Decarbonization Scenarios for Reykjavik's passenger transport II: The combined effects of behavioral changes and technological developments

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Executive summary

The global carbon budget left for not to exceed 1.5-degree warming is alarmingly low, only around 300-400 gigatonnes of CO_2, meaning no more than 10 years at the current global yearly emissions level of 40 gigatonnes. Moreover, the global average per capita emissions are ~5 tonnes per year, which is equivalent to the GHGs from just private transport in Reykjavik when including long-distance travel. While flights dominate these emissions in Reykjavik, private cars contribute over 2 tons per year per capita - a massive amount in global terms and given the rapidly shrinking carbon budget for 1.5-degree warming. The transformation of the transport sector, therefore, needs to be rapid and profound.

Despite the significant amount of work around the topic of sustainable urban mobility (SUM), the state of knowledge is still strikingly weak. In this report, we focus on two aspects with which the prevailing thoughts are largely based on weak knowledge or simply omitting important factors due to limited knowledge about them. The first of these is the potential of private vehicle fleet electrification to reduce the emissions from the transport sector, which is in the nexus in Chapter 1. Electrification is pushed forward by governments across Europe, and it is hoped to significantly push down the transport sector emissions in Reykjavik also. However, rapid turnover of the vehicle fleet leads to high production-phase emissions, typically occurring elsewhere than where the vehicles are used. Since the production phase emissions of EVs are substantially higher than those of combustion engine vehicles, in the short term there is no gain but rather an increase in the global emissions associated with EV adoption. In Reykjavik the renewable energy production system leads to relatively low “carbon payback times”, but still the scenarios we show in Chapter 1 highlight that fleet electrification needs to be accompanied by a significant reduction in car ownership for global decarbonization of transport in Reykjavik. It seems clear that even though electrification of the fleet is a desirable development direction in Reykjavik, it is not sufficient and should be supported with measures reducing car dependency. In Chapter 2 we show a concept for an optimization framework to guide the work of a city towards decarbonizing the transport sector with any given current or future status of the system. Chapter 3 sheds light on the future grid requirements when EVs change the demand and particularly the peak loads. While there are several technological and price mechanism-based solutions to lowering the peak loads, reduced car dependency remains as the solution with by far the highest associated benefits.

The second weakness, covered in Chapters 4 & 5, is the missing connection to any sustainability baselines of the indicators typically utilized to monitor the work towards a SUM system. What these indicators show is progress or improvement with different issues with sustainability-relevance, but they fail to tell when a system might be sustainable (or even just a certain aspect of it), or what it truly means for an urban mobility system to be sustainable. The latter issue might even lead to the wrong development direction being considered as progress towards a SUM system. In Chapter 4 we introduce a novel concept of a domain-specific sustainable consumption corridor, focused on urban mobility and accessibility, where we lay the foundation for the first framework for analysing the absolute sustainability of a mobility system. The framework consists of both ecological and social aspects of sustainability. The latter is particularly important for the mobility sector, as it provides an important means for meeting human needs and meaningful participation in the society and economy. Any effort at reducing car dependence, particularly in highly car-oriented locations, such as Reykjavik, has to be mindful of its implications on society and its welfare. The work shown in the chapter contributes to an equitable and just transformation of the transportation sector in the region. The work with the best possible indicators and the thresholds for them is in its infancy, but the framework created can guide the work in the future. Chapter 5 adds to this a long list of indicators suggested in academic literature, and a stakeholder engagement analysis in Reykjavik to allow for comparisons and gap analyses.

Based on the materials presented in this report, and the lessons learned from these different components, we suggest the following focus themes for future SUM system work in Reykjavik:

1) **Focus on the global impacts, not only those occurring within city limits.**
2) **Focus on reducing car dependency.**
3) **Focus on defining what it means for the transport system to be sustainable in Reykjavik.**
4) **Focus on finding and selecting a sufficient set of indicators with clear threshold values, upper and lower, for a sustainable state of the system.**

Disclaimer:

The authors listed as contributors to this report have participated in writing one or more chapters of this report, but not necessarily in all the chapters. The authors of each chapter are responsible for their contents. The report and its findings should not be regarded as to reflect the Icelandic Road Authority’s guidelines or policy.

Forewords

This report closes this two-year project in which the aim has been to support the work towards decarbonization of the transport sector in Reykjavik, and towards the broader target of reaching a sustainable mobility system in Reykjavik in the future. The project has been highly successful in terms of academic outcome. Two peer-reviewed academic papers have already come out, and three more are under development. The two already published are:

Dillman, Kevin Joseph, Reza Fazeli, Ehsan Shafiei, Jón Örvar G. Jónsson, Hákon Valur Haraldsson, and Brynhildur Davíðsdóttir. 2021. "Spatiotemporal analysis of the impact of electric vehicle integration on Reykjavik's electrical system at the city and distribution system level." Utilities Policy (68) 101145 https://doi.org/10.1016/j.jup.2020.101145.

Dillman, Kevin, Michał Czepkiewicz, Jukka Heinonen, Reza Fazeli, Áróra Árnadóttir, Brynhildur Davíðsdóttir, and Ehsan Shafiei. 2021. "Decarbonization scenarios for Reykjavik's passenger transport: The combined effects of behavioural changes and technological developments." Sustainable Cities and Society (65). 102614 https://doi.org/10.1016/j.scs.2020.102614.

The three chapters of this report not yet published as peer-reviewed academic papers are also being converted into such as we speak (Chapters 2, 4 & 5). In addition to these publications, the forthcoming doctoral thesis of the lead author of this report, Kevin Dillman, will largely be built on the outcomes of this two-year two-step decarbonization project for Vegagerdin. We greatly thank Vegagerdin for supporting this important work.

The outputs of these two continuum projects for Vegagerdin have also been disseminated to much broader audiences than the readers of the published articles or those of the first part report. The authors of this and the previous report have held numerous lectures to professionals in Iceland, Finland, and Poland utilizing the materials from these two projects. The materials have been shown to students at the University of Iceland on different environment and sustainability oriented courses, and this dissemination work continues. We also hope to find new funding to advance the work we started in this project with the concept of transport-focused sustainable consumption corridors. We believe that this concept has the potential for an important scientific breakthrough once developed further.

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Introduction

The City of Reykjavik has set an ambitious target of becoming carbon neutral by 2040 (City of Reykjavik 2016). Due to the renewables-based stationary energy production system covering the city, transport is in a dominant role in the decarbonization strategies of the city (City of Reykjavik, 2016). However, the current levels of car ownership in the city, and the greenhouse gas (GHG) emissions from transport, are both on a very high level currently in global comparisons (Czepkiewicz, Árnadóttir and Heinonen 2019, Heinonen, et al. 2021). At the same time, the role of public transport in the transport modal split is very low and the system relying only on buses has a very low public image (Heinonen, et al. 2021). Electrification of the transport fleet is considered as one of the key means to reach the decarbonization target (European Commission 2016, Iceland Ministry for the Environment and Natural Resources 2018).

The project reported here, “Decarbonization Scenarios for Reykjavik’s Passenger Transport II: The Combined Effects of Behavioural Changes and Fleet Change”, was set to study the potential outcomes of the current decarbonization visions, and to find alternative pathways to transport sector decarbonization in Reykjavik. This is a continuum project for “Decarbonization Scenarios for Reykjavik’s passenger transport: The combined effects of behavioural changes and technological developments”. In the first phase of the project, we studied the impacts of seven alternative development pathways, including changes in the modal split, distances travelled (through urban structural changes), car fleet composition, and the fleet size. We found and reported rather worrisome results for Reykjavik in rapid decarbonization being highly unlikely without significant reduction in the car fleet size – even with rapid electrification of the fleet (Dillman et al. 2020b). While the current emission accounts of the city only include the emissions taking place within the city (territorial accounting principle), the inclusion of the indirect component, the emissions from producing the vehicles, significantly reduces the mitigation effect of any scenario without a rapid decline in car ownership and the overall fleet size. Only with unexpectedly rapid decarbonization of the global production systems would electrification alone have a significant mitigation impact. This applies also to scenarios with reductions in travel demand and increases in public transport mode share, but without significant changes in car ownership.

In this continuum project, we on one hand extend the previous project by improving our scenarios and their outcome estimates, and on the other, we expand the scope of our work to cover the broader context of sustainable urban mobility systems (SUMSs) and their premises. The project was divided into five work packages which are all reported as their own entities under separate chapters of this report. Chapter 1 is called “Development of the decarbonization scenarios”, and it focuses on the improvement of the first scenarios reported in Dillman et al. (2020b). It depicts how only the scenarios with significant fleet size reductions reach even close to full decarbonization by 2040. Chapter 2, “Optimization framework for the decarbonization”, focuses on the development of a concept for a decarbonization pathway optimization framework applicable for a variety of towns/cities under different initial conditions, or for Reykjavik at a different point in time after first choosing a certain development direction. In Chapter 3, “Energy demand modelling considerations”, the energy system in Reykjavik is in the nexus. Electrification might significantly change the production system requirements in terms of adaptation to peak loads and adjusting across demand fluctuations, and this chapter shows predictions for these peak loads and fluctuations across a set of transport electrification options. Chapter 4, “Framework for mobility-focused sustainable consumption corridor”, expands the scope to SUMSs and their premises. A pressing deficiency in the current SUMS across the globe is that they, despite “sustainable” in the very name, lack any direct connections to what it means for a transport system to be sustainable. In this chapter, we develop a framework of a sustainable corridor for an urban mobility system with a social floor and an ecological ceiling. Chapter 5, “Sustainable Urban Mobility Indicator development through the lens of a participatory approach”, pulls together a set of SUMS indicators sufficient in including the key aspects of a SUMS based on academic literature and stakeholder views in Reykjavik. In the “Concluding remarks”, Chapter 6, we discuss the key takeaways and suggest policy options for SUMS development in Reykjavik.

Chapter 1: Development of decarbonization scenarios for Reykjavik

Background

This chapter builds off of the 2020 Vegagerðin report and discusses the developments made following the submission of that report. Following the submission of the 2020 report (Dillman et al. 2020b), the conceptual work developed during that research paper was enhanced and submitted for academic publishing and was published in the *Sustainable Cities and Society* journal. The citation below is for this article:

Dillman, K., Czepkiewicz, M., Heinonen, J., Fazeli, R., Árnadóttir, Á., Davíðsdóttir, B., & Shafiei, E. (2021). Decarbonization scenarios for Reykjavik's passenger transport: The combined effects of behavioural changes and technological developments. *Sustainable Cities and Society*, *65*, 102614.

The major changes from the 2020 Vegagerðin report worth mentioning within this chapter includes an improved axis framework and simplification of the scenarios, an improved methodological framework and visualization of it, and an improved decomposition methodology and results. A thorough overview of this work is given in this chapter, but if greater detail is sought, please see the cited work.

Introduction

Mobility plays a key role in our daily lives and how we interact with the city and our environment (Pardo and Jose 2010). From an environmental perspective, particularly for climate change impacts, the importance of understanding the dual impact of technological and behavioural changes to a city's mobility for both direct and indirect emissions is paramount This integrated perspective of both the behavioural/technological changes as well as the direct/indirect emissions is poorly documented in the research, and the 2020 report highlighted its importance (Dillman et al. 2020b).

Transportation plays a significant role not just in our daily lives, but also in global emissions. Globally transportation accounts for 20% of anthropogenic GHG emissions (Allen, et al. 2018). With an ever-increasing portion of the population living in an urban setting, how people move around in these cities and interact with them will play a crucial role in determining the GHG emissions associated with transport. According to the United Nations, in 2018 55% of the global population resided in cities, with an expected increase of another 13% by 2050, which will only be compounded by a growing global population (United Nations Department of Economic and Social Affairs 2019). Cities can act as strong macro-actors to shape transport systems. Cities can enact policies surrounding public transport, subsidies, and regulations, amongst other policy tools which can be used to impact and transform transport systems.

This is something Reykjavik has done, both historically and currently. From 1962-1983, the City of Reykjavik actively developed and promoted detached housing and "garden city" concepts, which were modern concepts at the time. This work led to high levels of suburbanization and sprawl (Sigurðsson 2017, Valsson 2003). The success of this work can be seen, where Reykjavik currently has some of the highest levels of car ownership in Europe, comparable to car-heavy U.S. cities such as Los Angeles and Phoenix. Recently, however, due to environmental concerns and concerns regarding car dependency, in the City of Reykjavik's current District Plan for 2010-2030, the city has begun to focus on sustainability, through a focus on densification, public transport, and electrification (City of Reykjavik 2014). The City has additionally published a Climate Policy which aims for the transport system to be emission-free by 2040. This work reflects the growing understanding of the importance of moving towards a net-zero GHG emission mobility system as well as the different approaches that can be used to try to attain this goal (City of Reykjavik 2016).

In trying to assess the potential decarbonization pathways there are two major inter-related conceptual frameworks we used to perform our research on the Reykjavik transport system. The first was developed by Creutzig et al. (2018), is the Avoid-Shift-Improve (ASI) framework, in which it is postulated that almost all actions that can be taken to decarbonize will fall into one of these strategies. Within the transport sector, the "Avoid" strategy describes the potential for avoiding the need for transport activities, decreasing travel demand, which can be linked to numerous actions such as the development of remote work, densification, low mobility behaviour, etc. The "Shift" strategy entails shifting travel demand to less emission intense modes, with larger shares of the population and travel demand shifting towards the use of public transport and active transport modes such as walking or biking. Finally, the "Improve" strategy considers all improvements to the different modal types, such as increased efficiency of combustion vehicles, or switching to electric vehicles and improving the powering electricity grid.

The second framework, produced by Holden et al. (2019), essentially takes Creutzig et al.'s (2018) framework and applies this higher level ASI framework and combined this thinking with the dominant developments within the transport sector to construct the "Three Grand Narratives", namely, "electromobility" (improve), "collective transport 2.0″ (shift), and "Low Mobility Societies" (avoid). The Electromobility narrative describes the transition to electrify transport systems, whether that be private vehicles or public transport. Collective transport 2.0 considers the modern development of shared transport in which both public transport and more modern mobility services such as Mobility-as-a-Service (MaaS) are taken into account. Lastly, the low mobility societies narrative describes society's potential transition through densification or behavioural changes empowered by digitalization to allow for decreased mobility.

Within our work, we used these frameworks to develop a two-axis system in which the Avoid/Low mobility and Shift/collective transport 2.0 and their interrelated aspects were merged to be considered as temporal changes to urban structure and lifestyles as one axis. The other axis took the Improve/electromobility aspects and used them to develop a technological development pathway.

Our research used this 2-axis framework to then develop six scenarios using the Story-and-Simulation (SAS) approach, much like in the 2020 Vegagerðin report, but with an improved axial framework. The SAS approach was formalized by Alcamo (2008) and is a scenario development method used to sync qualitative storylines and quantitative models and develop a consistency between the two.

The goal of performing this research was to understand:

1) What the effects of transforming the transport sector along a technological or behavioural development pathway were in terms of GHG emissions.

2) In following these pathways, what were the GHG direct and indirect impacts of doing so, particularly when considering the impact of electrification.

The goal of the study was to develop an understanding of the direct and indirect GHG implications of different technological and behavioural development pathways. The study showed that these pathways resulted in similar total GHG reductions by the end of the study period, however for largely different reasons. It is apparent from the study that an integrated approach is the approach that offers the greatest GHG reductions, however that quite radical changes would be needed to reach a decarbonized mobility sector. This approach provided novelty through the consideration of direct/indirect emissions as well as through the multi-faceted technological/behavioural perspective taken, where examples of such an approach were sparse to non-existent in the field of literature.

Methodology

Scenario development

When developing scenarios, often scenarios are developed using either a quantitative or qualitative approach. There are many methods in performing this in a siloed state. However, trying to simultaneously develop quantitative scenarios which are consistently described by qualitative scenarios presents an additional set of challenges. To bridge this gap, Alcamo (2008) formalized the SAS approach. The SAS development process can be seen in Figure 1.

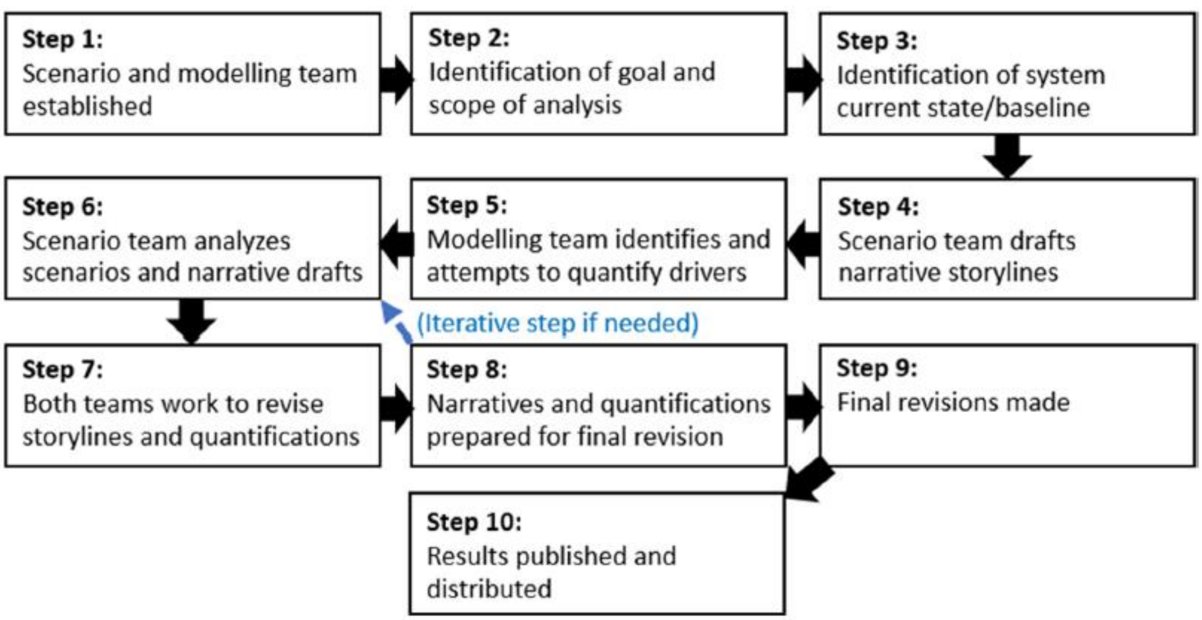


Figure 1. Steps in this research's SAS process. Modified from Alcamo (2008). (Figure taken from Dillman et al. (2021b))

Following Figure 1, the first three steps were to establish the research team and responsibilities, identify the goal and scope of the analysis, and finally to identify the current state of the system. The goal and scope of the analysis were to perform a direct and indirect GHG analysis of Reykjavik's transport system, taking only passenger transport into account, based on qualitative story lines describing developments along behavioural and technological development pathways, and integrated approaches of the two pathways. The current state and baseline of the system were developed according to travel behaviour surveys and public data provided by the city and state describing the transport system (Gallup 2017, Statistics Iceland 2020, Statistics Iceland 2020). For brevity, if more detail on the specific data used is sought, see Dillman et al. (2021b).

Following steps 4-6, storylines were developed according to the two-axis framework. A brief description of each scenario follows. For greater detail for each scenario, we again guide the reader to see Dillman et al. (2021b).

S1. Business-as-usual (BAU): The reference scenario in which the city's targets and policies remain, but no greater focus is placed on either technological or behavioural developments than is already existing under the current policies.

S2. Urban structural change + Lifestyle change (USC + LS): A significant effort is made to avoid travel demand through densification and reduce car ownership. An additional focus is placed on improving public transport and promoting active travel modes.

S3. Technological change (Tech): A strong support is shown for the adoption of EVs and MaaS is seen through the support of infrastructure and pro-EV policies which leads to higher car ownership but rapid electrification.

S4. Integrated Approach (IA): This combined approach takes the behavioural changes seen in S2 and combines it with the electrification efforts of S3.

S5. Worst case (WC): After the current policies expire which define the first years of the S1-BAU scenario, this scenario abandon's pro-environmental policies, seeing stagnation in EV transition rates and changes in environmentally beneficial travel behaviour.

S6. Radical change (RC): The potential impacts of climate change leads to significant pro-environmental policy changes emphasizing densification, even more rapid electrification, and significantly reduced car ownership, with the aim of rapidly decarbonizing.

Figure 2 is a visualization of these scenarios along the two-axis framework, where each scenario is included with brief descriptions of the socio-technological changes that are postulated for each scenario.

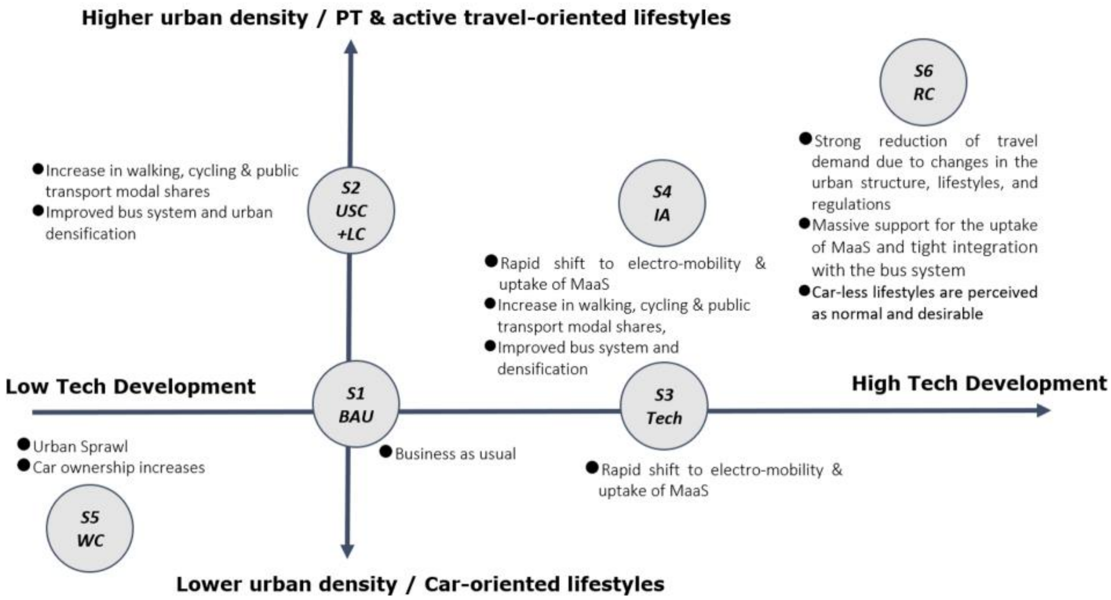


Figure 2. The 2-axis behavioral/urban form and technological changes framework. (Figure taken from Dillman et al. (2021b))

Performing Steps 5-7 of the SAS process, quantifications for each of the scenarios were developed using a variety of sources including the UniSysD_IS model (Shafiei, E.; B. Davidsdottir; J. Leaver; H. Stefansson; E. I. Asgeirsson 2015), other cities as examples, and travel demand (Gallup 2017). A full description of the development of the different key factors is described in detail in Dillman et al.'s (2021b) research, and a visualization of the key variables can be seen in Figure 3.

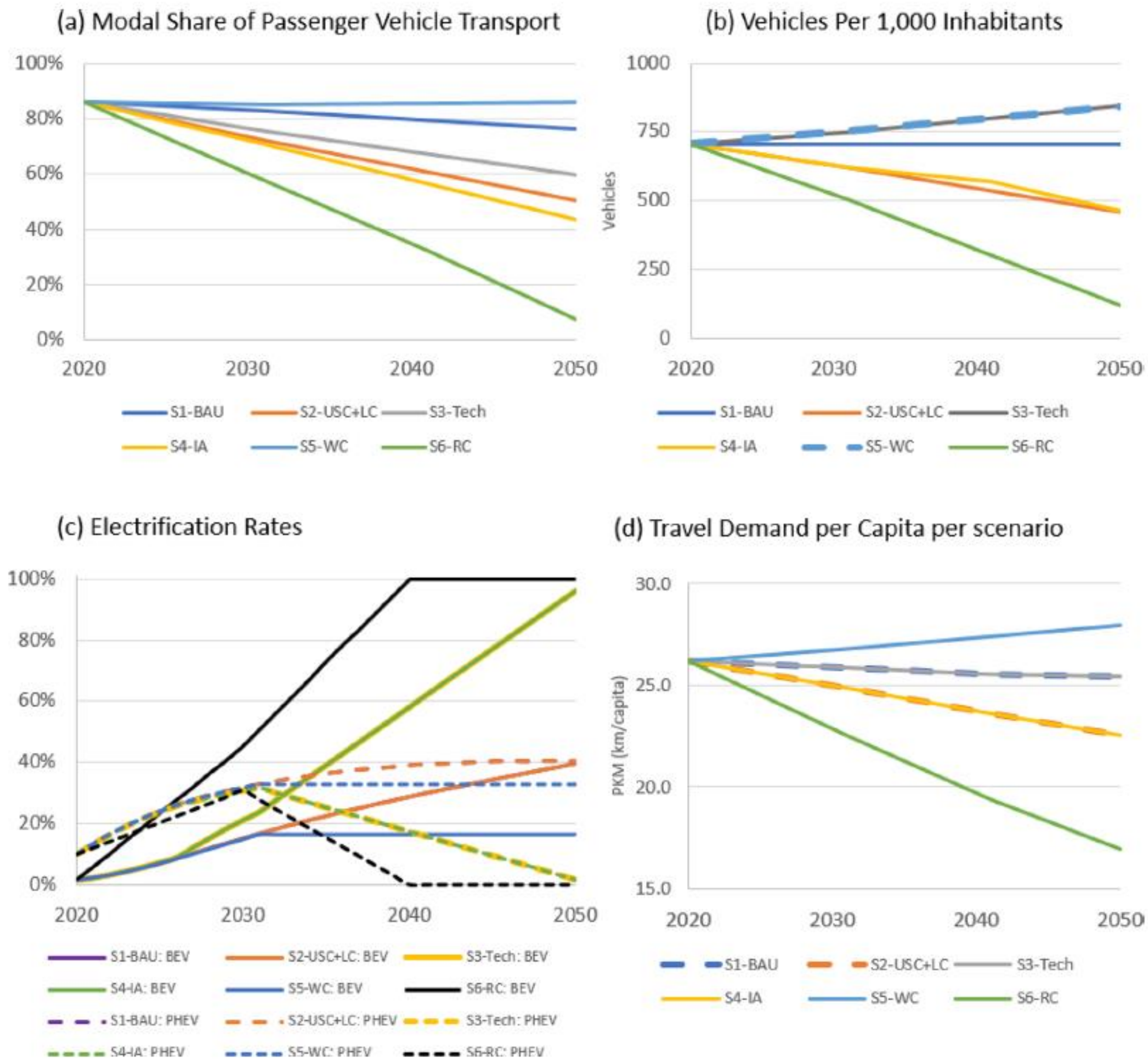


Figure 3. Key factors for each scenario (Image taken from Dillman et al. 2021b)

Figure 3a shows that the S6-RC scenario was assumed to take a strong momentum towards reducing the share of travel by passenger vehicles. Figure 3b shows the vehicle ownership rates, with the S4-IA and S2-USC+LC scenario leading to significantly lower rates than the other scenarios (with the exception of the radical change scenario). Figure 3c shows the electrification rates of the private fleet, where it can be seen that only the S6-RC scenario and the S3-Tech scenario reach 100% integration of EVs, by 2040 and 2050, respectively. Figure 3d shows the travel demand per capita, where the strong densification policies of the S6-RC scenario leads to significant decreases, where in second the S2-USC+LC and S4-IA approach follow similar rates of travel demand.

Modelling framework

A top-down approach was taken to calculate the GHG emissions from the transport sector. With an interest in understanding both the direct emissions from transport emissions as well as the indirect emissions embedded in the transport system, the total emissions from transport in year *t* can be represented such that:

$$C_{total}^{t} = C_{direct}^{t} + C_{indirect}^{t} \quad (1)$$

Where Ct(direct) represents the direct GHG emissions from tailpipe emissions and Ct(indirect) represents the indirect emissions associated with Well-to-Tank, vehicle production, disposal emissions.

In this research, Ct(direct) was calculated using the transport-focused Kaya Identity (Kaya 1989), a common approach taken due to its lack of redundancy (Luo, et al. 2017). Equation 2 displays this function, where *POP* represents the population being assessed, *TD* represents the daily travel demand per capita, *MSi* represents the modal share by distance of modal choice *i*, *UFi* represents the utility factor of modal choice, *FCi,j* represents the fleet composition of modal choice *i* by vehicle type *j*, and *EMFi,j* represents the Tank-to-Wheel (exhaust) emission factor of modal choice *i* by vehicle type *j*.

$$C_{direct}^{t} = POP * TD * MS_{i} * UF_{i} * FC_{i,j} * EMF_{i,j} \quad (2)$$

The indirect emissions from transport can be disaggregated by the Well-to-Tank emissions associated with fuel and/or electricity production, and the embedded emissions of vehicle production and disposal according to the number of vehicles purchased and disposed of each year. The indirect emissions associated with transport in year t can therefore be calculated as seen in equation 3.

$$C^t_{indirect} = C^t_{p\&d} + C^t_{WTT} \quad (3)$$

Disaggregating these variables, the emissions from production and disposal emissions $C^t_{P\&D}$ in year *t* can be estimated as shown in equation 4, where *Pi,j* represents the total new purchases of modal choice *i* by vehicle type *j*, *PEi,j* represents life cycle production emissions of modal choice *i* by vehicle type *j*, *Di,j* represents the total new purchases of modal choice *i* by vehicle type *j*, and *DEi,j* represents life cycle production emissions of modal choice *i* by vehicle type *j*. The life cycle production and disposal emissions for passenger vehicles were taken from Dillman et al.'s (2020a) vehicle LCA literature review.

$$C^t_{p\&d} = P_{i,j} * PE_{i,j} + D_{i,j} * DE_{i,j} \quad (4)$$

The indirect Well-to-Tank emissions C_{tWTT} can be similarly calculated as equation 5 using the Kaya identity as shown in equation 2, with the exception that instead of the emission factor being associated with the direct tailpipe emissions ($EMF_{TTW\ i,j,}$), the emission factor is instead associated with the WTT emissions associated with the life cycle emissions producing the energy source (fossil fuel or electricity) for modal choice i for the fuel usage of vehicle type j.

$$C^t_{WTT} = POP * TD * MS_i * UF_i * FC_{i,j} * EMF_{i,j} \quad (5)$$

With the calculations for both the indirect and direct emissions developed, a conceptual framework was then developed to understand how different decarbonization strategies can affect the GHG emission outcome within the analysis. This can be seen in Figure 4, where the equations for estimating the direct and indirect emissions are circled in orange, and how these variables are classified between a behavioural or technological change can be seen circled in blue and green, respectively. How a change in each variable (increase or decrease) would affect the GHG emission outcome (green for decrease, red for increase) is shown in the small graph associated with each variable. ASI strategies at three different levels are then provided to give context to the scenarios and to illustrate ASI actions that can be taken to affect the different variables.

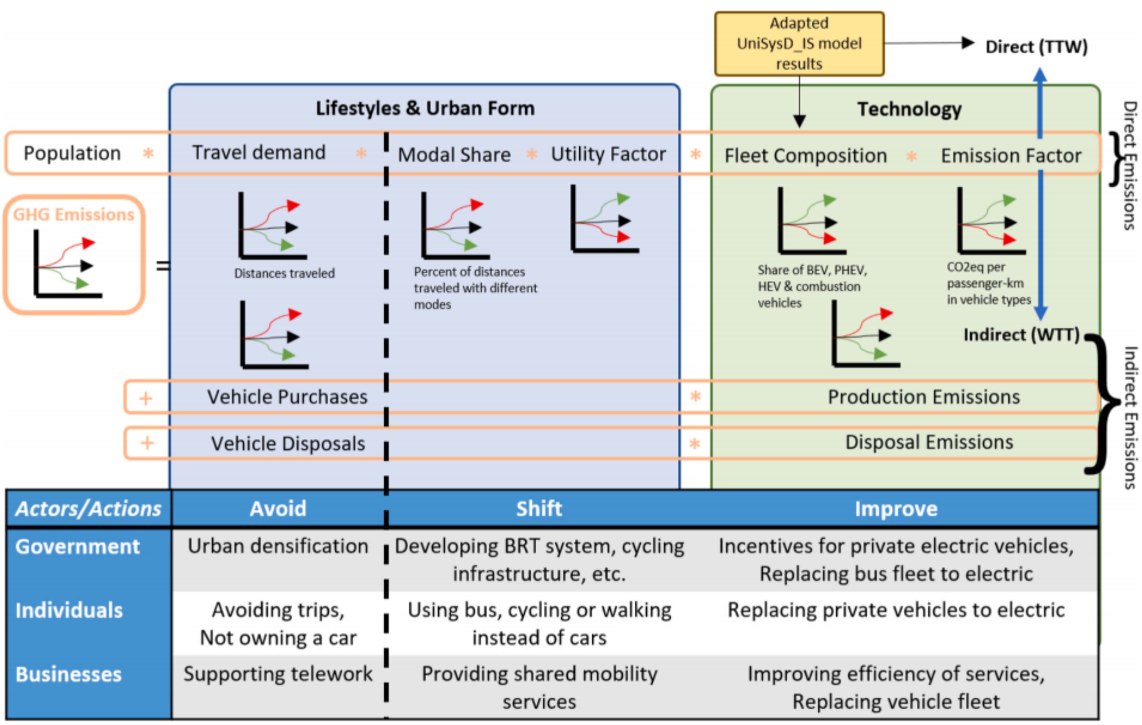


Figure 4 Model of modified Kaya identity direct GHG estimations for a transportation sector combined with indirect GHG emission calculation methodology. This model was integrated with Creutzig's et al. (2018) Avoid, Shift, Improve concept, and grouped into the 2-axis behavioural/urban form and technological changes framework used within this study. (Figure taken from Dillman et al. (2021b)).

Decomposition

The LDMI (Log Mean Divisia Index) method devised by Ang and Liu (2001) was used as the decomposition method of choice due to its prevalence in the research and its lack of redundancy. For brevity, the full decomposition is not shown here, but as the method is one of the major changes from the previous Vegagerðin report, the basis for the decomposition and the variable grouping for categorical decomposition can be seen in the following equations.

To perform the LDMI method, the direct and indirect emissions needed to be disaggregated, as seen in Equation 6, where the change in total emissions from year 0 to year *t* is the sum of changes in direct TTW to wheel emissions, emissions due to purchases, emissions due to disposals, and indirect emissions from year 0 to year *t.*

$$\Delta C_{total} = \Delta C_{direct} + \Delta C_{purchases} + \Delta C_{disposals} + \Delta C_{WTT} \tag{6}$$

Decomposing each subtotal, this same logic applies to the formulation of each of these subtotals according to their composing variables, as shown in equations 7a-7d.

$$\Delta C_{direct} = \Delta C_{pop} + \Delta C_{TD} + \Delta C_{MS} + \Delta C_{UF} + \Delta C_{FC} + \Delta C_{EMF(TTW)} \tag{7a}$$

$$\Delta C_{purchases} = \Delta C_{P} + \Delta C_{PE} \tag{7b}$$

$$\Delta C_{disposals} = \Delta C_{D} + \Delta C_{DE} \tag{7c}$$

$$\Delta C_{WTT} = \Delta C_{pop} + \Delta C_{TD} + \Delta C_{MS} + \Delta C_{UF} + \Delta C_{FC} + \Delta C_{EMF(WTT)} \tag{7d}$$

These variables were then grouped to derive to develop key scenario drivers to see the effects of changing population, technology, modal share, fleet size, and transport demand, as shown in equations 8a-8b.

$$\Delta C_{population} = \Delta C_{pop(direct)} + \Delta C_{pop(WTT)} \tag{8a}$$

$$\Delta C_{technology} = \Delta C_{FC(direct)} + \Delta C_{EMF(direct)} + \Delta C_{FC(WTT)} + \Delta C_{EMF(WTT)} + \Delta C_{PE} + \Delta C_{DE} \tag{8b}$$

$$\Delta C_{Modal\ Share} = \Delta C_{MS(direct)} + \Delta C_{MS(WTT)} \tag{8c}$$

$$\Delta C_{Fleet\ Size} = \Delta C_{P} + \Delta C_{D} \tag{8d}$$

$$\Delta C_{TD} = \Delta C_{TD(direct)} + \Delta C_{TD(WTT)} \quad (8e)$$

Results

Following the procedure and using the framework described in the methodology section, the direct and indirect GHG emissions for each scenario were calculated. Figure 5 displays the estimated annual total GHG emissions associated with each scenario.

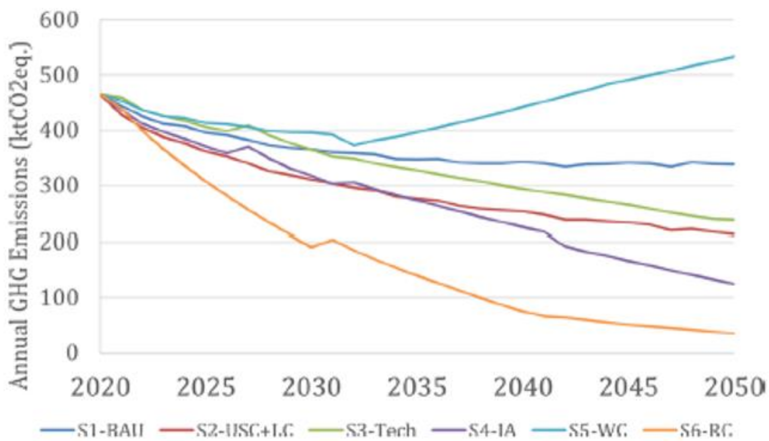


Figure 5. Annual total GHG emissions per scenario (image taken from Dillman et al. (2021b))

It can be seen that as expected, the results of the radical change scenario led to the greatest decrease in emissions, and the worst-case scenario led to the greatest decrease in emissions in 2050. More interestingly, it can be seen that the S2-USC+LC and S3-Tech scenarios result in similar levels of decarbonization though the pathway to get there was different, with the S3-Tech scenario leading to greater annual emissions in all years and therefore higher cumulative emissions.

The reasons for the decrease in emissions in these two scenarios were quite different, however. Figure 6a shows the annual direct GHG emissions for each scenario, and it illustrates that particularly in the last decade of the study that due to the integration of EVs, the S3-Tech saw significantly lower direct GHG emissions than the S2-USC+LC scenario, reaching nearly zero by 2050. However, Figure 6b shows the benefits of the S2-USC+LC (and especially the S6-RC) scenario's reduced vehicle ownership rates, where the indirect emissions associated with maintaining a larger vehicle fleet size can be seen. This relationship is enhanced by EVs greater embodied emissions than ICEVs (Dillman et al., 2020a), which leads the S3-tech scenario to at times have even higher indirect emissions than the S5-WC scenario.

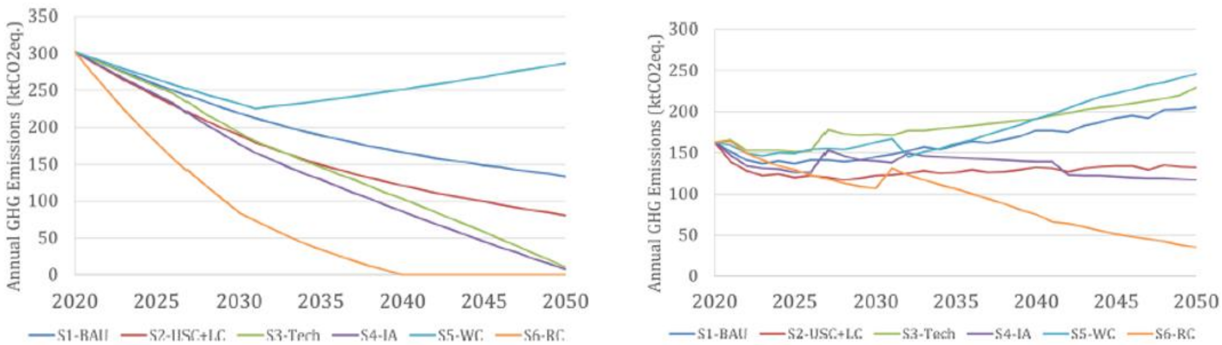


Figure 6(a) Annual direct GHG emissions and (b) Annual indirect GHG emissions

The effect of the different development pathways on the resulting emissions can be seen in greater detail in the results of the decomposition. Figure 7 shows the decomposition results, and it can be seen in Figure 7c that relative to the initial year, the S3-Tech scenario actually saw an increase in emissions due to the growing fleet size and associated embodied emissions. However, the emissions decrease benefits, particularly those from the technological changes led to deeper rates of decarbonization than the S2-USC+LC scenario.

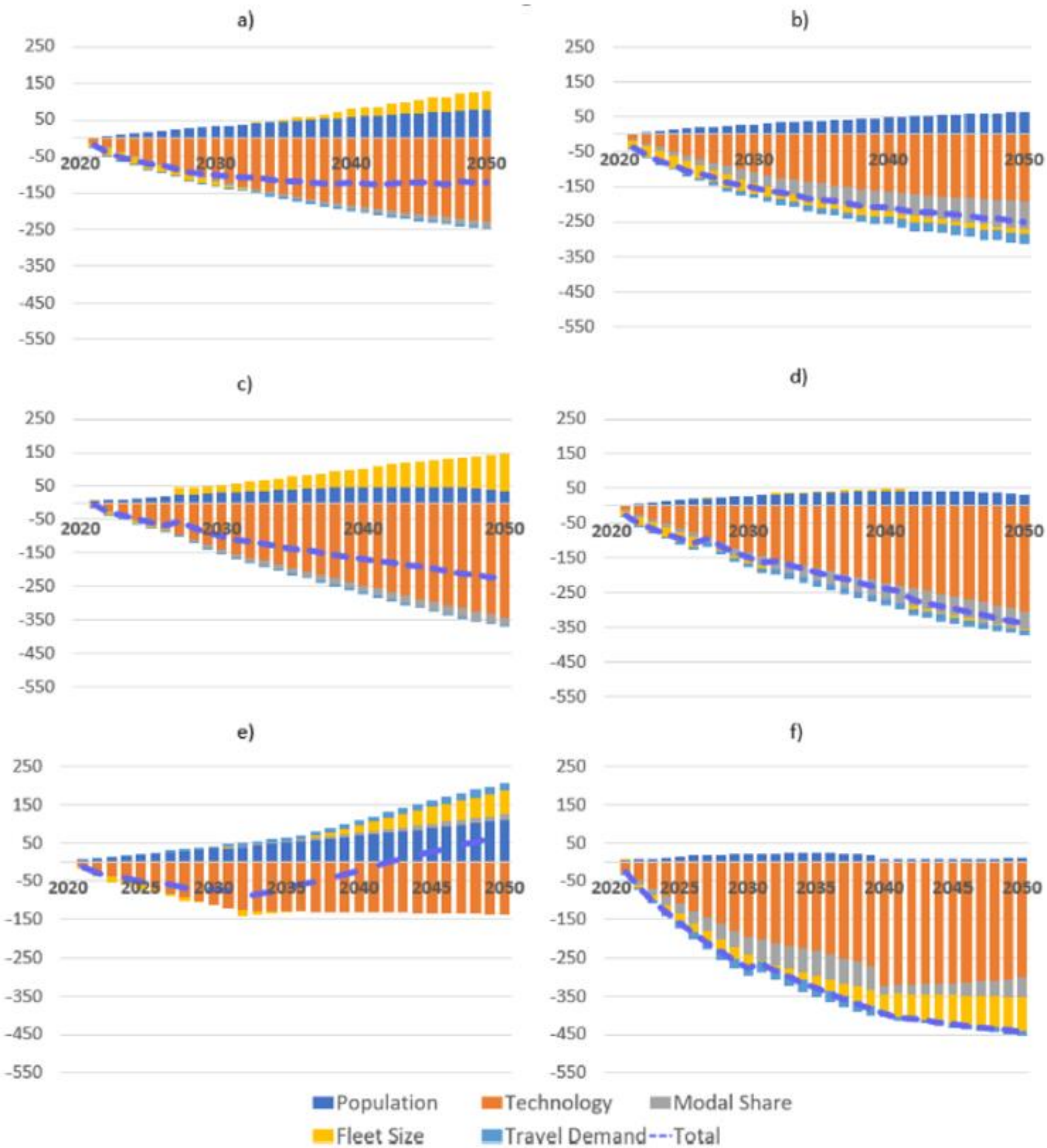


Figure 7. Decomposition analysis from 2020-2050 for scenarios a) S1-BAU b) S2-USC+LC c) S3-Tech d) S4-IA e) S5-WC f) S6-RC

For greater detail regarding the results of the analysis, including cumulative greenhouse gas emissions from each scenario, we again guide the reader to Dillman et al.'s (2021b) work.

Discussion and Conclusions

From the results, it can be seen that an isolated single-axis technological or behavioural approach will not lead to deep levels of decarbonization. Though, this is due to different reasons, where the great gains seen in the decrease in direct emissions in the S3-Tech scenario were offset by the high indirect emissions associated with transitioning to and maintaining a large EV car fleet. This contrasts to the S2-USC+LC scenario where behavioural changes led to decreased travel demand, reduced vehicle ownership, and personal vehicle modal share, however, there were still direct emissions associated with this approach due to the lack of full electrification. Rather, strategies from all of the ASI and three grand narratives should be incorporated to develop an integrated approach, where the benefits of electrification, alternative transport modes, and densification can be maximized. This was seen most clearly in the S6-RC scenario, where total GHG emissions decreased by almost 93% by 2050 compared to the 2020 baseline.

Reykjavik provides an interesting case study for a decarbonization study considering the benefits of technological and behavioural development pathways such as this one due to the city's highly decarbonized electricity grid and political interest in decarbonizing (City of Reykjavik 2016, Iceland Ministry for the Environment and Natural Resources 2018). While Reykjavik may not provide the most generalizable case study due to the highly decarbonized electric grid, it does however provide a good representation of the desired state of many regions in terms of reaching a decarbonized electrical grid. The E.U. Commission and many countries individually have identified EVs, paired with rapid decarbonization of the electrical grid, to be a key solution in terms of decarbonizing the difficult to address transport sector (European Commission 2016). This study however has shown that even in an already highly decarbonized grid with a policy focus on EV's, with the embodied emissions required to transition a large vehicle fleet and the direct emissions that will occur until the transition, the decarbonization is too slow to meet deep levels of decarbonization.

In fact, in reference to Reykjavik city's political interest in decarbonizing, in the city's current Climate Policy, the city has set a target of reaching zero direct emissions from the transport sector by 2040. Yet, only in the radical change scenario was zero direct emissions reached, and this scenario required a significantly more progressive set of policies than currently exist in order to reach this point. These conclusions are supported by results from Asgeirsson et al. (2019) and Shafiei et al. (2019), who additionally found that under the current support for electrification the city was highly unlikely to achieve the city's 2040 goal. Exacerbating the issue is that the City of Reykjavik's climate policy is only considering the direct (TTW) emissions in its policy and not the indirect emissions associated with vehicle production, disposal and the indirect WTT emissions associated with transport. Fleet size is not mentioned in the policy and as the results of this study show, the indirect emissions associated with a large fleet size and maintaining such a fleet, particularly one with a high level of EV integration, can lead to significant indirect-direct emissions trade-offs which can lead to marginal GHG reductions. While it is logical for a city to focus on the direct emissions occurring within the region's jurisdiction and there are additional benefits to working to decrease exhaust emissions (such as reduced PM emissions), when it comes to climate policy, GHG emissions are a global issue and the impacts of embodied emissions should not be forgotten or omitted.

Thus, through the development of the 2-axis behavioural and technological pathways and the associated GHG framework this study has helped to highlight some of the strategic differences between the two approaches and helped to quantify their impacts. The results have shown that it will require strategies from both demand and supply sides of the ASI/Three Grand Narrative frameworks in order to decarbonize, and if the city's goals are to be met, and even stronger more forward-thing policies will be required in order to reach deep levels of decarbonization (Holden, et al. 2019, Creutzig, et al. 2018).

Chapter 2: Optimization framework for city transport decarbonization

Background

When developing the framework for Chapter 1, the authors' saw the potential to expand the framework and create one that could optimize this framework for any city, and perhaps provide optimal pathways for each city, or guide a certain city, for example, Reykjavik, in its climate mitigation work at any point in the future after first following one pathway. Thus, as an expansion of Chapter 1's behavioural and technological approaches, we introduce Chapter 2 as essentially a mini-chapter in which this optimization framework is presented as an additional concept but has one that has not yet been implemented.

Introduction

With the looming climate crisis, the decarbonization of the global economy is a key focus of many of the world's leading countries. The transportation sector plays a key role in the functioning of the global economy, the emittance of greenhouse gas (GHG) emissions, and in our daily lives. Thus, many cities are considering how to best decarbonize their urban mobility systems. This was the basis of the scenario work described in Chapter 1 and in the Modelling section, how the direct and indirect GHG associated with an urban mobility system are derived is explained.

This research hypothesizes that each urban mobility system has an optimal decarbonization pathway according to the initial conditions of the system (in terms of the initial value of each variable) as well as the maximum potential for each case to decrease each variable. For example, in Chapter 1, an entirely behavioural approach and an entirely technological approach was taken for the Reykjavik case study. An integrated approach was taken as a combination of these two approaches. However, what if the optimal path is not one of these paths but another entirely? And what if there is only a limited amount of achievement that can be made on each front due to costs or political will or another similar factor? That is what this research aims to answer, where for example if Reykjavik had to chose either a technological approach, a behavioural approach, or some mix of the two, this work could assist in determining the optimal path that would lead to the least amount of GHG emissions according to what the city sees as possible. This research provides novelty in that the solution both provides an optimal decarbonization path considering both direct/indirect GHG emissions and behavioural/technological perspectives, which has been lacking in the literature (Dillman et al., 2021b). Even further, through an adaptable implementation, it could then rapidly perform this same analysis for any city provided reliable data could be acquired. This could prove to valuable tool in assisting cities in developing more effective and realistic climate policies.

Decarbonization Optimization

Assuming this modelling and framework is understood, an optimization script in which the cumulative GHG emissions from the urban mobility sector are minimized can be written (or designed). The amount to which each dependent variable can change in each period will be provided. The decision variable will thus be if a limited effort can be made to decrease each variable, which dependent variables should be prioritized to minimize total cumulative GHG emissions of the transport sector. The problem can be described as follows:

$$min_n = C_{total} \ where \ C_{total} = \sum_t \sum_i \sum_j POPt * TDt * MSt,i * UFt,i * FCt,i,j * EMF(TTW)t,i,j + Pt,i,j * PEt,i,j + Dt,i,j * DEt,i,j + POPt * TDt * MSt,i * UFt,i * EMF(WTT)t,i,j$$

s.t.

$TD_t = TD_{t-1} - TD_{t-1} * pTD_t * nTD_t$

$MS_t = MS_{t-1} - MS_{t-1} * pMS_t * nMS_t$

$UF_t = UF_{t-1} - UF_{t-1} * pUF_t * nUF_t$

……

$EMF(WTT)_t = EMF(WTT)_{t-1} - EMF(WTT)_{t-1} * pEMF(WTT)_t * nEMF(WTT)_t$

$nTD_t + nMS_t + nUF_t + \ldots\ldots nEMF(WTT)_t \leq N$

$0 \leq nTD_t , nMS_t , nUF_t ,\ldots\ldots, nEMF(WTT)_t \leq 1$

Where X represents the dimensions presented, *n*X represent the political will from 0-100% towards a specific dimension, and *N* represents the total political will available from 0 to the total number of *n*X variables, where the smaller the value of *N*, the lower total political will available to make changes.

Givens:
pX_t for all *t* and all X will be provided
X_0 for all X will be provided

Current Status

This model is currently in development, though due to the advanced nature of the project in which the solution space, if not correctly applied, would be computationally infeasible, a tiered strategy is being implemented. The tiered strategy is such that first a dynamic programming approach will be taken, where unrealistic alternatives are removed and the problem is simplified such that a “brute force” approach is applied so that all solutions are calculated and the minimum of all calculations will be taken. If this task proves to be infeasible a quadratic optimization approach will be attempted. Both of these approaches will be implemented using python.

Potential Applications

While the implementation of this optimization is not a trivial task, the output of developing this model could be useful for many applications. It would allow for rapid decarbonization analysis of different cities according to different initial conditions, helping guide cities with different per capita travel demand, EV integration, modal shares, and electrical grid intensities in finding the optimal decarbonization route. Once developed it could additionally potentially group cities according to their different initial conditions such that a framework similar to Kennedy et al.'s (2013) approach, shown in Figure 8, could be made.

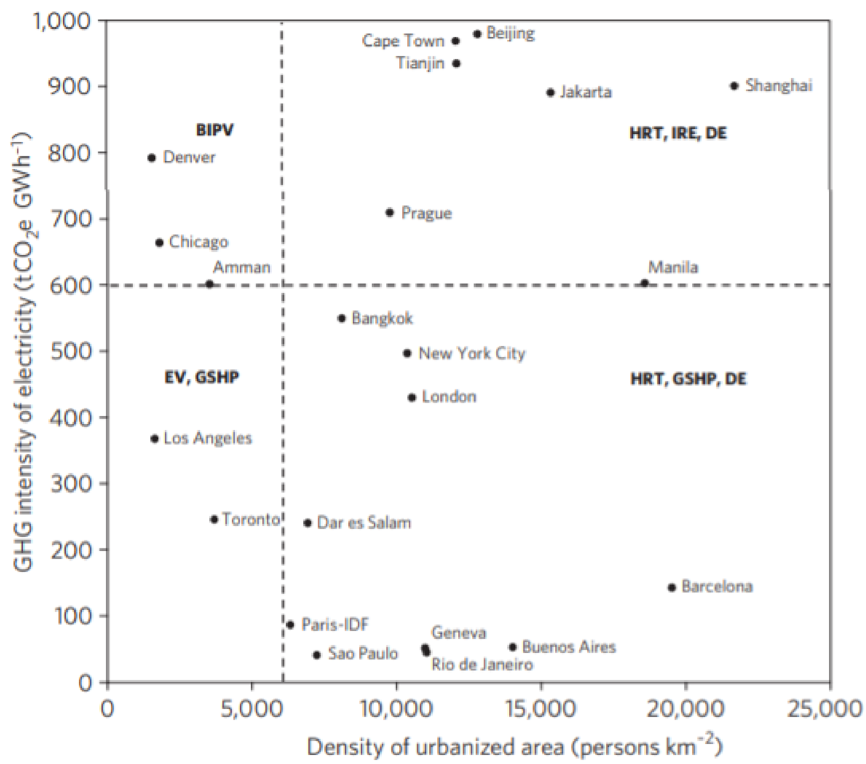


Figure 8. Examples of low-carbon infrastructure strategies tailored to different cities. Prioritization according to urban population density and the average GHG intensity of existing electricity supply. EV, electric vehicle; GSHP, ground-source heat pumps; BIPV, building integrated photovoltaics; HRT, heavy rapid transit; IRE, import renewable energy; DE, district energy. (Taken from Kennedy et al., 2014)

Chapter 3: Energy demand impact of EV integration on Reykjavik's electrical system

Background

The results of this paper were developed in partnership with a Rannís funded project which incorporated research from both the University of Iceland as well as the University of Reykjavik. The result of this partnership was an academic publication in the Utilities Policy journal, with the citation as seen below:

Dillman, K. J., Fazeli, R., Shafiei, E., Jónsson, J. Ö. G., Haraldsson, H. V., & Davíðsdóttir, B. (2021). Spatiotemporal analysis of the impact of electric vehicle integration on Reykjavik's electrical system at the city and distribution system level. Utilities Policy, 68, 101145.

The results in this chapter are based on this publication and there are some relations to work completed in Chapter 1. Within both of these papers, the UniSysD_IS model (Shafiei, E.; B. Davidsdottir; J. Leaver; H. Stefansson; E. I. Asgeirsson 2015) was used fully or adapted in terms of EV integration rates into the passenger vehicle fleet. While the EV integration rates in some pathways are similar, the decarbonization work in chapter one saw significant adaptations of the UniSysD_IS model. Therefore, while some generalizations of the results can be adapted to the decarbonization work, we would like to steer the reader away from making a direct layering of the two works as if the scenarios in each are equivalent, where the scenarios presented in this chapter are based on tax-policies considered by the Icelandic government and not from the Story-and-Simulation approach seen in Chapter 1.

Introduction

As mentioned in previous chapters, many, including the European Commission, the Icelandic Government, and the Reykjavik City government, consider EVs to be a prominent solution to decarbonize the transport sector (City of Reykjavik 2016, European Commission 2016, Iceland Ministry for the Environment and Natural Resources 2018). The benefit of EVs and their potential to lead to emissions reductions when operating in a location with low carbon intensity electricity has been documented (Dillman et al., 2020a), and with Iceland's use of almost entirely renewable energy sources for electricity production, there are few doubts that this would provide emission reduction benefits (at least for direct emissions). This integration of EVs poses several other questions, however, and the questions this chapter seeks to answer are:

1) Will the introduction of high energy-consuming vehicles impact that electricity grid? If so, when and where?
2) How will this change according to different rates of EV integration? How would different policy decisions impact this demand?

Methodology

To answer these questions, an understanding of the additional electrical demand presented by the integration of EVs needed to be assessed, at different rates of uptake according to different policy scenarios. We thus developed a process to extract these results which can be seen in Figure 9.

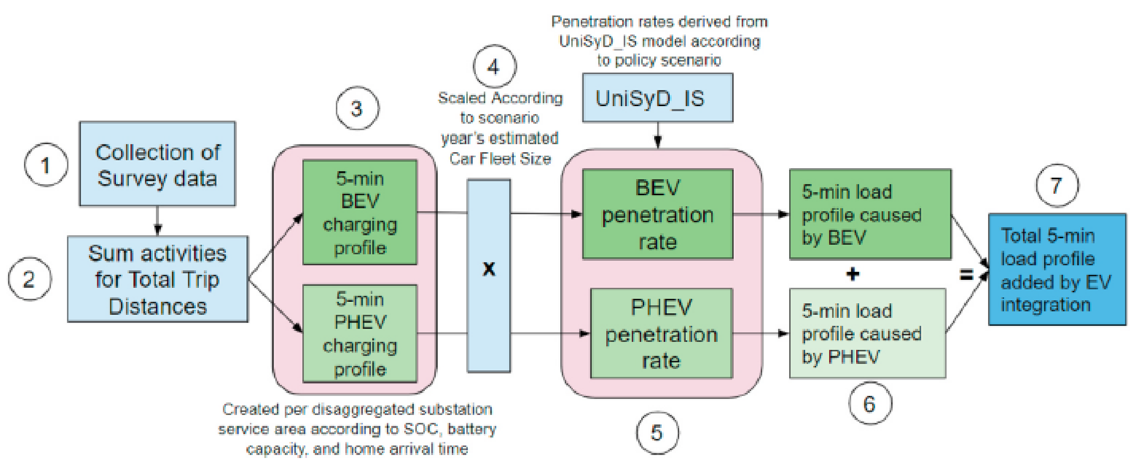


Figure 9. Illustration of the research process (Image taken from Dillman et al., 2021a).

This diagram illustrates the process followed within this analysis, where the first step requires a collection of survey data to understand the Reykjavik inhabitants' mobility patterns to develop a travel behaviour model which allows for the proceeding steps. A Gallup survey of the Reykjavik population's travel behaviour was used within this study to complete this first step. The Gallup survey was a recording of almost 24,000 travel activities from over 6,000 respondents, which provided a set of origin and destinations for each activity, as well as some descriptive data such as travel mode and the reason for the trip. Figure 10 illustrates a first assessment of the travel activities, where Figure 10b highlights Reykjavik's car dependence, where nearly 87% of the distance travelled by Reykjavik inhabitants was done by car.

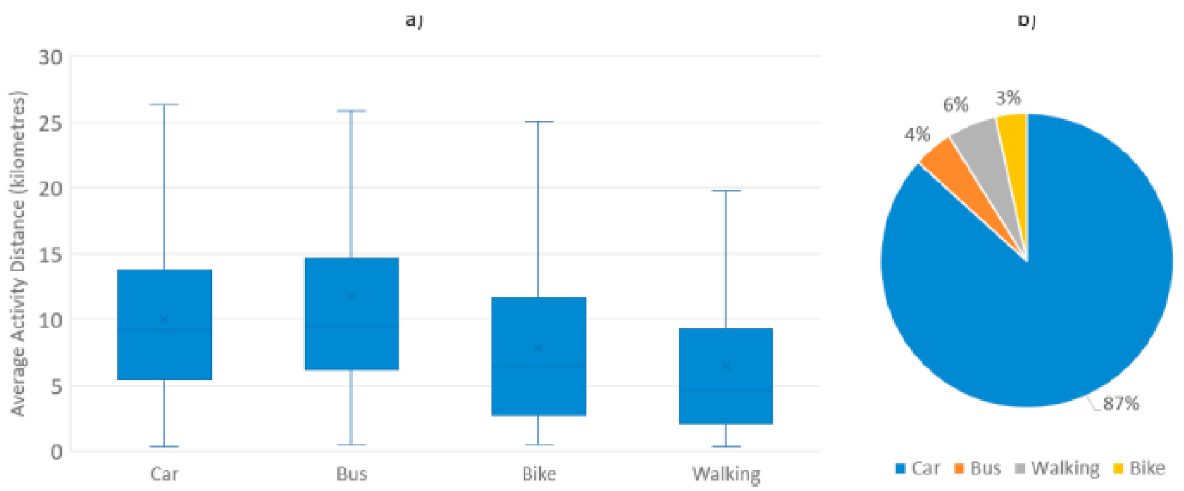


Figure 10. (a) Box and Whisker plot of the travel survey data (without outliers) per travel activity; (b) Percentage of total distance travelled by travel mode (Image taken from Dillman et al., 2021a).

Following the second step in the process, all activities were summed into "trips", where a trip was defined by a front door-to-front door activity chain, and all distance travelled by the activity chain was considered to be the distance of the trip. This summing resulted in nearly 7,500 trips being taken, where the breakdown of the trip distance can be seen in Figure 11.

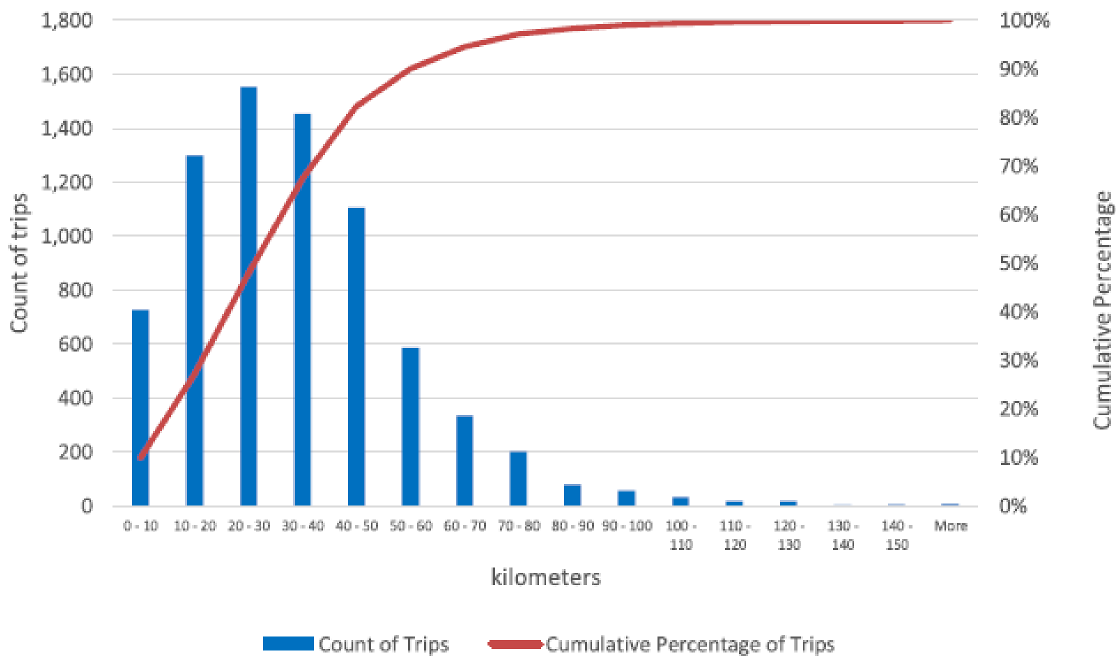


Figure 11. Histogram of trip distances in 10 km bins, with the line curve showing the cumulative percentage of all trips taken (Image taken from Dillman et al., 2021a).

Figure 11 shows that 82% of the trips taken were less than 50 km, and 99% of them less than 100 km. It can be seen that most trips occurred in the 10-50 km range. This distance driven per trip is an important factor when considering the amount of energy that will be consumed by an EV or Plug-in Hybrid Electric Vehicle (PHEV) due to the trip. Breaking down the day into 288 5-minute intervals as seen in other travel behaviour studies (Jiang, Ferreira and González 2012, Pasaoglu, et al. 2013), following the flow diagram, the next step was then to develop the charging profile for an associated BEV or PHEV. The battery capacity per BEV and PHEV was assumed to be 60 kW and 8kW, respectively. The EV home charging rate was assumed to be 7.2 KW. Using these assumptions and the trip distances per respondents, broken up by substation service area, the 5-min charging profile for each vehicle type was developed, shown in Figure 12.

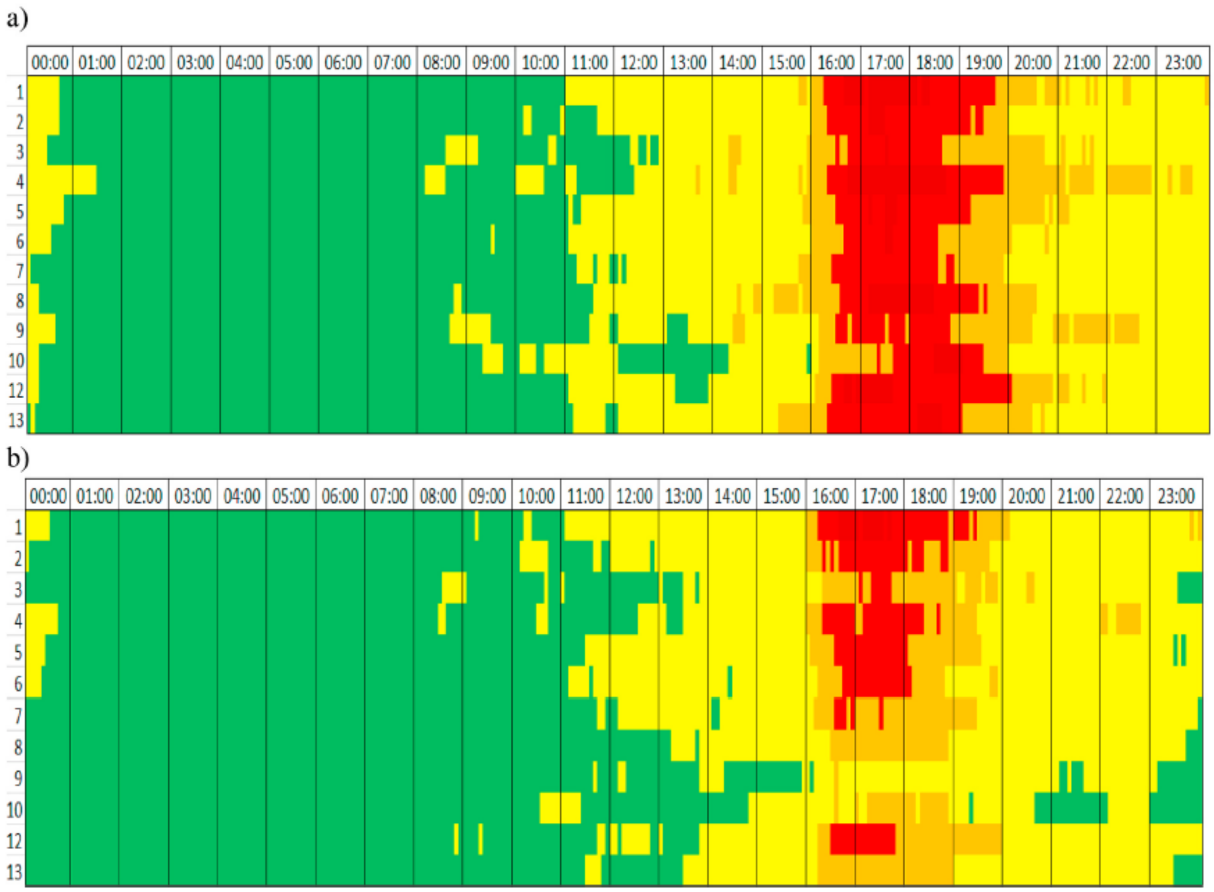


Figure 12. 5-min charging profile heat map of charging overlap (coincidence factor) of a BEV (a) and PHEV (b) car fleet by substation service area, where the substation service areas are labelled on the vertical axis. (Image taken from Dillman et al., 2021a)

This charging profile describes a state in which if all survey respondents were to own either an EV or PHEV, and went about their daily trips and returned home and immediately began charging their vehicles, according to the energy consumed by their trip, how much overlap of charging would occur in that substation's population. The colour scale represents the degree of overlap occurring, where due to the travel behaviour where many people arrive home after work between 16:00-19:00, this time period sees the highest levels of overlap. The colour scale is bokeh down as follows: Green between 0 and 2%, yellow between 2 and 10%, orange between 10 and 20%, lighter red between 20 and 30%, deeper red all values greater than 30%, where the maximum overlap for BEVs was 44% and for PHEVs 36%.

Following Figure 9, scaling this overlap to the size of the EV fleet, disaggregated by substation service area according to the estimated population, the next step was then to generate the annual estimates of EV and PHEV integration into the car fleet. Four EV integration scenarios were developed to model the impact of different policy scenarios on EV integration and the associated grid impacts. The four scenarios, namely, the business as usual (BAU), Proposal, Premium, and Banning scenarios can be seen with their associated description and tax policies in Table 1.

Table 1. Definition of Scenarios (Shafiei, et al. 2019)

Scenarios	Tax on fuels & vehicle use	Tax on vehicle purchase
BAU	Current fuel & vehicle usage tax	Equal VAT rates (24%) + current excise duty
Proposal	New tax proposal assumptions	New excise tax proposal assumptions
Premium	New tax proposal assumptions	New tax proposal assumptions + VAT exemption for BEVs after 2020
Banning	New tax proposal	New tax proposal assumptions + VAT exemption for BEVs after 2020 + Ban on the new sales of ICEV and HEV from 2030

The excise duty tax proposal mentioned in Table 1 can be seen in Figure 13, where it can be seen that excise tax would change from a step-wise function of the emission factor to a linear increase of the vehicle's direct emission factor.

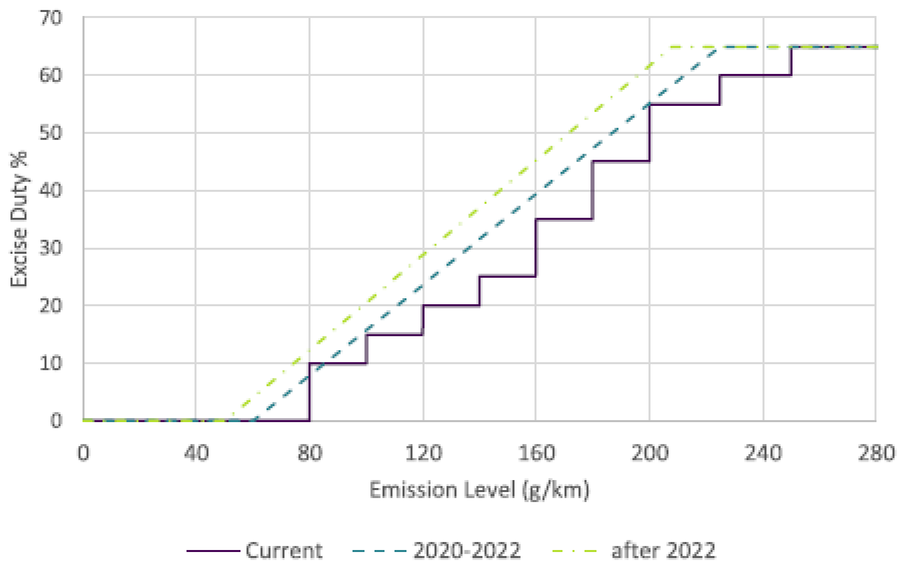


Figure 13. Comparison of the excise tax rate in the current and the new tax reform proposal based on registered CO2 emissions for light vehicles (Alþingi 1993, Icelandic Ministry of Finance and Economic Affairs 2018).

These scenarios and their associated tax structures were then used to describe the EV and PHEV integration rates from 2020-2050. With these values, the final steps of the analysis could then be completed where the 5-minute load for BEVs and PHEVs could be summed to get the total load per substation per scenario.

Results

With the process completed, a temporal and spatial peak load demand curve was estimated for Reykjavik passenger transport sector for each of the four scenarios considered. The peak load was then placed on top of Reykjavik's January average peak load, the month with the highest load, to test when Reykjavik's electric system may face levels of demand surpassing the system's capacity, and when this may occur temporally. This summed total load was mapped per substation, and the cost of the upgrades required to support these potential peak loads per scenario was then estimated over time, as well as the net present value of these upgrades.

Figure 14 shows the estimated peak load, defined as the sum of Reykjavik's January peak load demand, increased proportionally to expected population increase during the study period, and the additional load added by the integration of EVs and necessary charging, during each decade of the study period. It can be seen the BAU leads to the smallest increase in peak load, though it still sees a significant peak load because even in the BAU case, a significant rise in EV and PHEV ownership is expected to occur. The Premium and Banning scenario see the highest peak loads, and in the Ban scenario, it can be seen the load curves sees a significant jump once the sale of new ICEVs becomes prohibited.

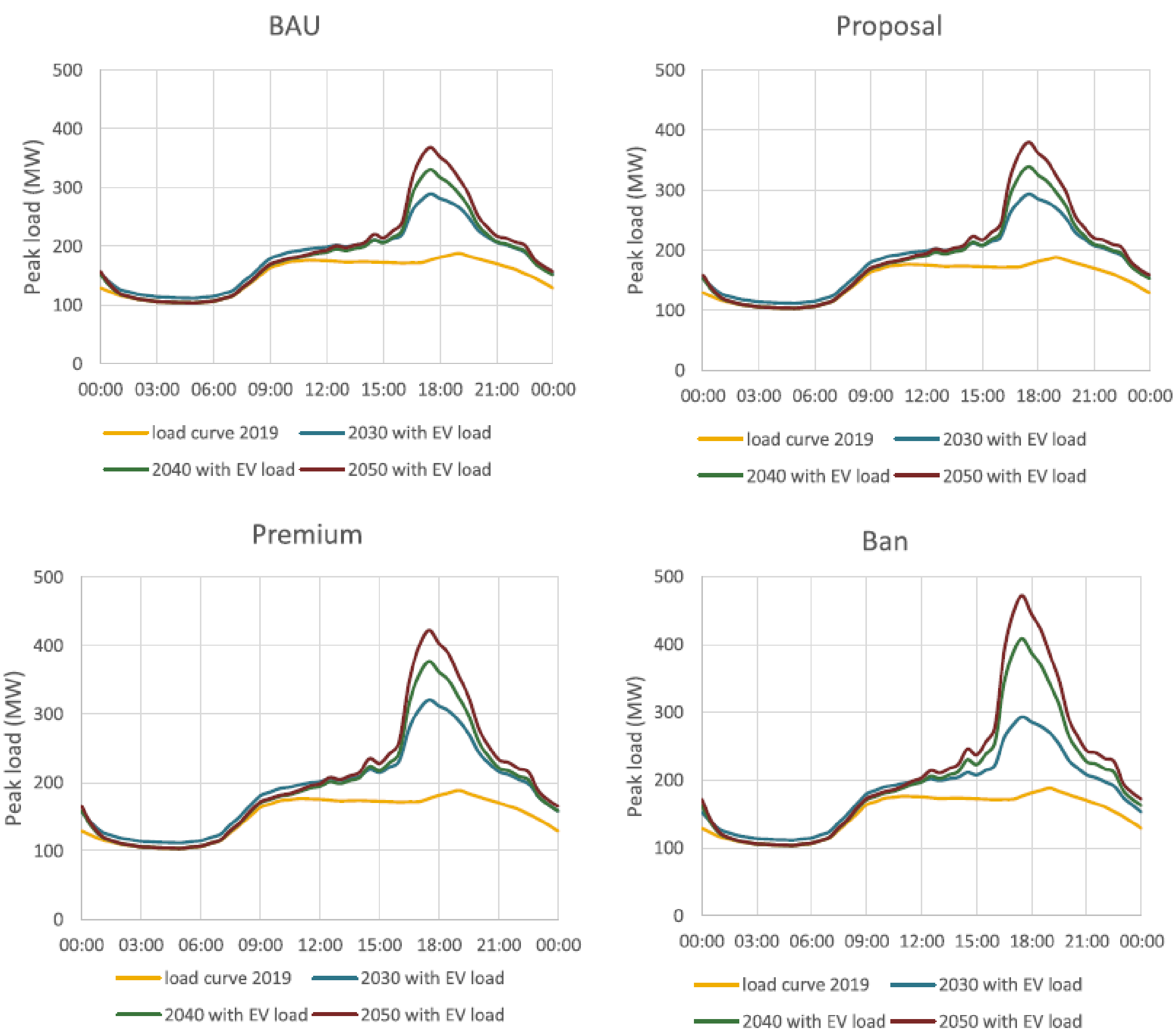


Figure 14. Reykjavik average January weekday peak load profile with added EV peak load profile (Image taken from Dillman at al., 2021a)

The cost implications of this scenario were estimated using N - 1 analysis, a common analysis within electrical engineering that assesses the system's capability to maintain itself if a single component fails. If the system would not be able to reliably operate with the component missing, it is at this time that it was considered an upgrade would be required. Thus, mapping the load curves from Figure 14 across Reykjavik's electrical system, the cost of each policy scenario can be seen in Figure 15.

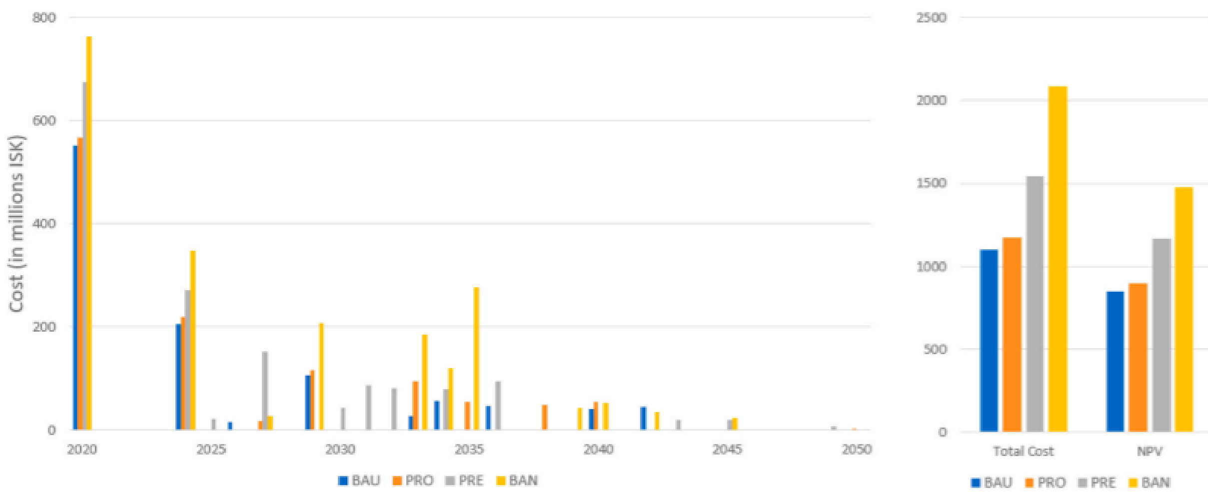


Figure 15. (a) Annual estimated component costs per scenario and (b) total cost from 2020 to 2050 in total and NPV.

It can be seen that each progressively more EV policy will lead to increased costs, both in total as well as in the NPV. This is logical as the greater the number of EVs, without policies guiding any behaviour change, a greater electrical load will be placed on the system, and this will inevitably lead to the need to expand the electrical system. It is worth noting that this chapter is a concise version of the published article by Dillman et al. (2021a), and for brevity's sake we refer the reader to this research.

Discussion

With both Reykjavik and the E.U. acknowledging the role EVs will have in decarbonizing the transport sector, the literature has called for greater research into the impact EVs could have at the city and distribution level (Daina, Sivakumar and W.Polak 2017). The results of this study highlight the importance of exactly this topic, where the Dillman et al. (2021a) states:

> “...the maximum peak load for Reykjavik’s electrical system was estimated to increase by 43–58%, 55–92%, and 67–114% in the best- and worst-case scenarios for 2030, 2040, and 2050, respectively. At the distribution level, it was shown that a single substation (Substation 5) was expected to receive over 25% of the load added by EV integration. It was estimated that more than 4 MW were added to a single sub-station (Substation 5) in 2019. This load on Substation 5 was estimated to increase to between 50 and 78 MW by 2050, depending on the policy scenario under consideration. It is estimated that this additional peak load on Substation 5 added due to EV charging, could increase the maximum peak load by 29–39%, 47–76%, and 58–95% in the best- and worst-case scenarios for 2030, 2040, and 2050, respectively.”

This impact to both the electrical grid as a whole and to Substation 5 in this case specifically highlights the importance of considering the impact of promoting EVs as well as the need to address this issue, both to reduce costs to the DSO and to the consumer.

The logical next question is to ask how this can be addressed. Often cited in the literature is to either promote education on the topic and encourage EV owners to charge at night when the peak load is low, or to develop push/pull policies surrounding consumer costs (Kang and Recker 2009, Dong, Liu and Lin 2014, Kim 2019) These push/pull policies could come from either the government in support of the implementation of home smart chargers which would delay the charging of an EV until later hours when the peak load is lower or from energy suppliers who could increase the price of electricity when the load is highest. As Iceland has some of the lowest electricity prices in the world, it may prove difficult to alter behaviour through pricing mechanisms on the electricity without making drastic increases (The World Bank 2017). Therefore, it is likely that the charging behaviour in Reykjavik may be more easily influenced through educational and pro-smart charging policies.

It is worth noting that there were some limitations to the approach taken within the study, and in particular that this study only considered home charging within the analysis. This home charging approach likely does not reflect reality in that not everyone will charge always when they come home, and may charge elsewhere, such as at work. The study acknowledges this, but also considered that this home charging approach was not an attempt to model reality, but instead to model the plausible worst-case scenario which could logically occur that the grid would need to be able to support, since the goal of the study was consider where and when the electrical grid could be put at stress risk due to the integration of EVs. We thus think the approach has served its purpose. The study recommends that while EVs certainly present the potential to decarbonize the passenger transport sector, and if the government wants to accelerate this transition, the government and grid operators need to prepare for the associated loads that will inevitably come with the transition.

Chapter 4: Framework for a mobility-focused sustainable consumption corridor

Background

One aim of this project was to develop a set of potential indicators to monitor the work towards a SUMS in Reykjavik. In the very early stages of this work, it became evident that there is an important shortcoming in the vast majority of all suggested such indicators, namely that they lacked any thresholds to show at which state a system actually could be called sustainable. Moreover, we found little work being done on defining what it would mean for an urban mobility system to be sustainable. This means that despite tens of indicators existing to guide the work towards a SUMS, they actually cannot guide such development. This recognition gave rise to this chapter, in which we bring the idea about the so-called sustainable consumption corridors to the domain of transport – for the first time according to our knowledge.

Introduction

Mobility is a fundamental aspect of our lives, one that defines our ability to interact and participate in nearly all societal functions and ongoings. So central is it to our lives that it has been considered to be a key satisfier to meet the human need (Costanza, et al., 2007), and a basic need in studies considering universal basic services (Coote, 2020; Rao & Min, 2017). Yet, concurrently, mobility is a key driver of human-caused environmental impacts, and from the consumption-based perspective, it ranks as one of the leading greenhouse gas (GHG) emission categories from personal behavior (IGES, 2019). Mobility systems additionally present an array of social issues, including but not limited to social exclusion and inability to access basic services due to lacking transport provisions, to health impacts from accidents and local air pollution (Lucas, 2012; Titheridge, Christie, Mackett, Hernández, & Ye, 2014).

These social and ecological externalities of the transport sector have been recognized, and thus the concept of sustainable urban mobility (SUM) was developed, building off previous assessments on sustainable development from the Commission of European Communities and the Brundtland Report (1987), which set the standard for the definition of sustainable development. SUM was first defined by the Commission of the European Communities Green Paper (1992), where it was suggested that transportation should be able to “fulfill its economic and social role while containing its harmful effects to the environment”.

Since then, there has been a plethora of research attempting to further define and refine sustainable mobility, with no consentaneously agreed-upon definition yet found (Holden, Linnerud, & Banister, 2013; Black, 2010; Schiller, Bruun, & Kenworthy, 2010; Banister, 2005). The expanding definition and broad notion of sustainable mobility has led to the formation of subsets of travel research, broken in fields such as leisure-travel (Holden & Linnerud, 2011; Czepkiewicz, Árnadóttir, & Heinonen, 2019), work-related travel (Glogger, Zängler, & Karg, 2008), and everyday travel (Banister, 2011). The expansive definition of sustainable mobility has additionally added a broader set of considerations of not just how transportation can affect the environment, but also social and economic aspects such as how transport can affect social equity (Gudmundsson & Höjer, 1996; Arsenio, Martens, & Ciommo, 2016), health and security (Banister, The sustainable mobility paradigm, 2008; Woodcock, Banister, Edwards, Prentice, & Roberts, 2007; Woodcock, et al., 2009), and quality of life (Steg & Gifford, 2005), amongst other factors. The SDGs put forth by the U.N. in the 2030 Agenda for Sustainable Development (2015) reflect the wide-ranging impacts of sustainable mobility, where mobility’s associated impacts are not categorized in one mobility goal, but rather across the goals, with mobility directly labelled in SDG3 target 3.6 and SDG11 target 11.2, though the impacts of mobility could be even further associated with them, though they are not directly mentioned (such as emissions of particulate matter affecting local air pollution (SDG3), GHG emissions from transport (SDG13), equity in travel (SDG10), and the production of vehicles (SDG12).

This varied definition of sustainable mobility in both breadth and depth runs the risk of stripping the term of meaning, a risk identified by Holden et al. (2013) in their research connecting sustainable mobility to the Brundtland Report. In their paper, Holden et al. (2013) argue that a more precise definition of sustainable mobility is needed and that these definitions and associated indicators require a minimum/maximum threshold to ensure that a sustainable state is sought as opposed to the rate of change incremental improvements from an unsustainable state to a less unsustainable state. Eight years after, SUM indicators still very seldom clearly define or suggest any thresholds, minimums, or maximums.

While Holden et al. (2013) themselves suggested a solution, their research was limited in two ways. The first was the lack of breadth captured by the narrowed four indicator scope. This presents the potential for some of the nuance identified in the score of other sustainable mobility indicators suggested in the research field, disregarded in Holden et al.'s (2013) work, to be lost. For a city desiring to measure the sustainability of its mobility system, the broad scope of the four indicators selected by Holden et al. (2013) may not provide the level of detail needed to sufficiently describe and manage the system towards a sustainable state.

The second limitation was the lack of frameworks in which the indicators/thresholds could be established. While the Brundtland Commission provides the extremely broad definition of sustainable development to which Holden et al.'s (2013) indicators/thresholds were tied to, they lacked a connection to more actionable frameworks.

One such framework developing around the same time as Holden et al.'s (2013) publication, although not transport-specific, was Raworth's (2012) "safe and just operating space for humanity", illustrated in Figure 16. This concept of social and environmental thresholds while not heavily considered in the field of SUM indicators, has come to prominence in the "Doughnut of social and planetary boundaries", displayed in Figure 16 (Raworth, 2012; Raworth, 2017). The doughnut economics model connects the concepts of staying within Earth's ecological carrying capacity whilst building a just and equitable social foundation for humanity.

Figure 16. The Doughnut of social and planetary boundaries (Raworth, 2017)

It is worth noting that in the initial version of the doughnut, the social floors were generated through the official submissions made by the world's governments to the 2012 United Nations

Conference on Sustainable Development in Rio de Janeiro (Raworth, 2012), and that of the 11 social criteria selected, accessibility of transport was ranked 12th, and not included due to the cutoff criteria.

The Doughnut Economic model received global recognition for its visualization of a socio-economic model describing an alternative to the modern-day neo-liberal economic model that works backward from a sustainable state to one that we could try to then adapt our current state towards. This has spurred greater thought from the academic community, and since then one fruitful development of Raworth's work has been the concepts of sustainable consumption corridors (Di Giulio and Fuchs 2014). This sustainable consumption corridor aims to specify the gap between the material social and planetary boundaries described by Raworth and adapt the definition of the corridor according to the domain or system at hand. The goal of these corridors is to provide a tool to gauge how one could live a 'good life' while respecting both of these boundaries as an individual and society as a whole. This theory provides the benefit of being able to zoom in further from the large arching goals provided by Raworth's framework to a more zoomed-in view of a specific lifestyle, domain, or sector.

This adaptation for the use of the corridor model was advocated by Fuchs et al. (2021), where the following was suggested accompanied by a set of defining questions:

> "*One approach would be to map the socio-material system of a consumption domain, such as mobility, food, or household energy use to gain a clearer understanding of that system. What actors are involved, who is included or excluded, and what social and political power dynamics are most apparent? What social norms, rules, regulations, or other controlling mechanisms exist? What does the materiality of that consumption domain look like, in terms of infrastructures and products? What skills and competencies are needed? What are the important social and environmental impacts and considerations? If needs are universal, the means of satisfying them are anything but. A car or a bike might satisfy the same needs, but a bike, in its usage phase, consumes no fossil fuels and releases no carbon emissions. Decisions can be made on which "satisfiers" have fewer negative social and environmental impacts over others.*"

This call to action through the approach suggested by Fuchs et al. (2021) and the limitations within SUM indicator research development is the research gap that this study aims to fill. Our research questions were posed as such:

RQ1: Can an urban mobility-domain specific sustainable consumption corridor be defined? What are the aspects material to defining the corridor?

RQ2: With the aspects defined, can a set of indicators be provided as a first suggestion of measuring where the system is performing relative to the corridor? And according to these measurements what thresholds can be attributed to them such that they define the ability to achieve inter- and intra-generational sustainability?

To achieve these ends, a review of the literature in fields such as SUM, SUM indicators, sustainable consumption corridors, ecological thresholds, needs theory, mobility social impacts, and mobility poverty was performed to generate an understanding of the material aspects that would define a mobility-focused sustainability corridor. Using this collected knowledge, based on the sustainable consumption corridor theory, a first sample corridor was developed. Then through this research, a set of indicators were suggested as first measurements to act as facets that define the different aspects of the corridor. Potential thresholds were then discussed, where a discussion was as far as this research could go as the science of developing fair and logical thresholds at a city level is beyond the current state of the research.

The authors of this study believe that this framework is novel and provides values in that it presents one of the first domain-focused sustainable consumption corridors. Additionally, through the research surrounding SUM indicators and thresholds (particularly those surrounding just ecological footprints and social floors), insights into how other corridors could potentially be defined and how this ties into dominating storylines surrounding urban mobility developments are provided. We believe that this is not a final implementation of a domain-focused corridor, but rather a first step that future research can build off of.

Methodology

In an attempt to answer the presented research questions, we undertook the following process. First, an understanding of what “a safe and just operating space” defined by sustainable corridor concepts for a specific domain needed to be developed. The aim was to understand how to move from Raworth’s high-level theory to a domain-specific corridor. To do this, material aspects to the domain needed to be defined to provide a form to the corridor. What ecological maxima and social minima exist and could be affected by the domain under consideration, in this case, urban mobility, then needed to be defined. With lines of the domain drawn, defining the corridor, indicator literature was then reviewed to see which themes and indicators could most aptly provide a set of measurements that could act to measure the material performance within the defined domain. The last step would be to then provide a quantified set of domain-specific thresholds for each aspect. Providing specific quantifications for these thresholds is a significant task which a large set of research has just begun to scratch the surface of and at a level too high for applicability at an urban level. Thus, exact thresholds are considered out of the scope of this research, and rather a discussion based on threshold/footprint literature is provided to give insight into the state of the literature and suggest future areas of study.

Defining the corridor

The first step to defining a sustainable consumption corridor requires one to understand what defines a sustainable consumption corridor. While at first glance the interpretation of the corridor seems obvious, its definition is more obscure than it first appears. To this point, first, a developed view of Raworth’s doughnut is shown in Figure 17.

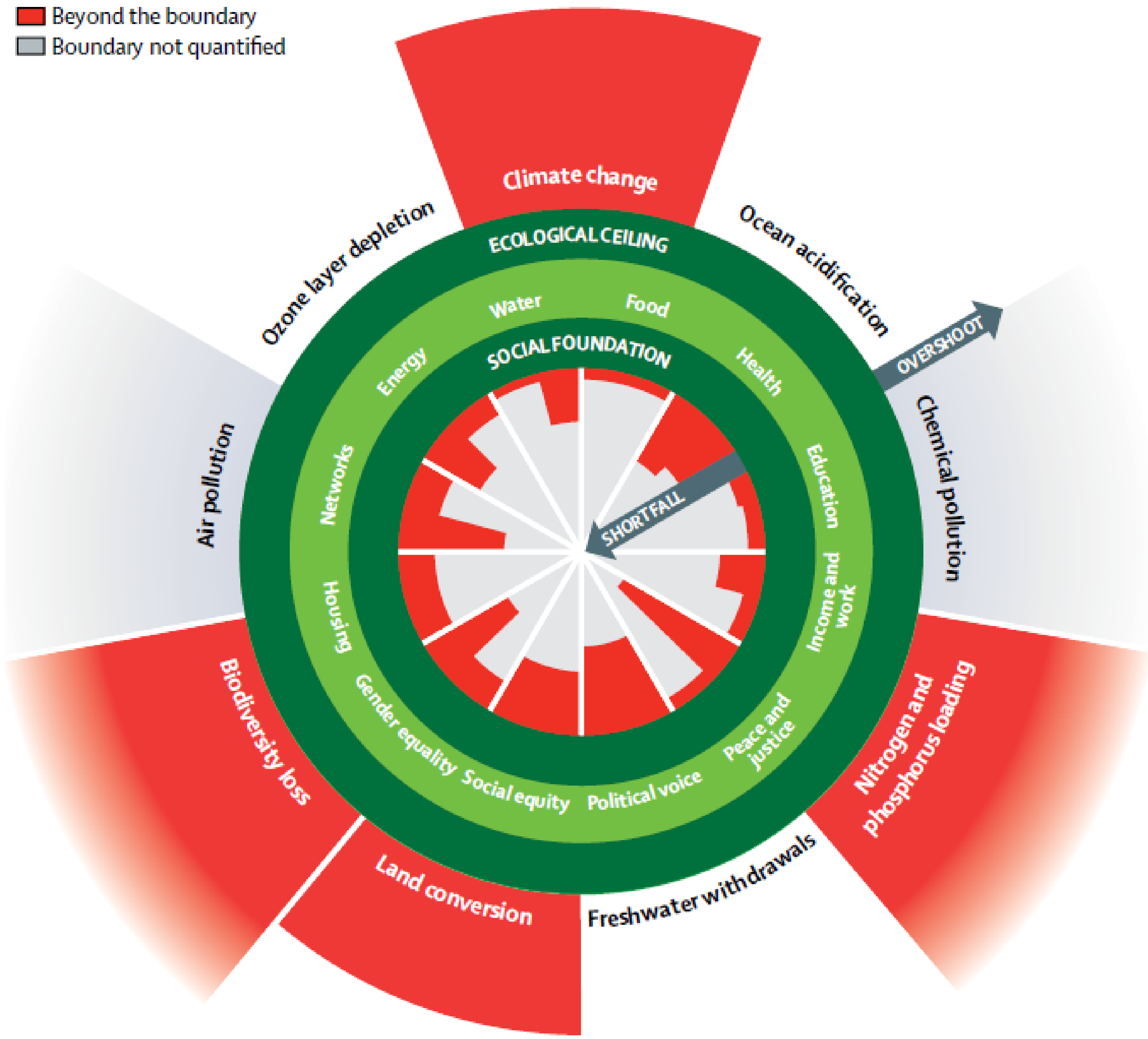


Figure 17. Shortfalls and overshoot in the Doughnut Dark green circles show the social floor and ecological ceiling, encompassing a safe and just space for humanity. Red wedges show shortfalls in the social floor or overshoot of the ecological ceiling. The extent of pressure on planetary boundaries that are not currently being overshot is not shown here (Raworth, 2017)

As shown in Figure 17, the doughnut is not simply a static theoretical drawing of ecological ceilings and social floors, but rather it has developed with its own set of indicators that measure global performance on each (it is worth noting that these measurements and their thresholds are still in constant stages of development and improvement) (Raworth, 2017). This doughnut framework has proven valuable for its global approach and has received international attention which has helped expand the notion of a safe and just operating space for humanity. Its global breadth and wide scope however present difficulty in its implementation spatially, temporally, and dimensionally.

Establishing thresholds for sustainable resource use and environmental impacts (i.e. *ecological ceiling*) is a challenging task. Raworth (2012, 2017) used the concept of planetary boundaries to guide the upper limits for a human-induced burden on Earth's ecosystems. Steffen et al. (2015) identified nine boundaries: climate change, biosphere's genetic and functional diversity, land-system change, freshwater use, nitrogen and phosphorus biochemical flows, ocean acidification, atmospheric aerosol loading, stratospheric ozone depletion, and novel entities, the first two being core for Earth system's stability. The thresholds are defined as states of the Earth System, whose crossing may trigger abrupt and non-linear changes in the functioning of the system, dangerously challenging social-ecological resilience at various spatial scales (Rockstrom et al. 2009). The thresholds have been proposed by natural scientists, but they are also based on normative assumptions that the destabilized Earth system is less favorable for human survival and well-being than a stable one (Steffen et al. 2018) and that crossing the thresholds undermines the conditions for people living now and in the future to satisfy their needs and have good lives (e.g. Fuchs et al. 2021, Kallis, 2019 see also for a critique). It relates to the "strong sustainability" criterion, according to which "each generation should inherit an adequate per capita stock of natural capital assets no less than the stock of such assets inherited by the previous generation" (Rees 1996).

There are numerous operational challenges to downscaling such thresholds to various spatial, temporal, and sectoral dimensions. For example, it is one task to suggest that there is a ppm threshold of CO2 in the atmosphere that humanity would want to remain below to avoid the most damaging effects of climate change, but it is another task altogether to say how the emissions humanity can emit should be allocated by country or other spatial units, how to do this fairly from a temporal aspect (Raupach, Davis and Glen, et al. 2014), or how to allocate the emissions to various sectors and life domains.

Temporal aspect. Planetary boundaries imply a sense of a permanent threshold (e.g. 350 ppm of CO_2 in the atmosphere suggested by Rockstrom et al. (2009)), but the current overshoot in key domains (e.g. > 414 ppm of CO_2 in March 2021) and continuing (and even increasing) anthropogenic impacts every year (e.g. close to 40 GtCO2 anthropogenic emissions in 2019), mean that avoiding crossing the thresholds or returning back to the "safe operating space" requires first sharp reductions in the yearly impacts, and then regenerative actions, such as sequestering carbon from the atmosphere or fostering biodiversity. The rate and tempo of required impact reductions is then a function not only of the planetary threshold but also of various assumptions on technological and social aspects of such transformation. For example, the assumption of a massive near-term deployment of "negative emission" technologies, such as bioenergy with carbon capture and storage (BECCS) allows for an assumption of a less steep decrease of yearly emissions than would be needed otherwise (Anderson and Peters 2016). Other kinds of assumptions include the reliance on GDP as a measure of societal cost and benefit (Kuhnhenn, et al. 2020), the role of lifestyle changes in reducing the impacts (van den Berg et al. 2019), or reverse impacts of the climate change itself (Keen 2020, de Blas, et al. 2020). For these and other reasons, climate change mitigation pathways vary widely in their assumptions and suggested emission levels and decrease rates (Grubler, et al. 2018).

Spatial aspect. While at a global scale the doughnut provides a useful tool, how does it transform at a country level? And at an urban level? And per capita levels? Local assessments of sustainability have often focused on comparing the ecological footprint of a locality with ecologically productive land of their own region or country (Rees 1996). More recently, planetary boundaries have been scaled down to a regional level by linking social well-being with sustainable management of resources located within the region (Dearing et al. 2014). These bottom-up approaches contrast with top-down approaches in which planetary boundaries and associated impacts are downscaled to a regional level based on some allocation formula. In this article, we combine the two approaches. We apply the top-down approach to the climate change boundary by suggesting the share in global impacts as an indicator. We then apply the bottom-up approach to the land-use system and biodiversity boundaries by suggesting indicators of land conversion, fragmentation, and biodiversity loss due to transport activities within a given region.

Downscaling global impacts to a regional level can be done most simply by relating the region's share of global impacts to the impact's levels that are deemed sustainable and to the current or projected population numbers, e.g. yearly CO2eq emissions per capita (O'Neill, et al. 2018). It can be nuanced by taking social and historical aspects into account, such as the level of affluence or development (UNFCCC 2021, Kuhnhenn, et al. 2020) or contribution to the impacts in the past (Hickel 2020), to differentiate responsibility.

Another aspect in which these approaches can differ is by taking either production- or consumption-based perspective, i.e. considering including only the emissions generated within the region or also including those caused by imported goods and services (Lenzen, et al. 2013). As "consumption corridors" by definition take the consumption-based approach, we also apply it in this paper by including indirect emissions associated with vehicles and infrastructures that are used in a given region but produced elsewhere.

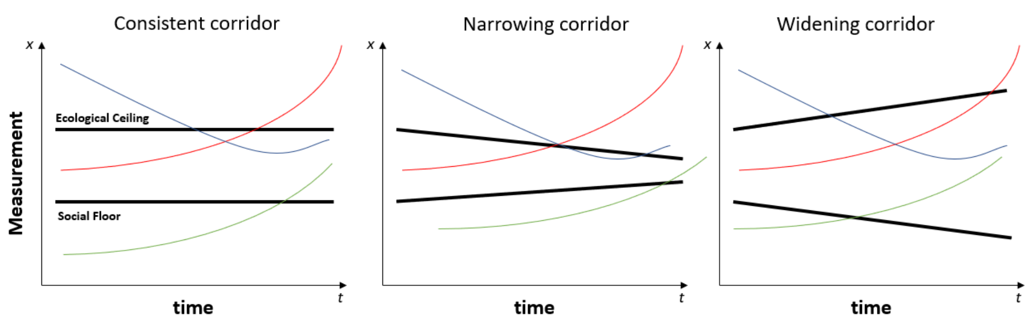
What about by sector? Taking mobility, for example, mobility provides the means to achieve some of the satisfiers for human needs, and yet in the case of climate change, how much emissions are acceptable from the mobility sector as compared to other sectors?

One way of doing it is to look at some climate change mitigation pathways and see how emissions from mobility are envisioned to (or should) reduce by 2030, 40 or 50, and then divide it by the projected number of people in that year. Assuming a fair share of emissions per person on Earth, we can then come up with an upper boundary allocated to mobility per year per person.

Another way would be to look at climate change mitigation pathways and calculate emissions per year per person (it has been done in some studies) and take some part of it (say, 30%) as a threshold for mobility. There are other ways but these are ones that we have been using in another paper we are working on (on degrowth-compatible urban living).

Thus, taking insights from Raworth's work, the sustainable consumption corridor framework was used as a more adaptable version of the doughnut. Based on the work and further research suggestion of Fuchs et al. (2021), we have developed an initial basic understanding of sustainable consumption in Figure 18.

a)



b)

Figure 18. (a) Descriptive illustration of a sustainable consumption corridor (image taken from Fuchs et al., 2021) and (b) Sustainable consumption corridors illustrating simplified examples of potential changes over time

Figure 18b illustrates the potential changing window of a corridor, where a corridor's ecological ceilings and social floors can change according to different socio-economic transformations, such as technological advancement, cultural changes, and ecological changes such as tipping points accelerating the rate of climate change which would then lower the potential operating ecological ceiling humanity as to work under, amongst other changes. The colored lines represent different regions or entities and their relative performance, where existing below the social floor can be correlated to a society in which social minima are not being met but are also not exceeding the associated ecological ceiling material to that domain. The area above the ecological ceiling represents a society that has a high social standard but is also surpassing the average limit of the material aspect required to maintain ecological sustainability.

Constructing the social floor

Taking this general understanding of sustainable consumption corridors, the goal was then to develop a domain-specific corridor, in the case of this study, a mobility-focused one. Starting from the bottom and more difficult to quantify social floor, the work was to understand what defined the social minimum characteristics of mobility, an area identified in Raworth's initial doughnut as important but left out due to cut-off criteria. This requires knowledge in fields such as human needs and needs satisfaction, social issues material to mobility, and mobility poverty.

A growing field of research has defined mobility as universal basic services (Coote, 2020; Rao & Min, 2017), yet a service does not necessarily define human need as understood by needs theory (Doyal & Gough, 1984; Max-Neef, 1991). Rather, mobility has been described as a need satisfier, by way of providing access to activities, social interactions, facilities, and goods that satisfy basic human needs (Mattioli 2016, Gough 2017, Brand-Correa et al. 2020). Travel has been described as a third-order satisfier, and particular travel modes, such as private cars, as fourth-order satisfiers (Table 2, Mattioli 2016, Gough 2017). Higher-order satisfiers, which are closer to the basic needs, include particular trips and provisioning systems, such as healthcare or employment systems (Table 2). In other words, moving around and having access to particular travel modes is considered a means to an end (i.e. satisfying human needs) and not an end in itself.

The chain of need satisfiers in table 2 illustrates the difference between mobility and accessibility, their measures, and policies that enhance each of them. While mobility is defined as the potential for movement and the ability to get from one place to another using one or more modes of transport, accessibility is defined as the ability to access or reach services, activities, or social interactions (Handy 2002). While the former is often enhanced by improving the ease of movement by certain travel modes (e.g. cars, buses), the latter is typically enhanced by improving access to local services and amenities. Following Handy (2002) and referring to the theory of needs, planning for accessibility focuses on the traveler rather than the transportation system and answers the question: do people have access to the activities they require to have their human needs met?

Focusing on accessibility rather than mobility is well suited for approaches based on sufficiency principles, including the doughnut and sustainable consumption corridors. Such approaches aim at “decoupling” human need satisfaction from energy use (Brand-Correa and Steinberger 2017) and preventing the “escalation” of need satisfiers, such as increased dependence on the private car as a means to satisfy human needs (Brand-Correa, Mattioli, et al. 2020).

Table 2. The chains of need satisfiers including travel and travel modes (based on Mattioli 2016, Gough 2017).

Basic needs	***Health, social participation, autonomy***			
Intermediate needs	Income	Nutrition	Healthcare	Relationships
1st order satisfier (societal level)	System of employment	System of food production and distribution	Health system	Social networks
2nd order satisfier	Employment	Shopping for food	Medical visits	Social visits
3rd order satisfier	Travel			

4th order satisfier	Travel modes (car, bus, bicycle, walking, etc.)

We surveyed the field of social sustainability literature across mobility indicators, needs theory and universal basic services, mobility poverty, and social issues in mobility to assess what could be defined as a minimum requirement to support all populations' ability to 'live a good life' (Fuchs, et al., 2021).

Within this research, the most holistic perspective that the authors found that most concisely captured these facets was Lucas et al.'s (2016) research on mobility poverty. An adaptation of the lexicon developed in this research was used to develop a basis for our mobility-focused social floor, seen in Figure 19. It is worth noting that we do not find this lexicon to be the definition of a mobility-focused social floor but a collection of categories that can be used to organize indicators that are included in the foundation's definition in further works and discussions.

Mobility based sustainable consumption corridor

Minimas	Mobility poverty	Accessibility poverty	Transport affordability	Exposure to transport externalities	SOCIAL FLOOR
defined by	A systemic lack of (usually motorised) transport that generates difficulties in moving, often (but not always) connected to a lack of services or infrastructures	The difficulty of reaching certain key activities – such as employment, education, healthcare services, shops and so on – at reasonable time, ease and cost	The lack of individual/household resources to afford transportation options, typically with reference to the car (in developed countries) and/or public transport	The outcomes of disproportionate exposures to the negative effects of the transport system, such as road traffic casualties and chronic diseases and deaths from traffic related pollution.	
Sources	Moore et al. (2013)	DfT (2014a), SEU (2003)	Carruthers et al. (2005), Litman (2015), Serebrisky et al. (2009)	Barter (1999), Booth et al. (2000)	

Figure 19. Adapted form of Lucas et al.'s transport poverty lexicon depicting the mobility-focused social floor.

Constructing the Environmental Ceiling

With the social floor established, the next step in the procedure was to approximate an ecological ceiling for the mobility sector. Where the drawing lines of social floors present a more ambiguous moral dilemma in selecting appropriate thresholds connected to human needs, ecological thresholds for the most part can be more directly estimated, though is still a developing field.

First introduced by Rockström et al. (2009) and updated by Steffen et al. (2015), the planetary boundaries (PB) framework provided the foundation for the "safe operating space of humanity", which Raworth then adapted to create the "safe and just operating space" with its social floors. The PBs can be seen in Figure 20, and they describe the globe's biophysical limits of certain measurements, beyond which could lead to a destabilized Earth system capable of reducing Earth's ability to support human life and development.

The strong basis of these thresholds and the clear ceilings they represent globally made them the clear choice for a mobility-specific sustainable consumption corridor. As an adaptation to this framework for this sector-specific use, the PBs were grouped according to their relevance to the transport sector, as shown in Figures 17 and 20.

defined by	Direct Emissions related to transport (Tank-to-Wheel Emissions)	Indirect Emissions related to transport (Well-to-Tank emissions, Production emissions, disposal emissions, embedded emissions in infrastructure)	Land use change/impact caused by transport system	Impact of transport system on biodiversity (collisions, fragmentation)	
Maximas	**Emission Based Thresholds (Climate Change, Air Pollution, Chemical Pollution, Ozone Layer Depletion, Ocean Acidification)**		**Land Conversion**	**Biodiversity loss**	**ECOLOGICAL CEILINGS**
Mobility based sustainable consumption corridor					

Figure 20. Proposed Ecological Ceilings for transport based of Planetary Boundaries framework (Rockström, et al., 2009; Steffen, et al., 2015; Raworth, 2017)

Climate Change, Air Pollution, Chemical Pollution, Ozone Layer Depletion, and Acidification were grouped as emission-based thresholds and land conversion and biodiversity were kept separate in an attempt to group the PBs according to the transport sector's relevant environmental impacts. Again, the authors acknowledge the interrelated aspects of these impacts, where for example land-use change also has a net carbon impact, and that these categorizations are not meant to provide exact definitions but rather an operating framework to organize the material factors for transport. Additionally, it is worth noting that some of the PBs have yet to be quantified (Steffen, et al., 2015) and that some of them such as Ocean Acidification are directly related to another PB (in this example climate change) (Sandin, Peters and Svanström 2015) and that in practice it would likely be useful to focus on reducing pressures on the boundaries which provide a more concrete ceiling, such as greenhouse gas emissions. However, while this paper will go into discussions around the quantifications of thresholds, no numerical approach will be made and thus all PBs will be left in for now.

Adding Themes and Indicators to the Corridor Dimensions

The next step in this process was then to assemble a list of the most relevant themes and indicators from the field of literature to map a more operational perspective of the sustainable consumption corridor to understand which levers can control the sector's performance within the corridor. After reviewing the field of literature, the most comprehensive set of themes and indicators associated with SUM indicators found by the authors was a study produced by Sdoukopoulos et al. (2019), who performed a review of over 78 SUM indicator studies and initiatives and created a list of the most widely used SUM themes and indicators within each theme. Using the list of themes and indicators produced by Sdoukopoulos et al. (2019), these indicators were mapped according to whether they could be considered to depict either one of the dimensions of the ecological ceiling or social floors material to urban mobility. This list and its determined relevance can be seen in Table 3.

Table 3. Indicators from Sdoukopoulos et al. (2019) with considered represented ecological ceiling and social floors

Theme	**Indicator**	**Ecological Ceiling**	**social floor**
Accessibility	Share of population living within 300–500m from public transport stations/stops		Mobility poverty
Active citizens	Degree to which public is involved in transport planning process		
Affordability	Share of household income devoted to transport		Transport affordability
Air pollutant emissions	Air pollutant emissions (mass unit) per capita	Emission based thresholds	Exposure to transport externalities
Air quality	Concentrations (μg/m3) of air pollutant emissions	Emission based thresholds	Exposure to transport externalities
Commuting	Average commuting travel time		Accessibility poverty
Contribution to economy and development	Share of GDP contributed by transport sector/Share of GVA generated by transport sector		
Cultural aspects	Degree to which cultural aspects are considered in transport planning		

Demographic and socio-economic characteristics	GDP per capita		
Economic productivity	Ratio of public transport revenues to the respective maintenance and operation cost		
Energy efficiency	Ratio of passenger-km travelled to the respective energy consumption	Emission based thresholds	
Fossil fuel energy consumption	Per capita fossil fuel energy consumption by transport sector	Emission based thresholds	
Fragmentation	Fragmentation of urban space	Biodiversity loss	
Freight transport	Modal split of freight transport/Average freight transport speed and reliability		
GHG emissions	Greenhouse gas emissions per capita	Emission based thresholds	
Hazardous materials and environmental damages	Number of tonne-km referring to transport of hazardous materials by mode		Exposure to transport externalities
Health impacts	Number of chronic respiratory illnesses, asthma attacks, respiratory restricted activity days and premature deaths due to air pollution		Exposure to transport externalities
Impacts to habitats	Annual number of collisions with wildlife	Biodiversity loss	
Impacts to sites of historical and architectural importance	Deterioration of historical buildings and other cultural assets due to acidification 9.1% – (–)		
Infrastructure	Road network length per 1.000 inh.		Mobility poverty
Institutional aspects	Existence or not of transport and environment observatories		
Integrated planning	Degree to which transport planning is comprehensive by considering all significant impacts and using the best evaluation practices		
Land consumption	Area taken by transport infrastructure 35.7%	Land Conversion	
Liveable public space and amenities	Total area of green spaces and parks per capita/Green areas as a share of the total urban area		Accessibility poverty
Mobility	Modal split	Emission based thresholds	
Multimodality	Number of available transport modes		Mobility poverty
New, smart and green technologies	Share of employees participating in teleworking programmes/Share of vehicle fleet powered by alternative propulsion technologies (electric, hybrid and fuel cell vehicles_	Emission based thresholds	

Non-motorised modes	Share of trips by non-motorised modes	Emission based thresholds	Mobility poverty
Parking	Share of free parking spaces		
Public expenditures, investments and subsidies in transport system	Public subsidies to transport system		Transport affordability
Public transport	Share of trips by public transport	Emission based thresholds	Mobility poverty
Recycling	Recycling rate for end-of-life vehicles	Emission based thresholds	
Renewables and alternative fuels	Share of renewable energy in total energy consumption by transport sector	Emission based thresholds	
Resource use	Total volume of raw materials used in vehicle manufacturing	Emission based thresholds	
Safety	Number of road fatalities per 100,000 inh.		Exposure to transport externalities
Security	Share of population feeling safe from violations and other relevant incidents during traveling		Mobility poverty
Social equity	Equity/justice of exposure to air pollution emissions		Exposure to transport externalities
Traffic congestion	Average time spent travelling under congested conditions per year per capita		Accessibility poverty
Traffic noise	Traffic noise levels/Share of population exposed to noise levels above the statutory threshold		Exposure to transport externalities
Transport costs and prices	Fuel prices and taxes		Transport affordability
Transport efficiency	Occupancy rate of passenger vehicles	Emission based thresholds	
Transport external costs	Total cost due to transport externalities		Exposure to transport externalities
Trips to/from school	Modal split of trips to school/Share of children driven to school by car		Mobility poverty
Urban planning and land-uses	Population density		
Vehicles fleet	Number of cars per 1,000 inh.	Emission based thresholds	Mobility poverty
Waste	Transport of solid waste per capita		
Water run-off	Transport infrastructure impervious area per capita		

Results

The results of this work resulted in the output of a mobility-focused sustainability consumption corridor, shown in Figure 21. The social floors and ecological ceilings defined in the methodology section were merged to define the corridor, where the goal was to develop an understanding of the interrelated aspects of meeting societal needs which mobility provides access to whilst remaining within an ecological safe space. The discussion section will review the potential for understanding how these minima and maxima could be established.

Figure 21. Initial illustration of mobility-focused sustainable consumption corridor using preliminary indicators taken from the literature

	New, smart and green technologies	% employees teleworking/Share of vehicle fleet powered by alternative technologies						
	Transport efficiency	Occupancy rate of passenger vehicles						
	Air quality	Concentrations (µg/m3) of air pollutant						
	Non-motorised modes	Share of trips by non-motorised modes						
	GHG emissions	Greenhouse gas emissions per capita						
	Mobility	Modal split						
	Public transport	Share of trips by public transport						
	Energy efficiency	Ratio of passenger-km travelled to the respective energy consumption						
	Fossil fuel energy consumption	Per capita fossil fuel energy consumption by transport sector	*Vehicles fleet*	Number of cars per 1,000 inh.				
	Renewables and alternative fuels	Share of renewable energy in total energy consumption by transport sector	*Recycling*	Recycling rate for end-of-life vehicles			*Impacts to habitats*	Annual number of collisions with wildlife
	Air pollutant emissions	Air pollutant emissions (mass unit) per capita	*Resource use*	Total volume of raw materials used in vehicle manufacturing	*Land consumption*	Area taken by transport infrastructure	*Fragmentation*	Fragmentation of urban space
	Themes	*Indicators*	*Themes*	*Indicators*	*Themes*	*Indicators*	*Themes*	*Indicators*
defined by	Direct Emissions related to transport (Tank-to-Wheel Emissions)		Indirect Emissions related to transport (Well-to-Tank emissions, Production emissions, disposal emissions, embedded emissions in infrastructure)		Land use change/impact caused by transport system		Impact of transport system on biodiversity	
Maximas	**Emission Based Thresholds (Climate Change, Air Pollution, Chemical Pollution, Ozone Layer Depletion, Ocean Acidification)**				**Land Conversion**		**Biodiversity loss**	

Mobility based sustainable consumption corridor

Minimas	**Mobility poverty**		**Accessibility poverty**		**Transport affordability**		**Exposure to transport externalities**	
defined by	A systemic lack of (usually motorised) transport that generates difficulties in moving, often (but not always) connected to a lack of services or infrastructures		The difficulty of reaching certain key activities – such as employment, education, healthcare services, shops and so on – at reasonable time, ease and cost		The lack of individual/household resources to afford transportation options, typically with reference to the car (in developed countries) and/or public transport		The outcomes of disproportionate exposures to the negative effects of the transport system, such as road traffic casualties and chronic diseases and deaths from traffic related pollution.	
	Themes	*Indicators*	*Themes*	*Indicators*	*Themes*	*Indicators*	*Themes*	*Indicators*
	Accessibility	Share of population living within 300–500m from public transport stations/stops	*Liveable public space and amenities*	Total area of green spaces and parks per capita/Green areas as a share of the total urban area	*Public expenditures, investments and subsidies in transport system*	Public subsidies to transport system	*Health impacts*	Number of chronic respiratory illnesses,respiratory restricted activity days and premature deaths due to air pollution
	Security	Share of population feeling safe from violations during traveling	*Commuting*	Average commuting travel time	*Transport costs and prices*	Fuel prices and taxes	*Air quality*	Concentrations (µg/m3) of air pollutant emissions
	Trips to/from school	Modal split of trips to school/Share of children driven to school by car	*Traffic congestion*	Average time spent travelling under congested conditions per year per capita	*Affordability*	Share of household income devoted to transport	*Hazardous materials and environmental damages*	Number of tonne-km referring to transport of hazardous materials by mode
	Infrastructure	Road network length per 1.000 inh.					*Traffic noise*	Traffic noise levels/Share of population exposed to noise levels above threshold
	Multimodality	Number of available transport modes					*Air pollutant emissions*	Air pollutant emissions (mass unit) per capita
	Non-motorised modes	Share of trips by non-motorised modes					*Safety*	Number of road fatalities per 100,000 inh.
	Public transport	Share of trips by public transport					*Social equity*	Equity/justice of exposure to air pollution emissions
	Vehicles fleet	Number of cars per 1,000 inh.					*Transport external costs*	Total cost due to transport externalities

Discussion

The research goals of this paper were to propose a sustainable consumption corridor for the mobility sector and a set of indicators that could allow for evaluating the performance of regions or cities in relation to this corridor. Figure 21 represents the first embodiment of this work, though we see this as an iterative work, where the corridor can be iterated and adapted according to the specific needs of the region, data availability, etc. The benefit of this approach is that compared to much of the SUM indicator literature which takes a 'weak sustainability' approach or would only describe the current performance and movement towards a slightly less unsustainable state, this corridor approach helps assist in defining what a sector-based sustainable state would be and how the material performance of the region in the corridor can be measured. As the indicators which describe each dimension are then put together, the primary actors leading to pressure on PBs can be addressed with a clear understanding of their connected social ties. These linkages are the value the corridor provides, where both the ecological and social challenges and their relationships can be seen at the same time rather than in a siloed manner.

However, while the scope of this work was able to provide a first definition of how a mobility-focused corridor could be defined and what should be measured, outside of the scope of this work was defining where the favorable values of indicators that represent the ceilings and floors should be set. On the social floor side, there is a plethora of literature describing the social issues associated with transport, however how to determine the appropriate levels of each indicator and what defines an absence of mobility poverty for an entire population and its subsets, for example, is an area for further research that still needs to be developed. From the ecological ceiling perspective, there has additionally been a plethora of research being produced from the highest levels of academic work attempting to quantify what a fair and equitable allocation of different allowable PB impacts are acceptable from different regions (Raupach, et al., 2014), sectors (Lettenmeier, Liedtke, & Rohn, 2013), and market segments (Sandin, Peters, &

Svanström, 2015), yet each of these approaches is fraught with their own uncertainties and ethical dilemmas, i.e. per capita footprints, grandfathered approach, historical justice. Thus, particularly with the differing circumstances of a region or city that would attempt to adapt this corridor framework, we have refrained from attempting to quantify exact thresholds within this work and instead acknowledge it as an important area of discussion and future work.

In introducing this framework, the primary limitation that we have considered is the somewhat arbitrary nature of defining social floor and assigning indicators to the selected dimensions. As proposed in previous literature, going beyond the arbitrary choices could involve a "dual strategy" in which experts and the public work together in a deliberative process (Gough 2017, Fuchs et al. 2021). In this report, we aim at providing expert input, which can be then supplemented by other work, such as surveys or workshops with key stakeholders (chapter 5) or members of the public. The latter could be particularly suitable for elaborating on the social floor and its indicators, e.g. through defining decent living standards for a given socio-cultural and socio-technical context. While we have attempted to ground the selections in literature as much as possible, arguments can be made of why another set of social dimensions or SUM indicators that describe them should be used. We have proposed this corridor for exactly this purpose, to be debated and iterated on to make the most operational corridor possible. We see that as the literature surrounding PBs and sustainable corridors continues to develop, this work in sector-focused sustainable consumption corridors can play an increasingly valuable role in assisting scientists and regions interested in living within a safe and just operating space define and operationalize this work. Thus, future work could continue to look at different sectors and consumption domains such as nutrition, household energy, etc. and when added all together, this research could paint a holistic picture of what a safe and just society would look like. And this vision was the goal behind this first work, in the hopes that it could be a catalyst for future such works.

Chapter 5: Sustainable Urban Mobility Indicator development through the lens of a participatory approach

Background

Despite the immaturity of the SUMS indicator field of research, covered in the previous chapter, a well-grounded set of indicators is crucial for a city to guide and monitor the work towards a more sustainable mobility system – while waiting for the absolute sustainability frameworks to develop. In this Chapter 5 we present a joint theory and participatory stakeholder analysis based approach to defining a sufficient set of SUMS indicators for Reykjavik.

Introduction

As discussed in the previous chapters, humanity is facing both socio and ecological crises, and mobility plays a key role both in exacerbating climate issues whilst at the same time providing the means for individuals to meet their social needs. The doughnut economy and sustainable consumption corridors provide frameworks to take the social minima that need to be supported whilst at the same time considering the ecological thresholds that should be surpassed to avoid ecological collapse (Raworth 2017). Chapter 4 thoroughly reviewed these concepts and presented a mobility-focused sustainability corridor, with the dimensions of the corridor adapted from published research.

In the development of sustainable consumption corridors, however, a participatory approach has been called for (Fuchs, et al. 2021). Therefore, to address this call and make a first step towards operationalizing a mobility-focused sustainability corridor, this research aimed to develop a list of indicators applicable for use within the corridor framework and performed a stakeholder engagement to assess expert knowledge perception of SUM to determine if there were any gaps within the indicator list. This operationalization was completed through a case study approach on the city of Reykjavik.

The research goals of this approach were to:

1) Determine if a set of indicators could be collected from the literature such that they could adeptly define the mobility-focused sustainability consumption corridor and to understand which indicators are threshold-relevant and which are not.
2) With the indicator list developed, determine if a set of field expert focus groups define SUM such that there is an obvious gap from either the corridor or indicator perspective.

The value of this undertaking was to i) validate the mobility-focused sustainability corridor concept ii) provide a list of case study- and threshold- relevant SUM indicators to be considered.

Methods

With the generally accepted idiom of “what you cannot measure, you cannot improve”, in the attempt to capture the complex nature of SUM and how to progress towards it, many sets of indicators to measure and assess the sustainability of mobility systems have been suggested. Through a system of parameters (indicators), the aim is to describe SUM’s many facets, with indicator sets ranging from a single holistic indicator to 100+ indicators (Gillis, Semanjski and Lauwers 2016, Gudmundsson 2004, Haghshenas and Vaziri 2012). This variation in the suite of SUM indicators selected throughout the field of research is a symptom of the challenges posed by the process of selecting a subset of indicators amongst a large population of potential indicators that exists which additionally can aptly depict a holistic view of the system under study according to the goal and scope of the work (Castillo and Pitfield 2010). This difficulty is exacerbated by the many different interrelated systems and institutional levels servicing the complex mobility systems which may have specific characteristics associated with the region of study (Sdoukopoulos, 2019). Additionally, each indicator and region pair may be subject to the data availability and ability to acquire needed data to calculate specific indicators (Sdoukopoulos, 2019).

To address these issues, systematic frameworks have been put forward (Castillo and Pitfield 2010). In this research, these frameworks have been adapted to develop our own framework, shown in Figure 21, in which an additional threshold criterion is applied to each indicator as well as a split between general criteria assessments and practical application criteria assessments are made. It is worth noting that in this process only the theoretical steps were applied, while the practical steps will be applied in future work. A supporting stakeholder engagement was performed however to give a deeper perspective for Reykjavik.

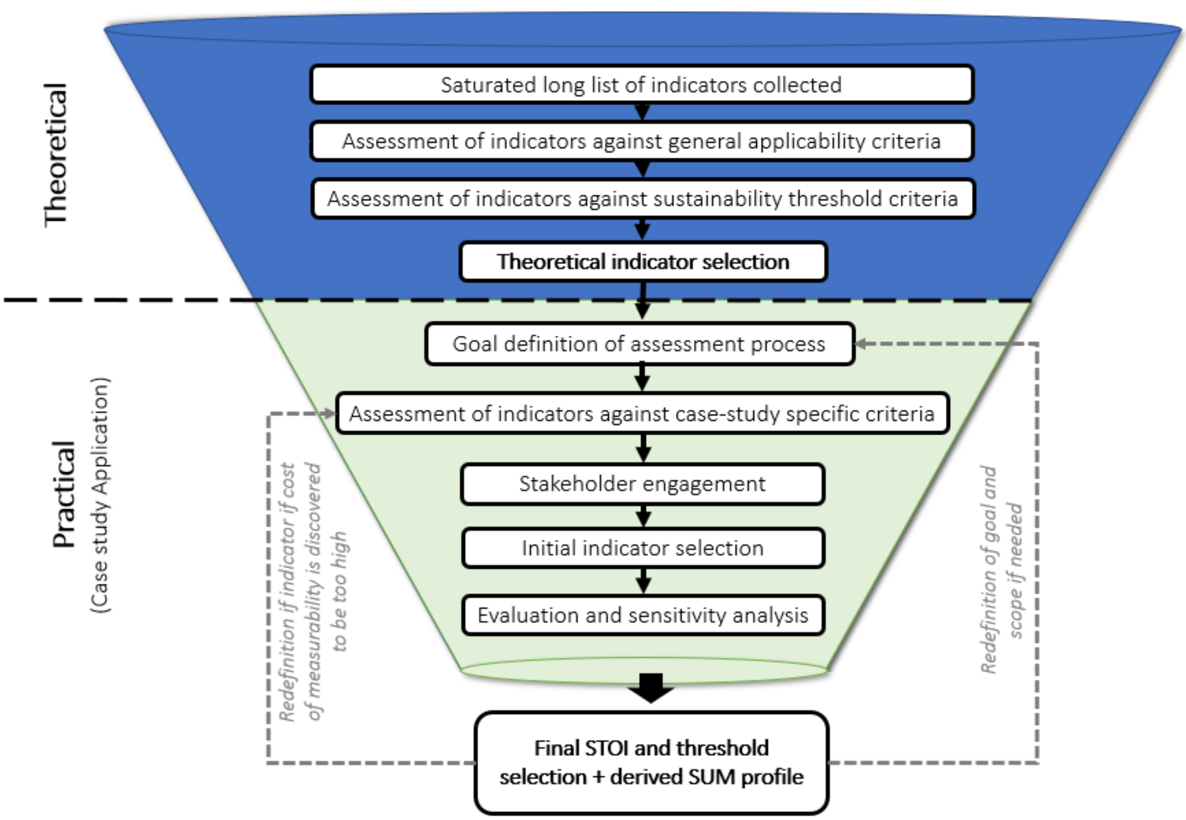


Figure 22. Development of Sustainability Threshold Indicators (STOI)]

Similarly, too many of the proposed frameworks, first, a long list of indicators from the field of research was collected until a satisfactory level of saturation is reached. These indicators were then filtered for repetition and assessed against general indicator criteria to ensure for applicability and validity of the indicators. With the additional lens provided by the Doughnut framework, the indicators were additionally assessed against a threshold criterion, ensuring that the indicator was depicting a main dimension of sustainability and could describe a sustainable system state. This results in the first set of theoretically applicable indicators. Following this, for a case study application, in the case of this study the city of Reykjavik, the second round of assessments will be performed. First, the theoretical goals are selected according to their applicability to the goal and scope of the case study. This initial subset is then assessed again according to their feasibility for the case study, in terms of cost and measurability. With this appropriate subset of potential indicators for the case study collected, stakeholder engagement, and a sensitivity analysis the results of the engagement are carried out to derive the final SUM profile defined by the set of STOI's and associated thresholds. The following subsections describe the steps of the process in more detail, with the case study presented as example results.

Indicator Selection

Initial Long List

In the initial indicator collection phase, the most cited works regarding SUM indicators were collected from Google Scholar and Scopus using the following search terms, "Sustainable Urban Mobility Indicators", "Sustainable Transport Indicators", and "sustainable urban transport Indicators". Articles were extracted until a sufficient point of saturation was reached, in this case, this was assumed to be the case when in three consecutive articles collected, 80% of the indicators had already been recorded. Only research from 2010 and on was considered to ensure the most recent and relevant studies were included.

The initial long list of 277 indicators was collected from 10 articles. Any repetitions of an indicator were noted and reduced to create a reduced long list of 162 indicators.

General Applicability Criteria

There exists generally accepted minimum criteria for indicator selection (Tafidis, Sdoukopoulos and Pitsiava-Latinopoulou 2017), though there exist different perspectives such as scientific, policy, methodological, and statistical criteria that can have overlapping goals (Joumard and Gudmundsson 2010). Table 4 has synthesized these general indicator criteria that the indicator needs to fulfill, with a potential overlapping criterion.

Table 4. General Applicability Indicator Criteria and Definition

Criteria	***Definition***
Validity	Indicator should be relevant and measure the desired factor (WHO 2006).
Reliability	Indicator should be reproducible (WHO 2006).
Sensitivity	Indicator should reflect and reveal important changes to the desired factor (Goger, A. and Arapis 2009)
Ethical Concerns	Indicator must comply with fundamental human rights (WHO 2006).
Transparency	Indicator should be easily understood and reproducible, particularly in regard to inputs, assumptions, and methods (Joumard and Gudmundsson 2010).
Interpretability	Indicator should be easily understood, particularly in regard to the interpretations that can be drawn from the indicator (Joumard and Gudmundsson 2010).
Scientific Validity	Indicator must be scientifically sound. --- Source?
Actionability	Indicator should measure the desired factor such that action can be taken to influence or change the indicator in the desired direction through policy or management (Joumard and Gudmundsson 2010).

With the initial long list of indicators collected, these indicators were first assessed according to the following set of general applicability criteria that should be applicable for any indicator to be considered valid.

Threshold Criteria

From this general criteria list, the Target Relevance criteria has been extracted and given its own step for two reasons. The first is due to the lack of application of sustainability thresholds in the SUM indicator literature. The second is connected to the aim of this research to expand upon the definition of Target Relevance and tie it closer to the definition of sustainability through the use of environmental or social minimum/maximum thresholds that could describe a sustainable state of the system. Table 2 shows the suggested expansion upon the definition of the Target Relevance criteria.

Table 5. Threshold Applicability Indicator Criteria and Definition

Target Relevance	Indicator should clearly measure performance against stated goals, targets, or thresholds (Joumard and Gudmundsson 2010).
Additional proposed criteria	*Indicator can be paired with an environmental or social minimum/maximum threshold that would describe a sustainable state of the system*

From the general applicability reduced list of 162 indicators, it was determined that 130 indicators met the threshold applicability criteria. This subset of indicators are the STOIs referred to in this study and are intended to apply to any SUM study seeking to utilize SUM indicators.

Stakeholder Engagement and Selection

To identify which mobility-related aspects are being considered by stakeholders, and which remain unmentioned or are in general not thought about, we conducted a stakeholder analysis. In this analysis, the central research question was: How do stakeholders think transportation in Reykjavík can be decarbonized?

In this work, stakeholders were considered to be those who influence or are influenced by transportation in the Reykjavík capital region. Before choosing the stakeholders to be engaged, a detailed stakeholder map was drawn. The map showed clearly a large number of stakeholders to urban mobility in the capital region. The map was used to select a diverse and balanced group of stakeholders to capture different perspectives and opinions. After choosing relevant stakeholders, invitations were sent out. The response rate was 96%, as stakeholders who could not participate, or felt that others in their organization were better suited for the discussions, had put us in touch with an alternative stakeholder.

We conducted four 1-hour focus groups, each with 4-6 stakeholders via Microsoft Teams. We took a semi-structured approach to allow for flexibility in the focus groups, but discussions were loosely guided by an interview protocol. The interview video and audio files were recorded and then transcribed. After each focus group, notes were made on what went well, what could have gone better and how in general the discussions went. A snowballing technique was used to identify any gaps in the stakeholder map, where stakeholders were asked if they could recommend to us any relevant parties. The snowballing however revealed that our initial selection was in line with their recommendations.

We used a thematic analysis method based on steps provided by (Corbin and Strauss 1990). As the analysis was inspired by the Grounded theory approach, it was flexible and allowed for a systematic analysis of the qualitative data. It was a simultaneous process where the remaining data collection could be guided by the prior focus groups' successes and failures.

Results

Results from the indicator collection

The results of this work can be seen in Table 6, where 130 sustainable consumption corridor threshold-oriented indicators were selected. The assumed theme was the theme associated to each indicator selected from the research. At which level the indicator was applied in each study and where, and the associated studies can additionally be found in the table.

Table 6. Selected sustainable consumption corridor threshold relevant themes and indicators

Assumed Theme	Quoted Indicator	Levels Considered	Countries	Studies
Accessibility	Access to basic services	Urban	Thessaloniki, Greece; Curitiba, Brazil; English Regions, UK	Tafidis et al. (2017), Miranda & Silva (2012), Castillo & Pitfield (2010)
	Quality of transport for disadvantaged people	Urban	Thessaloniki, Greece; Curitiba, Brazil: Global Cities; Taipei, Taiwan	Tafidis et al. (2017), Miranda & Silva (2012), Haghshenas et al. (2012), Shiau et al. (2013)
	Accessibility to (public) transit	Urban, General, National	Curitiba, Brazil: Global; Global Cities; Rio de Janeiro, Brazil: Asia and the Pacific	Miranda & Silva (2012), Gilles et al. (2016), Haghshenas et al. (2012), Santos & Ribeiro (2015), Gudmundsson et al. (2017)
	Street crossings adapted to users with special needs	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Accessibility to open spaces	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Parking spaces to users with special needs	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Accessibility to public buildings	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Time to get to the next public-transport stop	National	Subset of European Countries	Bojković et al. (2010)
	Distribution density of transit	Urban	Taipei, Taiwan	Shiau et al. (2013)
	Accessibility for mobility impaired groups	Urban, General	Thessaloniki, Greece; Global	Tafidis et al. (2017), Gilles et al. (2016)
	Public Transport Accessibility Level (PTAL)	National	Global Countries	Holden et al. (2013)
Affordability	Affordability (share of income devoted to transport)	Urban, National	Thessaloniki, Greece; Asia and the Pacific	Tafidis et al. (2017), Gudmundsson et al. (2017)
	PT affordability (share of households' income devoted to trips by means of PT)	Urban, General	Thessaloniki, Greece; Global	Tafidis et al. (2017), Gilles et al. (2016)
	Trends in PT prices	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Discounts and free rides	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Households which cannot afford a car	National	Subset of European Countries	Bojković et al. (2010)
Air pollutant emissions	Emissions of local air pollutants (CO, VOC, NOx, SOx, O3, PM, etc.) per capita	Urban, General, National	Thessaloniki, Greece; Curitiba, Brazil: Global; English Regions, UK; Global Cities; Rio de Janeiro, Brazil Subset of European Countries; Taipei, Taiwan	Tafidis et al. (2017), Miranda & Silva (2012), Haghshenas et al. (2012), Santos & Ribeiro (2015), Bojković et al. (2010), Shiau et al. (2013), Castillo & Pitfield (2010), Gilles et al. (2016)
Air quality	Cases of chronic respiratory diseases due to vehicle pollution	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Population exposed to air pollution deriving from the transport sector	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Air quality (PM10)	National	Asia and the Pacific	Gudmundsson et al. (2017)
Commuting	Commuting travel time	Urban, General, National	Curitiba, Brazil: Global Subset of European Countries	Gilles et al. (2016), Miranda & Silva (2012), Bojković et al. (2010)
	Fuel efficiency of PT fleet	Urban	Thessaloniki, Greece	Tafidis et al. (2017)

Energy efficiency	Share of vehicle fleet meeting certain air emission standards	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Energy intensity	National	Subset of European Countries	Bojković et al. (2010)
	Energy efficiency	General	Global	Gilles et al. (2016)
Fossil fuel energy consumption	Type of fuel used in PT fleet	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Per capita energy consumption, by fuel and mode	Urban, National	Thessaloniki, Greece; Curitiba, Brazil; English Regions, UK; Global Cities; Rio de Janeiro, Brazil: Global Countries; Taipei, Taiwan	Santos & Ribeiro (2015), Tafidis et al. (2017), Miranda & Silva (2012), Castillo & Pitfield (2010), Haghshenas et al. (2012), Holden et al. (2013), Shiau et al. (2013)
Fragmentation	Urban fragmentation	Urban	Curitiba, Brazil	Miranda & Silva (2012)
Freight transport	Percentage freight transported by road	Urban, National	English Regions, UK, Subset of European Countries	Castillo & Pitfield (2010), Bojković et al. (2010)
	Truck loading factor	Urban	Taipei, Taiwan	Shiau et al. (2013)
GHG emissions	WTW Emissions of greenhouse gases	General	Global	Gilles et al. (2016)
	GHG emissions from transport (CO2–CH4 tons) per capita	Urban, National	Thessaloniki, Greece; Curitiba, Brazil; English Regions, UK; Global Cities; Rio de Janeiro, Brazil: Asia and the Pacific, Subset of European Countries	Haghshenas et al. (2012), Tafidis et al. (2017), Miranda & Silva (2012), Castillo & Pitfield (2010), Santos & Ribeiro (2015), Gudmundsson et al. (2017), Bojković et al. (2010)
	Emission intensity of GHG	Urban	Taipei, Taiwan	Shiau et al. (2013)
Hazardous materials and environmental damages	Environmental damage relating to transport	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Studies of environmental impacts	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Proximity of transport infrastructure to designated environmentally sensitive areas (ESAs)	Urban	Taipei, Taiwan	Shiau et al. (2013)
Impacts to habitats	Habitat and ecosystem disruption	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
Infrastructure	Condition of transport networks	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Paved/unpaved Road network density	Urban	Thessaloniki, Greece; Curitiba, Brazil	Tafidis et al. (2017), Miranda & Silva (2012)
	Paved/unpaved length	Urban	Thessaloniki, Greece; Curitiba, Brazil	Tafidis et al. (2017), Miranda & Silva (2012)
	Streets signaling	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Transit lanes	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Streets with sidewalks	Urban	Curitiba, Brazil	Miranda & Silva (2012)
Land consumption	Land mix and take by transport infrastructure mode	Urban	Thessaloniki, Greece; Global Cities	Tafidis et al. (2017), Haghshenas et al. (2012)
	Rate of use of urban land	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
Mobility	Satisfaction of citizens and variety and quality of transport options	Urban	Curitiba, Brazil: Global Cities	Haghshenas et al. (2012), Miranda & Silva (2012)

	Travel distance	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Number of trips	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Service intensity of transit	Urban	Taipei, Taiwan	Shiau et al. (2013)
	Loading factor of transit (Occupancy) by mode	Urban, General	Curitiba, Brazil: Global; Taipei, Taiwan	Miranda & Silva (2012), Gilles et al. (2016), Shiau et al. (2013)
	Average passenger travel time	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Occupancy rates of private vehicles	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Mean Travel Time to Work	Urban	Rio de Janeiro, Brazil	Santos & Ribeiro (2015)
Multimodality	Daily or annual passenger-km by mode	Urban, National	Thessaloniki, Greece; Global Countries; Subset of European Countries; Taipei, Taiwan	Shiau et al. (2013), Tafidis et al. (2017), Bojković et al. (2010), Holden et al. (2013)
	Diversity of transportation modes	Urban	Thessaloniki, Greece; Curitiba, Brazil	Miranda & Silva (2012), Tafidis et al. (2017)
	Intermodal connectivity	Urban, General	Curitiba, Brazil: Global	Gilles et al. (2016), Miranda & Silva (2012)
	Modal split of transit by mode	Urban, National	Thessaloniki, Greece; Curitiba, Brazil; English Regions, UK, Rio de Janeiro, Brazil: Asia and the Pacific, Subset of European Countries; Taipei, Taiwan	Shiau et al. (2013), Gudmundsson et al. (2017), Castillo & Pitfield (2010), Tafidis et al. (2017), Miranda & Silva (2012), Santos & Ribeiro (2015), Bojković et al. (2010)
	Intermodal integration	General	Global	Gilles et al. (2016)
New, smart and green technologies	Use of clean energy and alternative fuels by fuel, by mode	Urban, National	Thessaloniki, Greece; Curitiba, Brazil: Global Cities, Global Countries; Taipei, Taiwan	Miranda & Silva (2012), Tafidis et al. (2017), Haghshenas et al. (2012), Holden et al. (2013), Shiau et al. (2013)
Non-motorised modes	Length of cycling and walking paths	Urban, General	Global; English Regions, UK	Castillo & Pitfield (2010), Gilles et al. (2016)
	Density of cycling and walking paths	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Cycle parking availability	Urban	Thessaloniki, Greece; Curitiba, Brazil	Tafidis et al. (2017), Miranda & Silva (2012)
	Bicycle fleet	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Number of cycling trips	Urban	English Regions, UK	Castillo & Pitfield (2010)
Public expenditures, investments and subsidies in transport system	Direct subsidies to PT	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Investment in transport infrastructure (per capita and mode as share of GDP)	Urban, National	Thessaloniki, Greece; Curitiba, Brazil: Global Cities, Asia and the Pacific	Tafidis et al. (2017), Miranda & Silva (2012), Haghshenas et al. (2012), Gudmundsson et al. (2017)
	Taxation of vehicles	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Total expenditure on pollution prevention and clean-up	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Total per capita transport expenditures	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Distribution of resources (public x private)	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Distribution of resources (motorized x non-motorized)	Urban	Curitiba, Brazil	Miranda & Silva (2012)

	Maintenance expenditures in transport infrastructure	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Public subsidies	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Transport infrastructure in remote areas	Urban	Taipei, Taiwan	Shiau et al. (2013)
	Transport subsidy in remote areas	Urban	Taipei, Taiwan	Shiau et al. (2013)
	Net public finance	General	Global	Gilles et al. (2016)
Public transport	PT network coverage	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	PT size in relation to population	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	PT comfort	Urban, General	Thessaloniki, Greece; Global	Tafidis et al. (2017), Gilles et al. (2016)
	PT occupancy	Urban	Thessaloniki, Greece; Curitiba, Brazil	Miranda & Silva (2012), Tafidis et al. (2017)
	Average age of PT fleet	Urban	Thessaloniki, Greece; Curitiba, Brazil	Miranda & Silva (2012), Tafidis et al. (2017)
	Transit service frequency (and peak)	Urban	Thessaloniki, Greece; Curitiba, Brazil	Miranda & Silva (2012), Tafidis et al. (2017)
	On-time performance	Urban	Thessaloniki, Greece; Curitiba, Brazil	Miranda & Silva (2012), Tafidis et al. (2017)
	Transit average speed	Urban	Thessaloniki, Greece; Curitiba, Brazil	Miranda & Silva (2012), Tafidis et al. (2017)
	Annual number of passengers	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Quality of public transport	Urban, National	English Regions, UK; Asia and the Pacific, Subset of European Countries	Castillo & Pitfield (2010), Gudmundsson et al. (2017), Bojković et al. (2010)
	Superior public transport network (trams, light rail, subway, BRT, VLT)	Urban	Rio de Janeiro, Brazil	Santos & Ribeiro (2015)
	The ratio of bus exclusive lanes	Urban	Taipei, Taiwan	Shiau et al. (2013)
Recycling	Recycling of used tires	Urban	Taipei, Taiwan	Shiau et al. (2013)
	Recycling of end-of-life vehicles	Urban	Taipei, Taiwan	Shiau et al. (2013)
Safety	Road safety and vulnerable users	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Traffic accidents	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Accidents with pedestrians and cyclists	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Accident prevention	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Traffic education program	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Vulnerable road user accidents	Urban	English Regions, UK	Castillo & Pitfield (2010)
	Fatality and injured of traffic accidents per capita	Urban, General, National	Thessaloniki, Greece; Global; English Regions, UK; Global Cities; Rio de Janeiro, Brazil: Asia and the Pacific, Subset of European Countries; Taipei, Taiwan	Haghshenas et al. (2012), Tafidis et al. (2017), Gilles et al. (2016), Castillo & Pitfield (2010), Santos & Ribeiro (2015), Gudmundsson et al. (2017), Bojković et al. (2010), Shiau et al. (2013)
Security	PT security	Urban	Thessaloniki, Greece	Tafidis et al. (2017)

	Security	General	Global	Gilles et al. (2016)
Social equity	Vertical equity (income)	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Quality of life	Urban	Curitiba, Brazil	Miranda & Silva (2012)
Traffic congestion	Congestion	Urban, General	Curitiba, Brazil: Global	Miranda & Silva (2012), Gilles et al. (2016)
	Average traffic speed	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Total time spent in traffic	Urban	Global Cities	Haghshenas et al. (2012)
Traffic noise	Population exposed to traffic noise	Urban, General	Thessaloniki, Greece; Curitiba, Brazil: Global; Global Cities	Miranda & Silva (2012), Tafidis et al. (2017), Haghshenas et al. (2012), Gilles et al. (2016)
Transport costs and prices	Direct user cost referring to travel by private vehicles	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Direct user cost referring to travel by PT	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Fuel prices and taxes	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Transport expenses	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Transit fares	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Household expenditure allocated to transport (%budget)	Urban, National	Global Cities; Rio de Janeiro, Brazil, Subset of European Countries	Haghshenas et al. (2012), Santos & Ribeiro (2015), Bojković et al. (2010)
	Operational costs of the public transport system	National	Asia and the Pacific	Gudmundsson et al. (2017)
Transport external costs	Internalization of costs	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Social/External costs of transport by mode	Urban	Thessaloniki, Greece, English Regions, UK	Castillo & Pitfield (2010), Tafidis et al. (2017)
Urban planning and land-uses	Vacant land	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Urban growth	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Urban population density	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Mixed land use	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Illegal settlements	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Parks and green areas	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Urban facilities (schools)	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Urban facilities (hospitals)	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Master Plan	Urban	Curitiba, Brazil	Miranda & Silva (2012)
	Mobility space usage	General	Global	Gilles et al. (2016)
	Functional diversity	General	Global	Gilles et al. (2016)
	The effect of public depot on freight transshipment	Urban	Taipei, Taiwan	Shiau et al. (2013)
Vehicles fleet	Private car ownership	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
	Average age of vehicle fleet	Urban	Thessaloniki, Greece	Tafidis et al. (2017)

	Structure of road vehicle fleet	Urban	Thessaloniki, Greece	Tafidis et al. (2017)
Waste	Transport-related waste and related recovery rates	Urban	Thessaloniki, Greece	Tafidis et al. (2017)

It can be seen in Table 6 that many of the themes have multiple suggested indicators, where some are more related than others. In providing this expansive list of indicators, the goal is to provide policy makers and potential stakeholders a robust list from each theme in which selected indicators can be applied regionally.

Results from the stakeholder analysis

The overarching themes from the stakeholder analysis were Raised awareness, Holistic view, Multimodal approach, and Energy transition. Each theme had several subthemes, which will be presented in more detail in Table 7. Example quotes from each subtheme are presented in the appendix. They demonstrate how the participants described the themes they emphasized, which then led to the selection of the four main and ten subthemes in the below table. The third column in Table 7 list aspects belonging to each main theme.

Table 7. Overarching themes and sub-themes identified through the stakeholder analysis

Overarching themes	Sub-themes	More detailed description (actions, opportunities, challenges etc.)
Raised awareness	Current attitude	Culture, weather, attitude towards public transportation, car ownership, responsibility, technocrats
	Attitude change	Flexible work arrangement, changed lifestyle, changed pace, resistance
Holistic view	Allow for mistakes / R&D	Tenders, appeals, political landscape
	Long-term and comprehensive thinking	Decisions made beyond political term periods, think in decades instead of years, vision for the future, clear long-term goals that help businesses organize themselves, prioritization, system boundaries, adapting, stop thinking in silo's, comprehensive approach, lifecycle approach
	Clarity & transparency	Simplify regulatory framework, increase visibility

	Coordinated goals	Ensure goals and actions are not working against each other, conversation between different stakeholders, responsibility of actors, action plan linked to goals, unrealistic goals
Multimodal approach	Incentives	Make alternative transportation modes competitive to private car, attractive & available (Scooters, car sharing, car rentals, bike sharing, public transportation, coordinated "frístundaakstur"), market failures
	Planning & infrastructure	Densifying, phase out gas stations, planning for better public transportation, walking and cycling rather than private cars, the market drives technological solutions rather than multimodal solutions
Energy transition	Planning & infrastructure	Charging stations all around the country, Keflavík electricity infrastructure, no development in alternative fuel vehicles other than electric, little demand and supply for biofuel and biogas
	Incentives	For individuals to switch to alternative fuel vehicles, for companies to switch to alternative fuel vehicles, for companies to produce alternative fuel, R&D incentives

Discussion

As discussed in the introduction of this chapter, SUM is a difficult to define concept and its facets can be measured in a myriad of ways, as seen by the wide-ranging field of indicators in the field of research and the long list produced by the results of this study. Defining and measuring *how to move towards* a SUMS, defined as a sustainable state, and not just a slight improvement as described in Chapter 4 can be equally as challenging. The results of this work thus provide an interesting perspective of providing an entire suite of indicators that can be assessed by policy makers for potential implementation of a sustainable consumption corridor. This work additionally provided a stakeholder analysis as a compliment to this work to see if stakeholders have the same perception of what a SUM system would look like.

The long list provided by this research is actually a first step towards the implementation of a sustainable consumption corridor, where it can be seen that in many cases there are similar indicators aiming to measure similar issues in different ways (such as the time it takes to get to the nearest public transit location as opposed to distance). This list can thus be reduced even further when performing the case study relevant steps shown in Figure 22. The next step in this research will then be to collaboratively work with Reykjavik stakeholders to select the most Reykjavik-relevant indicators and assess the availability of the data to create an initial measurement of the system and develop relevant thresholds. The implementation of this could assist in developing a participatorily generated operationalized sustainable consumption corridor.

When discussing the movement towards this participatory approach, of additional interest is the results from the stakeholder engagement, where specific issues saw a significant focus. In general, the results showed that stakeholders saw the issue from multiple perspectives, where raised environmental awareness, interest in a multi-modal approach, and the energy transition were key themes that emerged from the stakeholder assessment. Interestingly, the last theme was a “holistic view”, which highlights a systemic understanding from the stakeholders, where it was acknowledged that a coordinated approach with long-term thinking and transparency would be a key to a transition along any of the other three themes.

Reviewing these two results and particularly the sustainable corridor concept together an interesting takeaway is that while the stakeholders' feedback naturally accumulated into a formulation of an Avoid-Shift-Improve mindset and what governance needs to occur to achieve these gains, there was a lacking discussion surrounding social implications of transport. While themes surrounding social obligations in terms of attitudes arose, very little discussion was had on mobility poverty, or accessibility. Rather the discussion surrounding public transport is the culture surrounding Icelander’s general lack of use of public transport due both to perception of transit as well as due to its lack of coverage. This perception of public transport can be attempted to be measured using the “Satisfaction of citizens and variety and quality of transport options” indicator, where an attempt to measure the quality of the transport in the eyes of the public can be performed. However, the perceived quality of the transit system and cultural sentiments towards the transit system could potentially be misaligned. For example, in a quote from one of the focus groups, “*no Icelander was brought up with strong public transport here*”, this sentiment highlights a potential case where the quality of the public transit could be good, but historical-cultural implementation and use may lead to a lack of correlation between perceived quality and use. This highlights one of the weaknesses of indicators, where not all measurements may reflect reality.

The stakeholders did however emphasize the need for a holistic approach. While indicators may potentially have some shortcomings, a SUM indicator suite informed by stakeholders could work to develop such a holistic approach, where the indicators should be robust enough that it encapsulates a sustainable system, and the integration of thresholds is of key importance for understanding what needs to be reached and why. For without goals and targets, measurements have the potential to lose their meaning. It is for this reason that we have provided this suite of indicators, and through the coming work and the developments provided in this research, a safe and just operating space for Reykjavik’s urban mobility system can be defined and measured.

Chapter 6: Concluding remarks

The global carbon budget left for not to exceed 1.5-degree warming is alarmingly low, only around 300-400 gigatonnes of CO2, meaning no more than 10 years at the current global yearly emissions level of 40 gigatonnes (Ritchie and Roser 2020). Moreover, the global average per capita emissions are ~5 tonnes per year (Ritchie and Roser 2020), which is equivalent to the GHGs from just private transport in Reykjavik when including long-distance travel (Czepkiewicz et al. 2019). While flights dominate these emissions in Reykjavik, private cars contribute over 2 tons per year per capita - a massive amount in global terms and given the rapidly shrinking carbon budget for 1.5-degree warming. The transformation of the transport sector, therefore, needs to be rapid and profound.

Despite the significant amount of work around the topic of sustainable urban mobility, the state of knowledge is still strikingly weak. In this report, we have focused on two aspects with which the prevailing thoughts are largely based on weak knowledge or simply omitting important factors due to limited knowledge about them. The first of these is the potential of private vehicle fleet electrification to reduce the emissions from the transport sector, which was in the nexus in Chapter 1. Electrification is pushed forward by governments across Europe (Dillman et al. 2020), and it is hoped to significantly push down the transport sector emissions in Reykjavik also. However, rapid turnover of the vehicle fleet leads to high production-phase emissions, typically occurring elsewhere than where the vehicles are used. Since the production phase emissions of EVs are substantially higher than those of combustion engine vehicles (Dillman et al. 2020), in the short term there is no gain but rather an increase in the global emissions associated with EV adoption. In Reykjavik the renewable energy production system leads to relatively low “carbon payback times”, but still the scenarios we ran and showed in Chapter 1 highlighted that fleet electrification needs to be accompanied by a significant reduction in car ownership for global decarbonization of transport in Reykjavik. It seems clear that even though electrification of the fleet is a desirable development direction in Reykjavik, it is not sufficient and should be supported with measures reducing car dependency. In Chapter 2 we showed a concept for an optimization framework to guide the work of a city towards decarbonizing the transport sector with any given current or future status of the system. Additionally, Chapter 3 shed light on the future grid requirements when EVs change the demand and particularly the peak loads. While there are several technological and price mechanism-based solutions to lowering the peak loads, reduced car dependency remains as the solution with by far the highest associated benefits.

The second weakness, covered in Chapters 4 & 5, is the missing connection to any sustainability baselines of the indicators typically utilized to monitor the work towards a SUMS. What these indicators show is progress or improvement with different issues with sustainability-relevance, but they fail to tell when a system might be sustainable (or even just a certain aspect of it), or what it truly means for an urban mobility system to be sustainable. The latter issue might even lead to the wrong development direction being considered as progress towards a SUMS. In Chapter 4 we introduced a novel concept of a domain-specific sustainable consumption corridor, focused on urban mobility and accessibility, where we lay the foundation for the first framework for analysing the absolute sustainability of a mobility system. The framework consists of both ecological and social aspects of sustainability. The latter is particularly important for the mobility sector, as it provides an important means for meeting human needs and meaningful participation in the society and economy. Any effort at reducing car dependence, particularly in highly car-oriented locations, such as the Capital Region, has to be mindful of its implications on society and its welfare. We hope that the work included in the chapter contributes to an equitable and just transformation of the transportation sector in the region. The work with the best possible indicators and the thresholds for them is in its infancy, but the framework created can guide the work in the future. Chapter 5 added to this a long list of indicators suggested in academic literature, and a stakeholder engagement analysis in Reykjavik to allow comparisons and gap analyses.

Based on the materials presented in this report, and the lessons learned from these different components, we suggest the following focus themes for future SUMS work in Reykjavik:

1) Focus on the global impacts, not only those occurring within city limits.
2) Focus on reducing car dependency.
3) Focus on defining what it means for the transport system to be sustainable in Reykjavik.
4) Focus on finding and selecting a sufficient set of indicators with clear threshold values, upper and lower, for a sustainable state of the system.

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Appendix

Example quotes from each subtheme are presented in the following subchapters.

Raised awareness: Current attitude

Focus group 1: What should one say about carbon neutrality in a car city like Reykjavík where there are, don't we have more cars than children? ... Although naturally the city is so scattered that it is perhaps not strange that people feel the need to own cars. Public transport is also nothing to cheer about.
Focus group 1: Just the cars are just all way too many I think.
Focus group 1: no Icelander was brought up with strong public transport here
Focus group 3: one just needs to remember how conservative human beings are by nature and somehow think that nothing is changing
Focus group 4: people have started using the bike, or walking or even running to work much more than before
Focus group 3: awareness and recognition of the problem has increased incredibly much in recent years, but sometimes I feel like that we write it a bit off like other people's problem because we do not feel it quite as much on our own skin here as in other nations .
Focus group 4: humanity is so fixated on technological solutions, this western world we are all such technocrats. We believe that technology will solve all problems.
Focus group 4: I'm just not seeing that people will run to the train station that is far away and leave the car at home. The children also need to be driven at this time and this is just the way our society is here in Iceland and it does not offer these solutions.

Raised awareness: Attitude change

Focus group 1: There has been a great awakening among the nation regarding, for example, other modes of transport, whether it is bicycles or electric scooters.
Focus group 1: I believe that it is now possible to change people's attitudes and get more people here to use certain modes of transport, and umm public transport.
Focus group 4. So it's just a question of changing our behaviour
Focus group 3. But you just have to rethink life a little bit and you know how we are ready to live our lives.
Focus group 3: we are suddenly forced to change and what a great opportunity there is to have some kind of office in a system core where maybe you can just go to work maybe three days a week and go two days a week to a bigger place like this .
Focus group 4: ... cause a change of mindset that causes people to stop using their car and even go out when the weather is not perfect but even when the weather is then awful you can have the opportunity to be working from home
Focus group 3: I am completely in favor of paying for pollution. That's right, but it's worth looking at more aspects. This affects people and families ... If it goes too far, resistance will form.

Holistic view: Allow for mistakes / R&D

Focus group 2: people do not dare to take the step for fear that there will be some mistakes and mistakes are not acceptable in Iceland today. It's just sorry. The culprits are always being sought. It has hurt a bit for this attitude towards such specific things and people are always waiting for someone to make a mistake so that it can be discussed in Kastljós or something else. So you sometimes notice decision anxiety from that point of view.
Focus group 2: this way of thinking also kills everything like that, all the efforts to go into innovation, because innovation naturally means that there is quite a chance that there will be, I do not want to say a mistake, but that it is something that does not work as it was supposed to work and it needs to change but I, I mean everywhere in the countries around us it's just called, you know, research and development department and it's just recognized that you have to put some money into it because otherwise you will not be able to move on.
Focus group 2: we public companies need to apply this law to our procurement and everything gets appealed. It's just like that
Focus group 4: Everyone started suing *company* for trying to bring methane to the market and our hands were just tied.

Holistic view: Long-term and comprehensive thinking

Focus group 2: I think the role of the public sector is to look a little further ahead. Not always thinking in the short term, I do not know specifically how the times are now but the government needs to be able to put things this way, what are the long term effects of saving money today and what is one gaining something, one is losing maybe something in the long run for being able to save a little something today. Do you understand where I'm going?
Focus group 1: If the plan is in place, if the report for the next 5 years is what the government is really going to do, some election promises that are always betrayed, you know, then it's something that the private sector could take and work with.
Focus group 3: it's just a matter of priorities, you know where to start, you know, there are so many opportunities.
Focus group 3: Of course, you are looking at certain system boundaries, but you need to understand what is happening outside of them.
Focus group 4: Of course, we are dependent on technological advances in mechanical engineering and battery technology from abroad. We have very little to say about it, but we can adapt our production and energy to the equipment and tools available.
Focus group 4: not enough to reduce emissions at any given time or to be neutral at any given time because we have emitted a lot in the past.
Focus group 3: [we need to] reduce motor transport emissions, whether it is the production of vehicles, production or energy or driving itself. As we reduce motor vehicle driving, we are reducing emissions.

Holistic view: Clarity & transparency

Focus group 1: It often strands with the administration. Simple solutions.

Focus group 2: Very cumbersome in this process, planning issues are extremely heavy, you know, and changing the environment and it also comes into play with the charging stations that Heiðar and Jón Björn were talking about. That this can be a process of several years to get through all, all the organizational stages.
Focus group 1: there are still various shortcomings in regulations and other things that make it difficult for us.
Focus group 3: We pay close attention to particulate matter pollution because there is always regular news that it is so noticeable and measured every day. I find this climate thing much more intangible. ... It is always a good incentive to be able to compare yourself to others. A bit of peer pressure. ... Whether it would be possible to do something similar that tells us better what the situation is today and then we can follow the development.   Focus group 3: It's completely unclear still, nothing clear from 2017 since this was stated in the government charter what this entails [carbon neutrality of the capital area].
Focus group 3: I also often feel the need to know how, what criteria we are setting for policies.
    Focus group 4: then we can set ourselves a clear goal that we are going to use domestic energy sources instead of talking about carbon neutrality, or just talk about banning the import of something.

Holistic view: Coordinated goals

Focus group 2: There is one thing I would also like to mention that may not be a direct stimulus to us, but that is that the National Energy Authority may have one goal and the Environment Agency another goal that complicates, there is a lot of reporting on both parties and another maybe just simplify the goals and summarize it into one.
Focus group 2: for example, the city has had concessions for the construction of infrastructure in apartment buildings and the like, electric cars and the like, but the state then has its concessions and funding for the construction of infrastructure and so on. Conversation between municipalities and the state regarding doing this together and coordinating how it would be structured regarding infrastructure and also like we've talked a lot here, to look a little further ahead. Is something that would be beneficial
Focus group 4: no one is cooperating and no one is ready to take any steps. There is a lack of funding for this and there is something missing in this system that we have created and meanwhile these black oil importers have control over what consumers can do.
Focus group 3: Maybe to add the perspective of where you are locating the settlements and what you are offering in the local area and and what it takes for it to thrive and and to reduce the need to go far and in that area we are so often working against such goals.
Focus group 3: we are doing our best but still we are not achieving these goals. But what we are doing in this country regarding electric cars is among the best in the world. ... why do we have a goal that is completely unachievable? ... We are left with a difficult issue that is energy, decarbonization of transport
Focus group 3: the companies are so many and varied. So the ways we are going are going to be so different

Multimodal approach: Incentives

Focus group 2: one of the biggest projects in this area is the transport agreement and the Borgarlína and cycle paths and support for changed travel habits
Focus group 3: We have not begun to use economic incentives, that is to say, negative economic incentives with force in these matters. We are abolishing VAT on electric cars here and we are abolishing VAT on electric bicycles and bicycles and we are... these are positive, yes ok guys, some little carrots for you guys but we are not raising the carbon tax or trying in any way to reduce oil consumption, I feel.
Focus group 3: ...the government then needs to invest in better options and offer them
Focus group 4: We can not just let traders rule. We also have to somehow create incentives in a system that has built-in market failures
Focus group 4: stop encouraging people to use the car, both directly and indirectly, by continuing to support the infrastructure that makes it the only real option.

Multimodal approach: Planning & infrastructure

Focus group 2: when it comes to rushing to throw down charging stations, it is perhaps slow in some places, as one may encounter problems with plot boundaries and ownership here, and here the planning process, and then perhaps politics, on the contrary. While one feels many things are happening so fast in the world.
Focus group 2: Planning, planning I can not hammer enough on it. If we can just make it possible for people to walk more.
Focus group 1: many petrol stations here in the capital area are interpreted, are classified as, as development sites. They should clearly give way but then naturally have to go hand in hand with some alternative for people to charge their electric car
Focus group 4: The main opportunity for the capital area is first and foremost a change in travel habits and public transport. … Rather than the decarbonization but that is of course also important.
Focus group 4: I find it a bit sad when the discussion about the energy shift is that we should not change anything except switch to electric cars. However, it does not solve many of our problems like particulate matter.
Focus group 3: The least carbon emissions are walking or cycling, and I find that very often in the debate when it comes to technological solutions. How, in fact, how do we remove the exhaust from vehicles and instead of thinking "no maybe we do not need these vehicles" ... the market pushes us a lot in that direction [towards technological solutions].

Energy transition: Planning & infrastructure

Focus group 1: it's amazing to see the change over the last 10 years in the number of charging stations around the country. If I were to look at it today, there is a dense network of charging stations around the country
Focus group 2: infrastructure that has been a bit of a bottleneck

Focus group 1: there is a lack of electricity in the Suðurnes. This is just a ridiculous problem. You know that it is not possible to electrify the Suðurnes because it lacks electricity. Icelanders do not lack electricity. There is plenty of electricity. It's just lying somewhere so it's not there.
Focus group 3: one obstacle is clearly the cost. It is extremely costly to build, you know, new infrastructure and change society
Focus group 4: There are still a lot of private cars on methane, although car manufacturers have actually stopped developing the methane car. It's all in the electricity. All the capital that goes into new development on cars or, as they say, new, new technology for driving cars is in the electricity or hybrid cars and little development in methane.
Focus group 4: there is no great interest on the part of the oil companies, for example, to use this as an additive [biofuel from animal fat].
Focus group 4: There is no distribution system, it is not possible to buy methane, it is not possible to buy hydrogen.
Focus group 4: it always strands on who pays for what we want to install. For example, one biodiesel plant for making rapeseed biodiesel. It takes 800 million to one billion to build ... Just this little 800 million we need to make one factory to receive oil to convert into biodiesel that the oil companies could take and mix into the diesel instead of importing tens of thousands of tons of rapeseed oil..