Our second scenario uses the modal share of a less motorized European population, in our case: the Netherlands. There, cars represent only 47% of trips in 2019 (de Haas and Hamersma, 2020). The Dutch population is a little less motorized for lower distances, with cycling representing up to 47% of travel in the 1 to 2.5 km range of travel (see Figure 10). Our data only gives us shares of means per distance but excludes any indication as to how many trips are done in each distance category. We use the distribution of trips from the Swiss survey (Figure 8), which we assume to be similar in the Netherlands to estimate our Dutch $modal\ share_{i,z}$, portrayed in Figure 11.

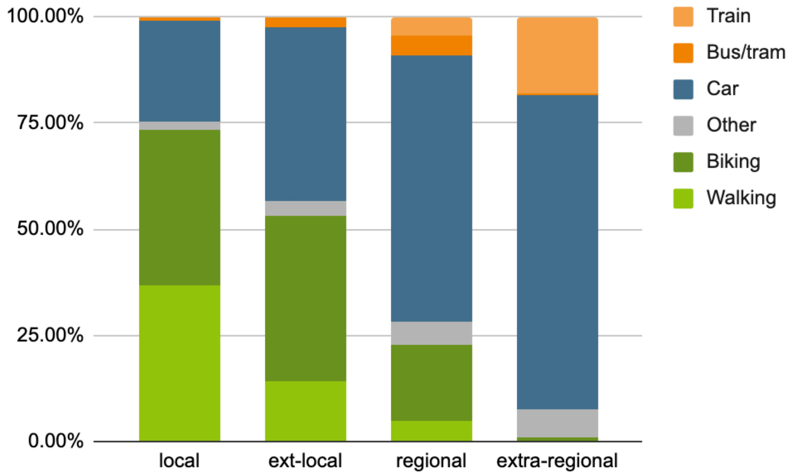


Figure 11: Average use of each means of transport per zone, using modal data from The Netherlands and trip length distribution from Switzerland

3.2.2.3 Can public transport replace all cars in DLS?

As a basis for determining the final energy required for mobility, we first estimate how far we could go towards fully replacing cars with public transport or soft mobility while satisfying decent living standards. We approach this question from two angles: number of trips and passenger-kilometers. But first, note that for the sake of simplicity, we do not consider health conditions, occupational needs, or other factors that make cars necessary for some people in today's organization of society, and to what extent such organization needs to change beyond renovating and repurposing neighborhoods.

Number of trips analysis

Today's modal shares are heavily influenced by the car-centric urban design of the past decades. Many individuals thus use cars for trips where public transport is available, or walking or cycling would be feasible, because of the ease of access of a personal car and the dominance of car infrastructure. A low-mobility society would, in contrast, be designed to prioritize cleaner and safer forms of travel. A most radical approach would be to assume that cycling and public transport almost entirely replace car usage, which would require drastically better urban planning, load capacity management of public transport, and widespread use of bicycles and e-bikes.

To assess whether cars could theoretically be replaced while retaining our estimated levels of sufficient mobility, we estimate -- roughly -- whether other means of transport could take over all the car trips.

For long distance travel, public transportation would substitute most car trips. We therefore ask how high the average occupancy of public transport would have to be to completely replace car travel. This implies various very broad assumptions, which we recognise may not all be realistic, but keep for the purpose of this analysis:

- We assume that more flexible societal working hours would avoid overcapacity in the morning and the evening, providing a more consistent number of passengers throughout the day.
- We take current vehicle capacity data from the Mobitools database (Büro für Mobilität AG, 2023), and assume that these capacities are reflected in our Swiss mobility survey.
- We assume that any trip by car can be replaced by public transport if the public transport has enough capacity. This implies that public transport reaches any desired destination that a car driver today might want to reach (or at least that public transport is used at least once in the trip, with the rest being done by bike or walking) or that activities associated with trips purposes are relocated in a way that is consistent with the current public transport system
- We also assume that reductions in the total number of trips might occur from unnecessary trips being foregone due to the decreased convenience of public transport compared to cars.

We take a list of every trip in the 2015 Swiss mobility survey data and classify for each trip the main mode of transport (*this being the mode of transport which is used to cover the most number of kilometers*). We extract the number of trips for which the main mode of transport is the car (94'844 trips) as well as public transport including Train, Postbus, Tram, Bus, and Other public transport, (totaling 23'522 trips). We then assume that all the trips done by public transport were in vehicles filled at the corresponding average occupancy extracted from Mobitools (each being between 15% and 33%), and so we increase all of their occupancy until the number of trips they can accommodate is equal to the sum of all the current car and public transport travel. An explanatory diagram is shown in Figure 12.

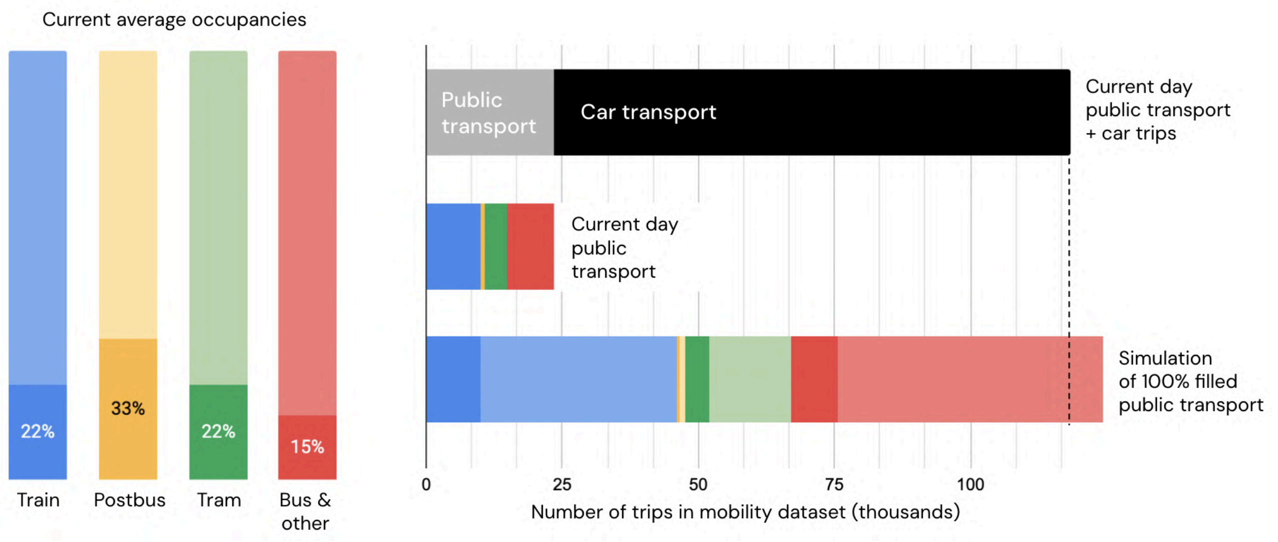


Figure 12: Illustration of methodology to estimate if current day public transport infrastructure could replace all car trips. We see that fully filled public transportation vehicles could theoretically account for all car trips. This would only be the case if all car trips aligned with available public transport and with very high occupancy

We arrive at the conclusion that all public transport would need to be at 94% average occupancy relative to today's capacity to entirely replace all car trips. This level of occupancy is unrealistic, as even air travel, where most trips are planned in advance and optimized for occupancy, only reaches 80%-85% today at country or regional scale. Highest achievable occupancy for buses and trams will be much lower.

Passenger-kilometer analysis

On the other hand, today's Swiss public transport provides 3372 pkm/capita (Table 5), which is slightly more than the *total* mobility of 3240 pkm/capita that we estimate is necessary for DLS. Depending on the modal split chosen, the share of public transport would be 15-50% of today's passenger-kilometers (Table 5). Even in the most extreme situation where all car journeys are replaced, public transport would only need to cover 1700 pkm, which should be easily achievable, especially given that buses, which can be rapidly reconfigured, provide a third of today's public transport capacity.

Why do the two types of analysis, by number of trips and passenger-kilometers, produce conflicting results? Which one is correct? A precise answer would require assumptions of neighborhood renovations and service reconfiguration based on geodata and goes beyond the scope of this paper, but it is highly likely that public transport could efficiently cover half of the service it provides today, especially if neighborhoods are optimized and bus and tram routes reconfigured, which can happen rapidly for buses, and within a few years for trams, together over half of today's capacity (Fig. 12). How to imagine such a scenario? Probably with lots of short bus and tram trips, with frequent buses on short routes, and many people traveling only a stop or two.

This conclusion justifies keeping the “no cars” scenario in constructing future modal shares.

3.2.2.4 Constructed modal share

Using a mix of best practice and assumptions about increased use of biking and public transport, shown in appendix #5, we create a zonal modal share for a carless scenario, displayed in Figure 13.

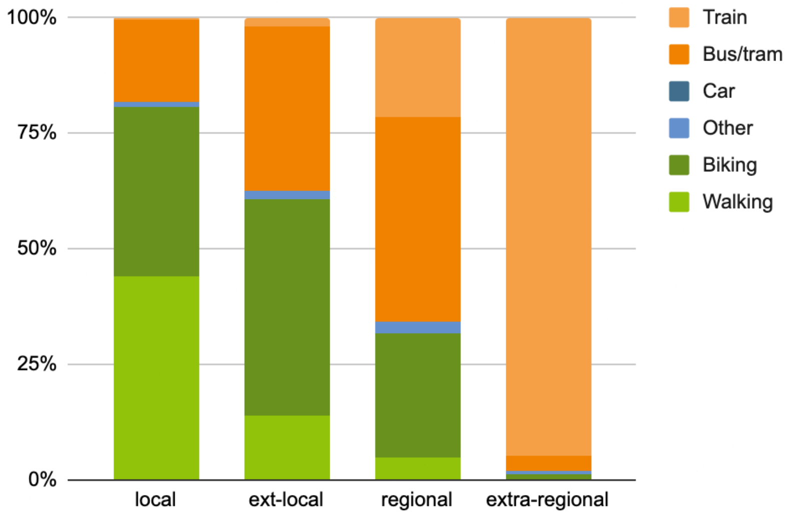


Figure 13: Average use of each means of transport per zone in the carless scenario using best practice assumptions from the other scenarios, and assuming increased bike transport (20-50% increase), train (50-200% increase) and all the remaining trips being fulfilled by bus, trams and coaches.

Using similar assumptions to the carless scenario's modal share, we also construct a second scenario which allows for some car travel to exist, which we call the "some cars" scenario. It takes the modal share of the carless scenario and adds some car usage in all zones except the local. The manner in which we add car transport is that it takes over half of bus and tram transport in the extended-local and regional level, alleviating some of the load on the public transport network, and ⅓$_{rd}$ of train transport in the extra-regional zone, as seen in Figure 14.

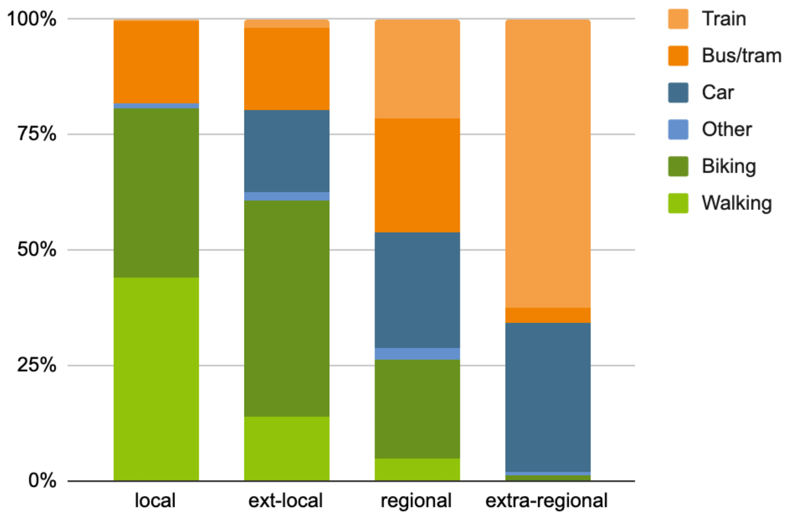


Figure 14: Average use of each means of transport per zone in the “some cars” scenario using the carless scenario’s modal share, and replacing half of the bus and tram transport in extended-local and regional and a third of train travel in extra-regional trips.

3.2.3 Aviation

The aviation sector is treated separately in our calculations for two main reasons:

First, this is due to the structure of the Swiss Microcensus survey, where air travel isn’t really included in the data we used, or at least only marginally.

Second, we believe the parameters for air travel defined by Millward-Hopkins et al. of one round short-haul flight every 3 years, (short-haul meaning less than 1'000 km) is not right for Switzerland. This is first and foremost because Switzerland is in the middle of Europe, where intra-continental high-speed rail is available and requires considerably less energy to transport passengers which, following our model’s framework, makes short-haul air travel unneeded and undesirable. Second, it is hard to find a coherent justification to link wellbeing and access to flight, and considering the energy that it represents (7% of total energy requirements in (Millward-Hopkins et al., 2020)) we believe a new reasoning should be put forward.

A study by the LEURE tells us that a climate-neutral global aviation would consist of 1.3 trillion passenger-kilometers in 2050 (Nick and Thalmann, 2022). We assume that Swiss people shouldn’t have a priority in air travel compared to any other population on earth, and so we multiply the global air travel by the share of the forecasted Swiss population in the 2050 global population. This gives us a much reduced 134 passenger-km/cap/yr compared to Millward-Hopkins et al. with 1'067 p.km/cap/yr. Considering Switzerland’s importance in global diplomacy and its housing of international organizations headquarters (*multiple UN headquarters, WHO, WWF, global trade organizations, Olympic committee*) as well as humanitarian aid with the headquarters of the Red Cross, we suspect that Switzerland may require an increased amount of air travel which would by all accounts be necessary for global wellbeing, so we choose to increase threefold the per-capita air-travel distance of the Swiss population to make up for an increased air-travel by a few, leading to a value of 402 passenger-km/cap/yr, compared to 1'067 p.km/cap/yr from Millward-Hopkins et al. and 8'986 p.km/cap/yr in Switzerland in 2015

The resulting energy, using energy intensities from Millward-Hopkins et al. can then simply be added to our results for ground passenger mobility, and together constitute the direct energy use of passenger mobility following DLS.

3.2.4 Transportation energy

To arrive at an energy footprint of mobility, we are still lacking $average\ energy\ efficiency_i$ for each means of transport. As explained above, passenger-kilometers per mode of transport need to be multiplied by average energy efficiencies (in J/km) to get the resulting direct energy of transport.

The energy efficiency however actually depends on quite a few factors, mainly the occupancy rate. Indeed, while a bus requires more energy than a car to drive the same distance, it can transport more people, leading to lower energy per passenger-kilometer. But as we saw in our “no cars” scenario, buses aren’t always full, which is why occupancy rates are necessary to describe average energy efficiencies. The mobitools platform (Büro für Mobilität AG, 2023) provides us with average Swiss occupancy rates for many modes of transport today, but we assume these rates to be increased in DLS Switzerland thanks to multiple changes in behavior and infrastructure, some of which we reiterate from the *Constructed modal share* section:

- The working hours are more flexible thereby distributing the load on the public infrastructure and avoiding the morning and evening rush.
- Buses have more varied (*and often smaller*) total capacities and are deployed dynamically to ensure maximum capacity in urban buses.
- Digital tools allow public transportation providers to more accurately forecast the capacity at any given time.

Table 4: Collection of available energy efficiency data from various reports and (Millward-Hopkins et al., 2020). All values that are not percentages are in (MJ/p.km)

	Values from EP2050+ report (BFE, 2020)	Values from IEA ETP 2017 report (International Energy Agency, 2017)	Values from (Millward-Hopkins *et al.*, 2020) combining efficiency gains with 2014 values from IEA ETP report
Means of passenger transportation	Final energy intensity in 2060	Final energy intensity in OECD in 2060	Final energy intensity in 2050
Car travel	0.64	0.60	0.34
Heavy road travel	0.24	0.22	0.18
Rail travel	0.28	0.23	0.06
Air travel (international)	0.53	0.69	0.94

For average efficiencies (in MJ/p.km), Millward-Hopkins et al. use 2017’s IEA transportation energy numbers, and apply various energy efficiency assumptions from (Cullen, Allwood and Borgstein, 2011). We compare these with values from the EP2050+ report (BFE, 2020), and predictions from the same IEA report that (Millward-Hopkins et al., 2020) gathers current values from. Portrayed in Table 4, we see that the Millward-Hopkins et al. values are quite optimistic, assuming large efficiency increases from technological improvement. Not all efficiency improvements are so ahead though, since in a 2023 study we find that across all sizes, models and propulsion technologies, the average improvement in efficiency between 2020 and 2050 is projected to be 63% and 68% for cars and buses respectively (compared to 70% and 60% in (Millward-Hopkins et al., 2020)) (Panos *et al.*, 2023).

Since our model is not limited to these 4 modes of transport, we make other assumptions for the remaining categories, these being:

- Biking: If biking is assumed to take much of the capacity for medium-range travel, we say it is fair to assume that 25% of bike trips are done with electric bikes. A 2009 book on energy efficiency tells us that an electric bike has an efficiency of 1 kWh per 100 person-km, which rounds to 0.036 MJ/p.km (MacKay, 2009).
- Motorcycles: Motorcycles aren't very commonplace in Switzerland, but some of our scenarios still give it weight, even if limited, in the total modal split. Mobitools tells us that the average occupancy of a motorcycle is 55%, and many reports often group together with the same value. We do not know if this is due to assumptions about car occupancy rates or some over-dimensioning of motorcycle engines, but we assume that the value for car travel fits for motorcycles.
- Trams, trolleys, mountain buses and urban buses are all assumed to be on average equal to the values given by heavy road travel.

In our report, as we are doing a Swiss-specific study, we use energy intensities from a Swiss-specific scenario (i.e. Energy Perspectives 2050+ report) rather than the more optimistic values from (Millward-Hopkins et al., 2020).

3.3 Results and comparisons

Our results give us many insights on both validating some of our approaches and comparing them to (Millward-Hopkins et al., 2020). A display of yearly distances traveled according to different methods in Table 5, allows us to draw our first conclusions.

First, we can conclude that our "best practice" approach focusing on the least motorized agglomerations in Switzerland is not very efficient, being more than twice as much as what Millward-Hopkins et al. estimated for Switzerland. This makes some sense as our "best practice" approach was relatively top-down and focused on the unrestricted behaviors of the best 36% of the population today, who even if not very mobile are still living in a world designed for car travel and therefore will be more likely to go further than necessary. It does put into perspective how mobile the Swiss population is today compared to what previous DLS calculations say it could be.

Table 5: Comparisons of passenger-kilometers between different approaches to DLS mobility.

Method used or population considered		Annual mobility excluding air travel (pkm/cap/yr)	Annual car transport (pkm/cap/yr)	Annual public transport (pkm/cap/yr)
Swiss population, 2015 Microcensus		13'754	7'611	3'372
Based on DLS best practice (Japan)		4'829	716	2'862
Interaction-based approach	Swiss modal share	3'241	1'717	495
	Dutch modal share	3'241	1'708	233
	“Some cars” scenario	3'241	587	1'143
	“No cars” scenario	3'241	0	1'704

Putting the “best practice” approach aside, we do see positive results from our main method, the “interaction-based” approach, for which we created 4 scenarios: one with current-day Swiss modal share according to distance, one with current day Dutch modal share according to distance, one in which car travel is entirely replaced and one where some cars still exist. They all work with lower yearly ground mobility than (Millward-Hopkins et al., 2020) despite using less optimistic energy intensities and while, according to our rationale, supporting a decent life in Switzerland. We now look at these activity levels combined with energy efficiencies to obtain energy levels per capita. Displayed in Figure 15 are the energy consumptions of the 4 scenarios side to side split between air travel and ground transportation compared to (Millward-Hopkins et al., 2020).

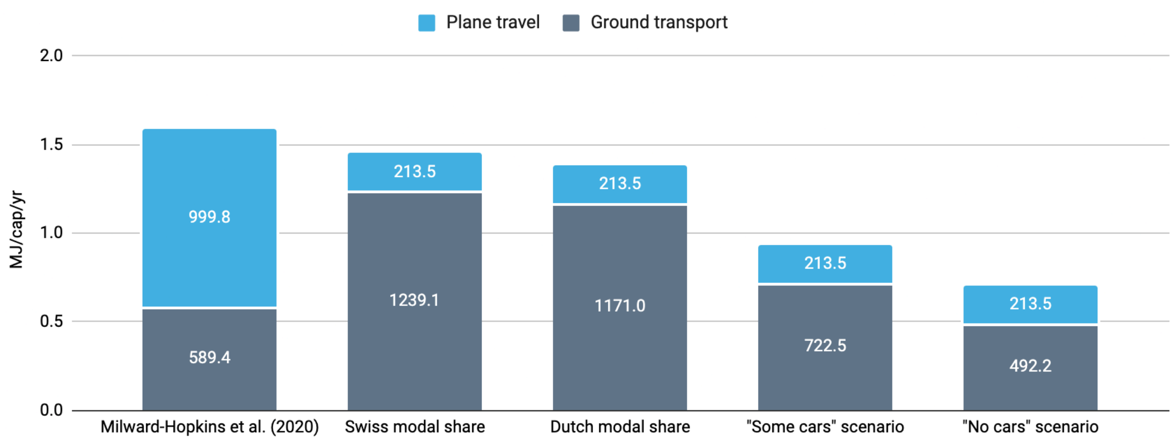


Figure 15: Comparisons of the energy use per capita for our different interaction-based scenarios and (Millward-Hopkins et al., 2020).

From these results we can conclude that our assumption to treat air travel not bottom-up (giving every individual the arbitrary access to one round trip on a short-haul flight every 3 years pays) but top-down based on global climate-neutral aviation numbers ends up reducing air transport’s energy footprint quite noticeably. This is exacerbated by the fact that the aviation efficiency numbers from (Millward-Hopkins *et al.*, 2020) were about 1.8 times bigger than those of the EP2050+ report.

For ground transport, we see that our decision to use the EP2050+ energy efficiency numbers have an impact on ground transportation, being higher in some scenarios than the more optimistic (Millward-Hopkins et al., 2020) efficiencies, but combining with the decreased aviation we are able to achieve a smaller direct energy footprint on all four scenarios.

We also see that despite using a lot more bicycles in their daily travel, the Dutch mobility habits end up consuming a similar amount of energy than the Swiss one. This can be explained by the fact that even though the Dutch use more bicycles for local and extended-local travel, they still use a comparable amount of cars to the Swiss. The Swiss also make up for some of the bicycle mobility with increased public transport compared to the Dutch, leading to only marginal differences in terms of energy. Our constructed modal shares reduce the car-dependency, and show a strong reduction in energy use. The “no cars” scenario is also the only one to have a lower ground transportation energy than (Millward-Hopkins et al., 2020).

Combining air and ground transport, our model of direct energy use in passenger mobility is able to reach a lower requirement than (Millward-Hopkins et al., 2020), going from 1.58 GJ/cap/yr in (Millward-Hopkins et al., 2020) to **0.93 GJ/cap/yr** and **0.72 GJ/cap/yr** for the “some cars” and the “no cars” scenarios respectively.

4. Limitations and discussion

4.1 Methodological and modeling limitations

Limitations of the current exercise can be separated into limitations with the methodology itself, and drawbacks of the available data and related quantitative assumptions.

Regarding the former, three limitations are key:

- First, the method considered only one demographic characteristic that influences the number of trips made for different purposes, namely age. It also did not consider that some people may be restricted to particular transport modes. A more refined method may consider how characteristics like migration, health status, or caring duties influence the number of trips people require to meet their needs, the distances necessary, and the modes they can use. This could, however, be implemented into the methodology relatively simply, assuming appropriate data were available (similarly, the methodology could easily be extended to consider rural areas explicitly).
- Second, all the trips people currently take were assumed to be relevant to meeting needs, and hence essential for decent living. But many trips may not be reasonably categorized as decent, either as they are related to wants, not needs, or because they are arguably involuntary (for example, the commute of someone who is not permitted to work from home).
- Finally, determining what share of trips for each purpose can take place within each zone is very difficult for some purposes, particularly leisure. Even assuming that zonal distances can be well defined, and the nearest facilities accurately placed within each zone, one cannot then assume that accessing the nearest facilities will meet one's needs. Work is an obvious example, as a married couple may live locally to only one of their places of work, forcing the other to commute a significant distance.

Regarding the latter, there are many issues relating to the current quantitative modeling assumptions. Some key examples are: the assumed model splits based upon the zonal distances (Figure 7 shows that Swiss citizens' choice of mode is very sensitive to trip distance at short distances); the assumed zonal split of trips for leisure; and indeed the size of the zones themselves, particular the extra-regional average of 100km.

With limits in mind, the above results can be considered as a first estimate of minimum mobility energy requirements in Switzerland. Further studies could consider how mobility sufficiency may be influenced by Swiss culture and social norms, detailed characterisations of demographic and geographic factors, and feasible scenarios for the necessary transitions, including infrastructures, technologies, and social norms.

4.2 Discussion

4.2.1 Sector dependencies

Our model of mobility relies on the adaptation of the built environment to function properly. Cars have become an integral part of many's daily activities through years of car-centric planning, and a complete removal of cars in today's Switzerland without rethinking the infrastructure in which it operates would probably lead to reduced wellbeing of the population (*we assume*). People would probably be left stranded in towns with very little to satisfy their needs in their immediate surroundings. The dependencies between sectors arise from both behavioral and infrastructure changes.

For the infrastructure, we first of all can talk about the necessary relocation of all residential buildings, their densification through increased shared space and renovations while abandoning car-dependent habitat. The building sector is not the only one that comes into play, as the public space needs to be re-adapted to provide services locally, which people could access with a bike or public transport. This has implications on freight, which would need to bring goods closer to people in a way that moves away from large far-away malls, and closer to neighborhood grocery stores and facilities offering essential services, including health through primary care.

On the behavioral side of things, we assume that people move closer to where they work, which has implications on how families live together and what a career looks like. Anyone that can't move closer but can telework would, using their personal computer and household as a home-office, or local co-working spaces if the infrastructure exists. The assumed increase in bike usage and public transport are essential in making the car-less world work but might require people to take more time to travel. Public transport is not necessarily slower than cars, but can be more unreliable, which could be problematic in a society like today that structures itself using specific timings and where tardiness isn't very socially acceptable. Leisure is also a major behavioral aspect which would change with our new mobility requirements, wherein people would find more ways to satisfy their needs for leisure through local community means, and travel would naturally become more concentrated to regions close to the household.

4.2.2 Migration and culture

Our work on the mobility system of DLS Switzerland is defined around both daily and occasional mobility from one's household. Accordingly, we do not address what happens during and after migration to new households. In this section, we attempt to open a discussion around the consequences of migration and cultural considerations of low mobility.

First of all, we highlight that visiting friends and family is a large part of leisure travel, which is a large part of general travel in our data. Important for belonging and social wellbeing, we assume that most of the trips where people visit friends would be relatively local if a strong sense of community exists locally, similarly to what we saw in car-less housing in Switzerland and

Germany, where a lot of the leisure was concentrated within the local community (Baehler and Rérat, 2022).

While this might be true in daily mobility, this might not be the case following exceptional mobility, where individuals move to a new community. Exceptional mobility might happen when people go to university, or move closer to a job, or due to more complex patterns of migration. Taking the example of moving to university, we expect individuals to weave a new social fabric with the local community close to their campus, and ultimately end up trying to keep in touch with two communities at the same time. That is even without considering that the individuals from the university's community might also want to go back to their home community, which increases the number of locations to potentially go. Keeping in touch can be done effectively through ICTs, however we still expect people to occasionally travel to keep in touch with individuals from a previous community.

Since our report studies needs we must come back to our assumptions and see if, out of all trips with a purpose of visiting friends and family, 13% being regional and 5% being extra-regional can guarantee decent living. We believe that this is the case. It roughly amounts to 11 regional trips and 4.6 extra-regional trips on average for each resident, which we believe is within decent living standards if we once again assume that ICTs and strong local communities are present everywhere.

It is somewhat harder to tell if this amount of extra-regional travel is adequate for individuals whose family isn't anywhere near the regional level, such as might be the case for the 2'190'293 foreign nationals living permanently in Switzerland at the end of December 2021 (State Secretariat for Migration, 2021). If we assume that their families live in their original country of residence, and that 4.6 extra-regional trips is not enough to see extra-regional friends and family at a level that ensures wellbeing, then we could include in our model an additional amount of extra-regional travel specifically for immigrants visiting their loved ones back home. Seeing as ⅔ of foreign nationals in Switzerland today are (*in decreasing amount*) from Germany, Italy, France, Kosovo, Portugal, Turkey, North Macedonia, Serbia, Spain, and the UK, we estimate that one round trip of on average 1500 km per year could fulfill needs of social wellbeing and belonging in a way that access to ICTs might not.

A short calculation giving 25.68% of the Swiss residing population a 1500 km trip by train every year would increase the average energy consumption by 107 MJ/capita/year, resulting in an overall direct energy of passenger transportation of 1.04 GJ/capita/year, so around a 12% increase. The results are visualized in Figure 16. We see here that thanks to the high energy efficiency of trains, international travel could still be done in some capacity with a relatively small impact on energy use.

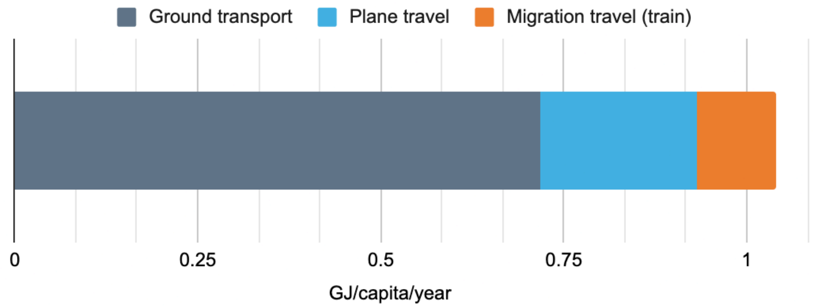


Figure 16: The effect on direct energy of passenger mobility of adding 1500 km yearly of migration travel to every foreign national resident of Switzerland in the "some cars" scenario.

While our model considers local and extended-local travel to be overwhelmingly capable of providing decent living (only 3.38% of trips in our model are regional or extra-regional), it is interesting to think of the cultural impact that more local living would have on a population. Our Swiss DLS do not include much tourism since the needs it satisfies can also be fulfilled by much less energy-intensive means. With similar reasoning, work tourism, international tourism, and the aviation industry are all reduced, leading in many ways to a reduction of opportunities for Swiss people to meet others who live well beyond their local community. Much could be questioned about our current system of international mobility, where people often travel far for short stays and with limited interaction with the local populations, but it is important to think about how much wellbeing is impacted by being able to experience life far away from home and meet others with different cultural backgrounds.

We believe that it is quite achievable for the population to experience life, culture, and ideals outside of their local communities without needing to travel very far. Meeting people with very different cultural backgrounds is already possible in current day Switzerland, where 25.7% of the population is a foreign national, and thoughtful media, artistic works or well designed online spaces could also provide meaningful cultural impact. Generally speaking, well-designed ICTs, crafted to enable collaboration and cultural exchanges are in our opinion a reasonable solution, coupled with increased community collaboration to help provide social wellbeing to individuals who travel little outside or their communities.

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6. Appendix

Appendix 1: Decent living standards—material requirements indicators. From (Rao and Min, 2018)

Decent living standard dimensions	Household requirements	Collective requirements
Physical wellbeing		
Nutrition		
Food	Total calories, protein, micronutrients	
Cold storage	Fridge (or other technology)	
Shelter	Solid walls and roof	
Living conditions		
Sufficient, safe space Basic comfort (bounded temperature/humidity) Hygiene	Minimum floor space Modern heating/cooling equipment In-house improved toilets Minimum, accessible water supply	Electricity, water and sanitation infrastructure
Clothing	Minimum clothing materials	Washing machines per 1000 persons
Health care		
Accessible and adequate health care facilities		Minimum health expenditure per cap Minimum physicians per 1000 persons
Air quality		
Maximum ambient particulate matter ($PM_{2.5}$)	Clean cook stoves	Restricted transport infrastructure
Social wellbeing		
Education		
Nine years schooling		Equipped schools Teachers per 1000 persons
Communication	Phone (1 per adult)	ICT infrastructure
Information access	Television/internet device	
Mobility	Access to public transport, or vehicle, if essential	Public transport and road infrastructure
Freedom to gather/dissent		Public space, sq. m. per 1000 persons

Appendix 2: Average number of trips in Switzerland per person per day in 2015

	All motives	Work	Training or school	Shopping	Leisure	Work and service travel	Services and accompanying others	Other (incl. don't know/no indication)
Total	3.37	0.71	0.25	0.75	1.3	0.12	0.21	0.03
Age								
6-17 years old	3.51	0.13	1.49	0.35	1.43	0.02	0.08	0.03
18-24 years old	3.52	0.85	0.4	0.55	1.45	0.09	0.15	0.04
25-64 years old	3.58	1.03	0.05	0.79	1.23	0.17	0.27	0.03
65 years old and older	2.57	0.07	0.02	0.96	1.34	0.03	0.11	0.04
Monthly income of household								
Up to 4'000 CHF included	2.77	0.35	0.07	0.91	1.23	0.07	0.12	0.04
4 001 to 8 000 CHF	3.38	0.78	0.06	0.87	1.26	0.14	0.24	0.03
8 001 to 12 000 CHF	3.66	0.99	0.08	0.79	1.31	0.16	0.27	0.04
More than 12 000 CHF	3.77	1.12	0.09	0.7	1.37	0.19	0.28	0.03
Don't know/no indication	3.21	0.4	0.75	0.55	1.31	0.06	0.12	0.03
Degree of urbanization of residence								
Urban	3.4	0.72	0.24	0.79	1.3	0.11	0.2	0.03
Urban-influenced	3.32	0.69	0.27	0.69	1.3	0.13	0.22	0.04
Outside of urban influence	3.31	0.73	0.25	0.67	1.27	0.14	0.21	0.03

Appendix 3: Investigating best practice through a top-down approach

One approach we studied could simply be to think of decent mobility as the mobility of people living decently today.

Since many people today in the developed world tend to travel more than necessary for their wellbeing, and since we can find a positive correlation between income and traveling distances (Biedermann, 2023), it is important to isolate the part of the decent living population which travels the least, or using the lowest energy-intensive mobility. This subset of the general population can be chosen at different scales:

Previous DLS work has been crude, and as a starting point has looked to Japan -- a country with high wellbeing and historically low mobility of 7'000 km/cap/yr. Millward-Hopkins *et al.* (2020) use this as a central estimate for urban mobility in all countries, increasing this to 10'000 km/cap/yr in rural areas. The model from Millward-Hopkins et al. uses these numbers to estimate mobility worldwide, creating a formula which also takes into account land density, stemming from the rationale that distances traveled tend to decrease with a higher lived density. The assumptions from (Millward-Hopkins *et al.*, 2020) are transcribed here :

For n representing each nation: $MOB_n = MOB_{base} \times (f_{fixed} + f_{variable} \times \frac{LD_{base}}{LD_n})$

- We take 7,000 and 10,000 km/cap as base estimates of mobility requirements in urban and rural areas, respectively (each termed MOB_{base})
- A proportion of mobility (f_{fixed}) is independent of region, consisting of travel that does not depend upon local population density.
- The remainder ($f_{variable}$) is inversely proportional to population density in the nation.
- Population density is better captured by removing land that's mostly uninhabited to give a lived density (LD), which better represents that encountered by people in their daily lives.
- For the base lived density (LD_{base}) we use the median of our data – 189 persons/km^2.

The formula is created to generate mobility numbers that are in line with estimates while giving a coherent spread of values worldwide. It can be rather crude in its scaling, and not as well-suited for the study of one country in particular, which is why we try to find new ways to calculate mobility which do not rely on Japanese data and try to get closer to Swiss ideal numbers.

To do so, we can look at the city-wide scale or the neighborhood scale as mentioned in this report's introduction, but these don't give us much applicable data that could be representative of Switzerland as a whole. We consequently use the Swiss micro-census survey (Biedermann *et al.*, 2017) to find our desired passenger-kilometers data using current best-practice. We find a sample of Swiss residents who travel less than others, assuming that they still live decently on the virtue of being Swiss residents, where average quality of life is high.

Since the 2015 micro-census data is originally composed of individual daily trips by Swiss residents, we cannot infer broader mobility habits. Any attempt at ranking the trips by distance is going to highlight the individuals who didn't travel much on the day they were surveyed, but it doesn't tell us how much they *usually* travel. In the report, aggregates are calculated based on individual travel patterns that are then extrapolated to a region using the region's population distribution (BFS, 2017). By doing so we are able to gather the average yearly travel of individuals *in that region*. This is useful for us as we can then rank each region according to their individual motorized mobility and find a subset of the Swiss population which has the lowest motorized mobility. Ranking this way is not anodyne, because even when we assume that personalized cars have a multitude of negative effects which clash with DLS (health, pollution, alienation, destruction of soil, biodiversity threat), we also see empirically that lower car use tends to correlate very strongly with lower daily mobility, which is our goal here.

The smallest geographical aggregation we could find from the microcensus data was the aggregation into agglomeration. According to the 2012 definition (BFS, 2018a), "agglomeration" refers to a grouping of communes comprising more than 20'000 residents with one dense center. The 2012 definition gives us 49 agglomerations in Switzerland, out of which 48 have an aggregation of mobility from the 2015 microcensus (Stein (AG) was removed due to having too small of a sample (BFS, 2017)). We can extract their population data in 2015 (BFS, 2022), and cross it with their daily mobility data (*in km*), which is divided into "soft mobility", "private motorized transport" and "public transport". We then rank each agglomeration from the least motorised to the most and select the best ones until we reach 25% of the Swiss population. Once we have the subset, we can do a population-weighted average of their mobility habits and extract the passenger-kilometers of the least motorized representative subset of the Swiss population.

The selected agglomerations can be seen in Table 5. Notice how the inclusion of the very large Zurich agglomeration makes our subset appreciably larger than our 25% goal, being around 36% of the Swiss population in 2015.

Table 5: Ranking of agglomerations (2012 definition) according to their ranked private motorized daily transport distances in their 2015 Microcensus aggregation

Agglomeration	Permanent resident population, 2015	Cumulative population in subset	Soft mobility [daily p.km]	Ranked private motorized transport [daily p.km]	Public transport [daily p.km]
Genève (CH)	578'961	578'961	2.8	16.8	5.7
Biel/Bienne	104'515	683'476	3.2	18.2	11.6
Brig - Visp	47'016	730'492	4.4	18.4	22.4
Basel (CH)	540'963	1'271'455	3.1	18.4	9.8
Rapperswil-Jona - Rüti	46'345	1'317'800	3.5	18.8	15.6
Lugano (CH)	151'101	1'468'901	2.1	19.0	3.5
St. Gallen	165'922	1'634'823	3.1	19.4	7.6
Zürich	1'333'420	2'968'243	3.0	19.8	10.9
25% of the 2015 Swiss population		2'081'782			

While changing everyone's behavior to that of the "best" practicing population subset provides us with a solid estimate, it does tend to exhibit larger distances and energy requirements than what we believe to be sufficient for wellbeing. This makes sense since the “best practice” methodology works by looking at current day behaviors, which are necessarily influenced by our current day car-centric infrastructure. It should be noted that this approach could give even lower passenger-kilometers by making simple additional assumptions on modal shift away from the most energy-intensive modes of transport like private motor vehicles, especially when traveling for motives such as leisure, although we weren’t able to coherently justify reductions in mobility from this reduced subset.

Appendix 4: Swiss cities dataset used for estimating average distances traveled in extended-local and regional zones

City	Distance to regional capital [km]	Nearest city in dataset	Distance to nearest city [km]
Winterthur	19.8	Bassersdorf	9.8
Biel/Bienne	25.5	Nidau	0.0
Thun	24.6	Steffisburg	0.0
Bellinzona	0.0	Minusio	16.5
Uster	13.5	Greifensee	3.1
Vernier	3.6	Onex	1.9
Sion	0.0	Veyras	14.8
Yverdon-les-Bains	28.8	Cortaillod	24.9
Emmen	3.7	Lucerne	3.7
Dübendorf	7.4	Dietlikon	0.4
Rapperswil-Jona	47.8	Lachen	4.5
Dietikon	11.0	Geroldswil	2.2
Wetzikon	20.6	Rüti	6.7
Meyrin	6.4	Vernier	3.2
Carouge	2.3	Plan-les-Ouates	2.2
Kreuzlingen	0.0	Romanshorn	16.2
Wädenswil	18.3	Männedorf	3.1
Riehen	4.5	Birsfelden	3.4
Allschwil	17.7	Binningen	3.1
Renens	4.1	Chavannes-près-Renens	0.8
Wettingen	22.1	Ennetbaden	1.9
Nyon	34.3	Gland	5.0
Bülach	15.8	Niederglatt	3.5
Vevey	17.6	Corsier-sur-Vevey	0.0
Opfikon	6.8	Wallisellen	3.0
Reinach	11.5	Aesch	1.8
Baden	20.3	Wettingen	2.0
Onex	4.2	Confignon	1.3
Adliswil	6.4	Kilchberg	1.5
Schlieren	7.4	Oberengstringen	1.5
Volketswil	11.8	Greifensee	2.8
Thalwil	10.3	Oberrieden	1.1
Olten	31.5	Aarburg	3.7
Pully	2.6	Paudex	1.1
Regensdorf	8.6	Unterengstringen	2.4
Ostermundigen	3.3	Muri	2.5
Littau	2.7	Lucerne	2.7
Pratteln	6.1	Frenkendorf	1.9
Freienbach	21.7	Richterswil	4.2
Wallisellen	6.2	Dübendorf	1.5
Wohlen	18.1	Widen	6.4
Morges	10.3	Préverenges	2.6
Steffisburg	24.6	Thun	0.0
Binningen	14.6	Bottmingen	1.1
Arbon	23.9	Horn	3.3
Stäfa	20.7	Männedorf	3.4
Küsnacht	7.2	Erlenbach	1.9
Thônex	3.5	Chêne-Bougeries	0.0
Meilen	13.9	Uetikon am See	3.3
Versoix	9.2	Coppet	4.2
Richterswil	21.3	Wädenswil	3.1
Zollikon	4.6	Küsnacht	2.9
Gland	30.0	Nyon	5.0
Muri	3.2	Ostermundigen	2.5

City	Distance to regional capital [km]	Nearest city in dataset	Distance to nearest city [km]
Ecublens	5.7	Chavannes-près-Renens	1.2
Prilly	3.0	Renens	1.3
Chêne-Bougeries	3.5	Thônex	0.0
Rüti	26.2	Rapperswil-Jona	6.1
Le Grand-Saconnex	4.2	Vernier	3.9
Münchenstein	10.4	Arlesheim	2.7
Villars-sur-Glâne	3.1	Fribourg	3.1
La Tour-de-Peilz	19.5	Vevey	2.3
Spreitenbach	24.0	Dietikon	3.1
Veyrier	4.8	Thônex	1.8
Bassersdorf	10.1	Dietlikon	2.7
Männedorf	17.5	Uetikon am See	1.7
Romanshorn	16.2	Arbon	7.8
Oberwil	14.4	Therwil	1.6
Brugg	15.2	Windisch	1.4
Plan-les-Ouates	4.5	Carouge	2.2
Neuhausen am Rheinfall	2.2	Schaffhausen	2.2
Aesch	10.5	Reinach	1.8
Birsfelden	12.7	Basel	2.5
Lutry	4.4	Paudex	1.2
Therwil	14.3	Oberwil	1.6
Sursee	19.0	Emmen	16.7
Urdorf	8.7	Schlieren	2.2
Widnau	20.0	Au	3.7
Epalinges	4.2	Belmont-sur-Lausanne	3.1
Rorschach	10.8	Goldach	3.1
Goldach	9.7	Horn	1.4
Arlesheim	9.0	Dornach	1.5
Zuchwil	2.4	Solothurn	2.4
Kilchberg	5.6	Adliswil	1.5
Neuenhof	21.7	Wettingen	2.1
Lachen	23.9	Rapperswil-Jona	4.5
Fällanden	7.5	Schwerzenbach	1.6
Oberentfelden	4.5	Unterentfelden	1.2
Aarburg	14.6	Olten	3.7
Chiasso	40.2	Vacallo	1.9
Buchs	2.2	Aarau	2.2
Crissier	5.1	Renens	1.9
Au	19.8	Widnau	3.7
Dietlikon	7.8	Dübendorf	0.4
Chavannes-près-Renens	4.5	Renens	0.8
Windisch	15.8	Brugg	1.4
Minusio	16.5	Muralto	2.3
Heimberg	21.7	Thun	3.1
Nidau	25.5	Biel/Bienne	0.0
Dornach	29.8	Arlesheim	1.5
Bottmingen	13.9	Binningen	1.1
Oberengstringen	7.1	Unterengstringen	1.1
Frenkendorf	4.3	Pratteln	1.9
Rolle	24.3	Gland	5.9
Buchrain	6.2	Emmen	3.8
Massagno	20.8	Savosa	0.0
Uetikon am See	15.8	Männedorf	1.7
Rüschlikon	10.2	Thalwil	1.3

City	Distance to regional capital [km]	Nearest city in dataset	Distance to nearest city [km]
Peseux	3.4	Neuchâtel	3.4
Interlaken	42.5	Hilterfingen	16.1
Cologny	3.3	Geneva	3.3
Erlenbach	8.9	Küsnacht	1.9
Colombier	6.3	Cortaillod	2.2
Courtepin	7.8	Fribourg	7.8
Greifensee	10.8	Schwerzenbach	2.7
Préverenges	7.7	Ecublens	2.4
Gerlafingen	5.8	Zuchwil	3.9
Schwerzenbach	8.7	Fällanden	1.6
Oberrieden	11.1	Thalwil	1.1
Geroldswil	10.5	Dietikon	2.2
Niederglatt	13.4	Bülach	3.5
Schönenwerd	39.5	Unterentfelden	3.0
Niederlenz	9.5	Hunzenschwil	4.2
Cortaillod	8.4	Colombier	2.2
Saint-Sulpice	5.1	Ecublens	1.3
Confignon	5.3	Onex	1.3
Morbio Inferiore	38.4	Vacallo	1.3
Caslano	27.6	Magliaso	1.5
Gross Höchstetten	15.1	Muri	12.0
Unterentfelden	3.5	Oberentfelden	1.2
Paradiso	24.4	Sorengo	2.3
Niederrohrdorf	19.4	Neuenhof	3.2
Hilterfingen	27.9	Thun	3.2
Hunzenschwil	6.0	Buchs	3.9
Unterengstringen	8.2	Oberengstringen	1.1
Langendorf	1.5	Solothurn	1.5
Belmont-sur-Lausanne	4.2	Pully	1.9
Widen	23.5	Dietikon	4.6
Port	24.0	Biel/Bienne	1.8
Ennetbaden	22.1	Wettingen	1.9
Feuerthalen	36.2	Schaffhausen	1.3
Rheineck	16.7	Au	5.3
Vacallo	38.4	Morbio Inferiore	1.3
Corsier-sur-Vevey	17.6	Vevey	0.0
Balerna	38.5	Morbio Inferiore	1.3
Coppet	40.8	Versoix	4.2
Turgi	18.6	Windisch	2.8
Coldrerio	38.6	Balerna	1.3
Rickenbach bei Wil	22.2	Kreuzlingen	22.2
Horn	27.1	Goldach	1.4
Muralto	18.0	Minusio	2.3
Hauterive	3.1	Neuchâtel	3.1
Corseaux	16.4	Vevey	1.3
Canobbio	18.7	Cureglia	1.3
Savosa	20.8	Massagno	0.0
Tolochenaz	13.0	Morges	3.2
Vezia	21.2	Massagno	1.3
Veyras	14.8	Sion	14.8
Sorengo	23.0	Vezia	1.9
Magliaso	26.2	Caslano	1.5
Cadempino	19.5	Cureglia	1.3
Paudex	3.3	Pully	1.1
Cureglia	19.0	Canobbio	1.3

Appendix 5: Constructed modal shares

The constructed modal shares were created by reusing data from both the Swiss and Dutch modal shares according to distance, while others were imposed by us or calculated based on others. The following table explains what method was used for each value.

Color code for method used in each cell :

Increased from Swiss value
Swiss value
Increased from Dutch value
Dutch value
Reduced from Dutch value
Complement of all others split between two modes
Complementary to sum of all others
Imposed value

No cars modal share							
km	zone	Walking	Biking	Other	Car	Bus/tram	Train
0.5 - 5	local	44.18%	43.66%	1.14%	0.00%	10.13%	0.89%
1 - 6	ext-local	14.08%	46.66%	1.77%	0.00%	36.26%	1.23%
3.5 - 75	regional	4.84%	26.84%	2.66%	0.00%	44.29%	21.37%
75	extra-regional	0.00%	1.06%	3.17%	0.00%	3.00%	92.77%

Some cars modal share							
km	zone	Walking	Biking	Other	Car	Bus/tram	Train
0.5 - 5	local	44.18%	43.66%	1.14%	0.00%	10.13%	0.89%
1 - 6	ext-local	14.08%	46.66%	1.77%	18.13%	18.13%	1.23%
3.5 - 75	regional	4.84%	26.84%	2.66%	22.14%	22.14%	21.37%
75	extra-regional	0.00%	1.06%	3.17%	30.92%	3.00%	61.84%