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Driving Urban Transitions (DUT):

Strengthening the climate neutrality of cities and well-being of citizens through sustainable transport and mobility

Authors: Anu Tuominen (VTT), Henna Sundqvist (VTT), Mari Hukkalainen (VTT), Minna Aittasalo (UKK Institute), Jouni Tuomisto (Kausal Oy)

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beyond the obvious

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Summary

The aim of the project was to strengthen the transport climate actions of the six Finnish Cities mission cities—Espoo, Helsinki, Lahti, Lappeenranta, Tampere, and Turku—by identifying and concretizing measures that promote both transport climate targets and the well-being of city residents. The project contributes to the greater targets for reducing cities' GHG emissions from transport, a challenge that is addressed in the EU Climate-Neutral and Smart Cities (EU Cities Mission), where 112 frontrunner European cities aim for climate neutrality by 2030, as well as in the European Partnership for Driving Urban Transitions.

The project contributions towards the aim are the following. The project:

- identified key measures of a generic action portfolio supporting behavioural change towards both sustainable urban mobility and well-being of individuals,
- developed a model to assess the co-benefits of selected measures on sustainable urban mobility and well-being,
- developed a tool for transformative capacity building to support cities in the implementation of sustainable mobility and health promotion activities.

The project results showed that sustainable mobility actions targeting to increase in active modes and modal shifts from private cars to sustainable modes do not provide extensive contribution to climate change mitigation. The previous scientific research and the modelling exercise of the project indicated that the wider benefits of those actions come from health and wellbeing impacts of individuals.

The project also produced recommendation on how to further promote sustainable mobility actions with health benefits as an integral part of future mobility, climate action and other relevant plans.

Espoo, 14.1.2025

Written by
Anu Tuominen (VTT), Henna Sundqvist (VTT), Mari Hukkalainen (VTT), Minna Aittasalo (UKK Institute), Jouni Tuomisto (Kausal Oy)

Reviewed by
Carlos Lamuela Orta (VTT)

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VTT's contact address
anu.tuominen@vtt.fi

Distribution (customer and VTT)
Project group and Advisory Board

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1. Introduction and objectives

To address the ongoing anthropogenic climate crises, the European Union has established ambitious climate targets, including a 55% reduction in emissions by 2030 and achieving climate neutrality by 2050 (European Commission 2019). Cities play a crucial role in meeting these targets, as 75% of the EU population resides in urban areas (European Commission 2024). This concentration makes cities hot spots for energy consumption and greenhouse gas (GHG) emissions, especially from transportation.

For instance, in Finland, the share of transport in country's total GHG emissions was approximately 23% in 2023. Transport is the largest source of emissions within the national non-Emission Trading Sectors (ETS) (Siljander et al. 2023), and thus one of the key sectors where emission reductions are needed, especially in urban areas aiming for carbon neutrality. Transport GHG emissions have generally decreased from 2008 to 2023, but in the coming years, the amendment to the distribution obligation law outlined in Prime Minister Orpo's government program and the potential slowdown in electric vehicle sales are expected to increase emissions.

Measures to reduce greenhouse gas emissions from transportation in Finland are divided into three main groups, which align with the European Commission's Strategy for a Sustainable and Smart Mobility (European Commission 2020):

- Replacing fossil fuels with alternative power sources
- Renewing the vehicle fleet through transportation taxation measures
- Improving the efficiency of the transportation system

From the perspective of urban carbon neutrality, the most cost- and resource-efficient group of measures—improving the transportation system—has received relatively little attention in national-level policy discussions. Therefore, it is important to explore the opportunities it presents in more detail. The transport system is a broad entity that includes various infrastructures, vehicles, services, administrative structures, legislation, and actors such as companies, municipalities, individual consumers, and other decision-makers. All actors have their own transportation-related needs, desires, and goals, and they should be guided and encouraged to take sufficient emission reduction measures and change their behavior in a direction favorable to climate change mitigation. Therefore, achieving transport GHG emission reduction targets require a system-level change and a sustainability transition, involving the actions of all the aforementioned groups. Previous research has shown that it is essential to build a set of measures where individual actions support each other, enhancing the overall impact, acceptability, and feasibility.

Due to the complexity described above, demonstrating and making visible the effects and impacts of GHG emission reduction measures in transport is often perceived as challenging. Identifying the benefits that encourage climate actions is also not always straightforward. Therefore, more information is needed on the impacts and co-benefits of sustainable mobility, including financial effects. Improving personal well-being, in particular, seems to motivate the use and promotion of sustainable modes of transport, which is why more information is needed on the combined effects of actions related to these topics (e.g., Suomalainen et al. 2024).

Cities have a long tradition of car-based transport and urban planning. This is reflected in the reduced physical activity and, consequently, the decline in public health and increasing health care costs. While the car-centric lifestyle still prevails, there are also weak signals of a shift towards more active, healthy, and sustainable mobility patterns in Finland: carlessness is becoming more common in dense and large cities. In the Oulu region, the popularity of cycling is significant compared to other urban areas in Finland. In Helsinki, the conditions for reducing car use have increased. According to the recent national studies measuring school children's physical activity, children in urban areas are more active than those in rural areas (Paloniemi et al. 2023). Figure 1 shows the modal shares of walking and cycling as a share of trips in Finland in 2021.

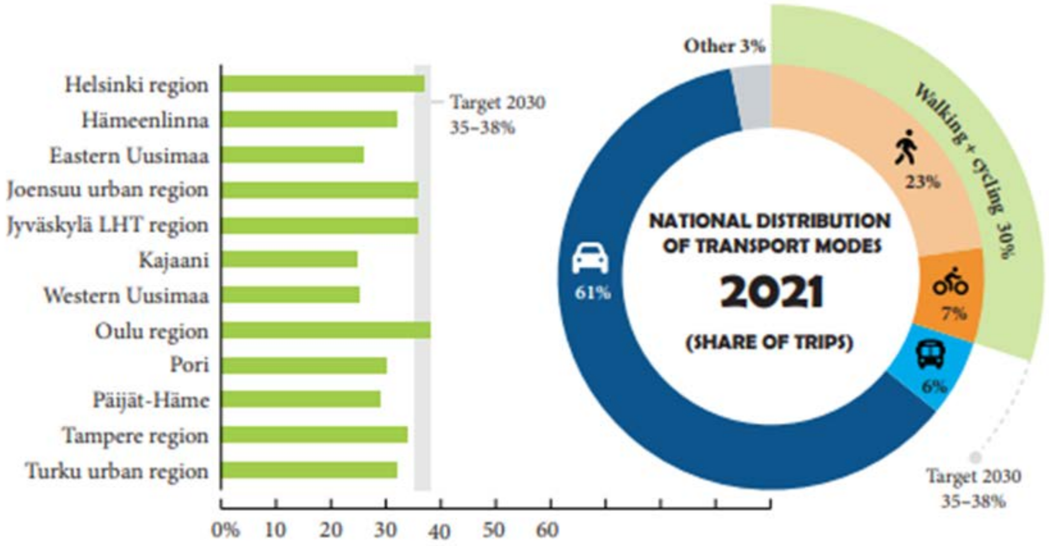

Figure 1. Walking and cycling as a share of trips in 2021 (Paloniemi et al. 2023 based on National Travel Survey 2021).

The climate change is a global challenge. Another critical challenge of the western societies is the sedentary lifestyle. The combined effects of these two represent a severe environmental of and public health crisis. For example, in Finland insufficient physical inactivity leads to annual societal costs of approximately 1.5 billion euros in the country (Kolu et al. 2022). Further, too small amount of vigorous and moderate physical activity causes annual costs of more than 3 billion euros. Only about a third of children and a quarter of adults meet the national physical activity recommendation in Finland. The figure is even lower for the elderly and disabled persons. For about 40 percent of children and young people, the physical condition may hinder daily activities (Valtion Liikuntaneuvosto 2023).

European Commission has introduced several Horizon Europe research and innovation initiatives in urban context, such as Driving Urban Transitions (DUT) for a Sustainable Future program which is a joint-programming initiative. The European Partnership DUT program's sustainable mobility-oriented activities under *15-Minute City Transition Pathway* aim at 'rethinking the existing mobility system and urban morphology to encourage sustainable mobility choices, redistribute urban space and reorganize our daily activities so to make our cities more climate neutral, livable and inclusive' (Urban Europe 2024).

Cities' transition work is supported via the EU Mission *100 Climate-Neutral and Smart Cities by 2030* (European Commission 2024) and related NetZeroCities programme and knowledge platform (NZC), supporting cities in putting their climate ambitions into action. Six Finnish cities: Espoo, Helsinki, Lahti, Lappeenranta, Tampere, and Turku, have been accepted to be part of the EU Cities Mission and they have received the EU Mission Label. The label acknowledges successful development of Climate City Contracts (CCC's), which outline the cities' overall vision for climate neutrality and contain an action plan as well as an investment strategy.

The six Finnish Mission Cities, in collaboration with some national level actors, have established a national network for collaboration. This work builds on a recent national project, *Climate-Neutral and*

Smart Cities Mission: Co-Creation Support Project for Cities[1]*,* initiated by the network and commissioned by the Finnish Ministry of Economic Affairs and Employment and Ministry of Environment in 2023. As a result of the project, solution proposals and ideas were generated for various themes related to sustainable mobility transition. For example, the need to emphasize the health and well-being benefits of sustainable urban mobility and to make the impacts more visible was identified.

This report and work contribute to the implementation of the aforementioned initiatives in Finland. The work aims to strengthen the transport climate actions of the six Finnish mission cities—Espoo, Helsinki, Lahti, Lappeenranta, Tampere, and Turku—by identifying and concretizing measures that promote both transport climate targets and the well-being of city residents. The goals of the project include:

1) **Identifying key measures to create a generic action portfolio** supporting behavioural change towards both sustainable urban mobility and well-being of individuals,

2) **Developing a model to assess the co-benefits of selected measures** on sustainable urban mobility and well-being, and finally,

3) **Supporting cities in the implementation of activities** through transformative capacity building.

[1] Ilmastoneutraalit ja älykkäät kaupungit -mission kaupungeille suunnatun yhteiskehittämisen tuen hanke, (Sitowise, 2023).

2. Promoting sustainable mobility and behavioural change

2.1 Sustainable Mobility approach

The classical approach of Sustainable Mobility first introduced by David Banister in 2008 (Banister 2008) emphasises **four types of actions required to increase the sustainability of the transport systems**. These are: 1) actions to reduce the need to travel (less trips); 2) actions to encourage modal shift; 3) actions to reduce trip lengths; and 4) actions to encourage greater efficiency in the transport system.

Actions to reduce the need to travel aim to prevent unnecessary trips (especially by cars), replacing trips by a non-travel activity or substituting it by for example on-line activity. **Actions to encourage modal shift**, refer to policy measures that can reduce levels of car use through the promotion of walking and cycling and by developing the new transport hierarchy. This can be achieved for example through slowing down urban traffic and reallocating space to public transport, through parking controls and road pricing, and through making it easier to use public transport (Banister 2008).

Actions to reduce trip lengths are land-use policy measures, which address the physical separation of activities and the means by which distance can be reduced. The actions are targeted towards patterns of urban form and layouts (e.g., mixed use developments, space and route layouts, car-free areas and the availability and locations of public and private services), which in turn may lead to a switch to green modes of transport. Finally, in the **actions to encourage greater efficiency** in the transport system, the role of technology is important, as it impacts the efficiency of transport directly through for example alternative fuels, engine design and renewable energy sources.

2.2 Socio-ecological model

Socio-ecological models (e.g., Sallis et al. 2008) are widely used **multilevel approaches** in the fields of health behaviour and public health (Figure 2). They integrate multiple life contexts relevant to modifying individual person's behaviour (Stokols 1996). Multilevel approaches may improve the effectiveness of behaviour change interventions and better reach population groups, which are underrepresented in single-level interventions (Stokols 1996).

Previous studies indicate that adults' travel behaviour is influenced by complex set of multilevel factors (e.g., Sulikova and Brand 2021). Multiple levels are included also in the conceptual framework of active travel behaviour (Götschi et al. 2017). As a result, the most recent reviews on interventions changing travel behaviour support multicomponent approaches (Cleland et al. 2023, Roaf et al. 2024). However, the reviews also show that such approaches have not been widely utilized in studies promoting change in travel behaviour.

Figure 2. Example of multilevel socio-ecological model.

2.3 Behaviour Change Wheel

Behaviour Change Wheel (BCW) is a synthesis of 19 frameworks of behaviour change found in the research literature (Michie et al. 2011). The purpose of BCW is to help the stakeholders in designing and evaluating effective and executable behaviour change interventions.

The hub of the wheel is COM-B model, which includes three sources needed for the Behaviour (B) to occur: Capability, Opportunity, and Motivation (COM). At the first stage of the process the stakeholders identify what needs to happen in COM in order change B (Figure 3). At the second stage the stakeholders map intervention options most likely to facilitate behaviour change. At the third stage the stakeholders seek best behaviour change techniques (BCTs) and delivery modes for implementation. BCW has been applied to planning (e.g., Krusche et al. 2022, McVicar et al. 2022) and evaluation of travel behaviour interventions (Arnott et al. 2014).

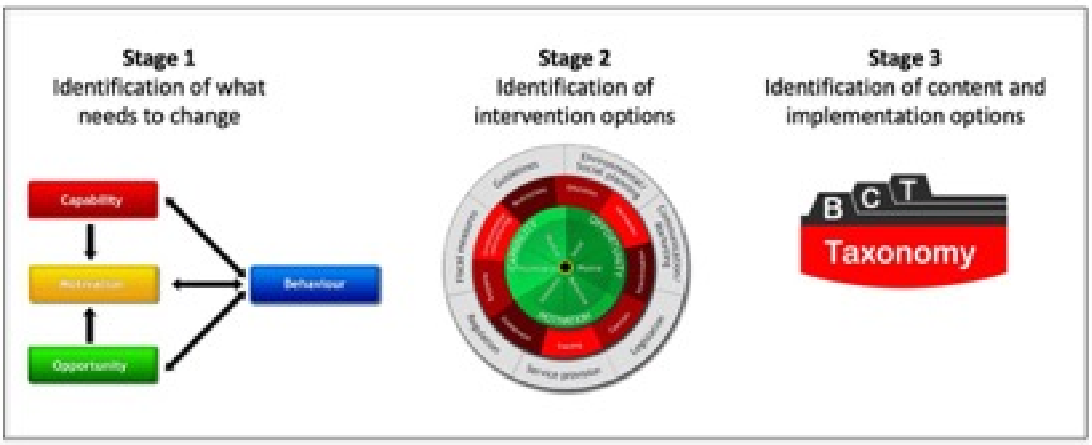

Figure 3.The stages of intervention planning according to BCW (simplified from Michie et al. 2014).

2.4 Supporting sustainable mobility transition in cities through capacity building

During the past decade, local actors have been active around Europe in developing and implementing measures supporting sustainable and active transport. However, the implications of different governance approaches and related activities are hard to assess in local scale due to complex real-life transitions. Fostering local actors' transformative capacity is seen to support their ability to steer transformations. **Transformative capacity** is perceived as *"the ability of public and private actors to steer urban development in a radically different direction from historical pathways"* (Castán Broto et al. 2019).

The role of local capacity building was also addressed recently in the STYLE-project (Healthy Lifestyles to support sustainable growth) funded by the Strategic Research Council of the Academy of Finland, with an aim to create understanding of the key elements that build transformative capacity towards active and sustainable transport in the local context in Finland. The following framework was developed for local purposes to support cities in their capacity building in developing more sustainable and active transport systems.

The developed framework (Tuominen et al. 2022) presents the essential elements in assessing the level of local transformative capacity towards active sustainable transport and provides municipalities and other interested stakeholders with a practical tool to identify and follow the local transformative capacity and contribute to wider sustainability transition. The framework has seven elements and related key factors, which are presented in Figure 4.

ELEMENTS	KEY FACTORS
MULTIFORM GOVERNANCE	• **Visionary individual(s) driving the change** • High-level commitment from the municipality council • Human resources and a budget for development activities • Active stakeholders working constantly to implement the activities/change • Intermediaries supporting the change through their own actions • Knowledge transfer, training with different user groups (youth, the elderly, children, families)
SYSTEM AWARENESS	• Continuous monitoring of active mode volumes • Commonly accepted hierarchy of transport modes (walking-cycling – public transport followed by other means) in planning and resource allocation • **Long-term development strategies and short-term implementation plans for infrastructure to receive measurable results and make an impact**
FUTURE ORIENTATION	• **Local development programmes for active modes with regular updates** • Climate, health issues among the priorities of organisations applying WTP
EXPERIMENTATION	• Long-term focus on and investment in selected themes, allowing the public to experience the change and adjust • **Gradual, step-by-step approach to demonstrate the impact of each measure to decision-makers** • Collaboration of different stakeholders in experiments, sharing the responsibilities
DELIVERING THE IMPACTS AND IMPLICATIONS OF THE EXPERIMENTS	• Continuous campaigning, information sharing, branding and media visibility, since target groups renew and change • **Governmental programmes and grants as a significant funding resource for active mode experiments, but currently lacking process and evaluation criteria for assessing the impacts and scaling up the results.**
EMBEDDING NEW SOLUTIONS, BEST PRACTICES	• Clear responsibilities of stakeholders on sharing information, knowledge, lessons learned, expertise and marketing • Position and resources for an active mode coordinator to bring credibility among other modes and support the active mode identity • **Resources for replication of best practices** (e.g., in WTP), not just for developing new solutions • Delivering practical guidelines, certificates that are easy to take into use as a result
WORKING AND LEARNING ACROSS AGENCIES AND SCALES	• **Clear responsibilities for knowledge production and transfer in collaboration with different stakeholders at local level** • Projects and processes across administrative sectors at local regional and national levels as tools for knowledge production and social learning

Figure 4. Local Transformative Capacity Framework (Tuominen et al. 2022).

2.5 NetZeroCities Climate Transition Map

NetZeroCities Knowledge Platform[2], established by the programme[3] funded by European Commission supports the European Climate Neutral and Smart Cities Mission of the first 100 cities to reach climate-neutrality by 2030. The project has developed a transformative approach, **Climate Transition Map**, for cities accelerating decarbonisation. This transformative approach illustrates and guides cities towards reaching climate neutrality.

The transition requires collaboration, understanding interdependencies between actors and actions to uncover the barriers hindering or preventing change. The pathway to climate neutrality according to the Climate Transition Map is an iterative process consisting of six entities: 1) Building a strong mandate, 2) Understanding the system, 3) Co-designing the portfolio, 4) Taking action, 5) Learning and reflecting, and 6) Making it the new normal (Figure 5). For each of the entities the main aim, tasks and activities to proceed and support as well as required resources are described in this tool.

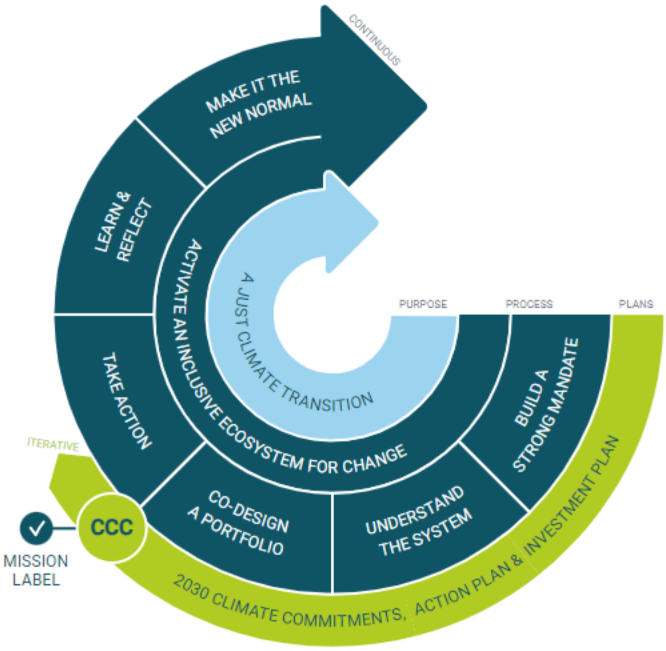

Figure 5. NetZeroCities Climate Transition Map[4].

[2] https://netzerocities.app
[3] https://netzerocities.eu/
[4] https://netzerocities.app/ClimateTransitionMap

3. Methods

3.1 The Approach

The methodological approach of the work entailed qualitative and quantitative elements. Qualitative research focused on document analysis, conducting semi-structured interviews of the representatives of Finnish mission cities, and organising a participatory online workshop. Furthermore, the work included the analysis of co-benefits by quantitative modelling of the impacts.

The work began with the document mapping and analysis. Finnish mission cities' Climate City Contracts (CCC) and Sustainable Urban Mobility Plans (SUMP) formed the basis of data (Table 1).

Table 1. Finnish mission cities' policy documents used in the analysis.

Policy document	Mission cities
Climate City Contract (CCC)	Espoo, Lahti, Lappeenranta, Tampere, Turku
Sustainable Urban Mobility Plan (SUMP)	Helsinki, Lahti, Lappeenranta, Tampere, Turku

Next, information on effective sustainable urban and active mobility measures were sought from academic journal articles, research projects' publications and knowledge platforms, such as NetZeroCities project's knowledge portal[5]. The academic literature search was limited only on review articles, presenting summaries of individual cases.

The policy measures identified through document analysis and stakeholder interviews were compiled into a comprehensive list, categorized based on different frameworks, such as Behavioral Change Wheel (BCW) and Socio-ecological model, as well as existing sustainable urban mobility policy categorizations.

Starting from the comprehensive list, a short list of effective measures forming the Generic Action Portfolio was selected based on wider evidence found from the literature (review articles and summary reports), expert evaluation (project team) and stakeholder validation workshop. A part of these shortlisted measures was included in the modelling exercise (*see Chapter 6*). The selection was based on the availability of sufficient quantitative data.

3.2 Participatory research methods: Stakeholder interviews and a workshop

As mentioned earlier, participatory research methods, such as stakeholder interviews and a workshop were applied to collect data, validate findings and engage stakeholders. Regarding stakeholder interviews, a semi-structured interview protocol (Yin 2014) was applied as it allowed flexibility and gaining in-depth understanding on the studied topic. The interview protocol covered following five themes:

1) Climate City Contract and related sustainable urban mobility measures
2) Effective climate actions in urban transport,
3) Measures to promote public transport, walking, and cycling,
4) Measuring, data availability and modelling of impacts

[5] https://netzerocities.eu/

5) Implementation support: transformative capacities, collaboration and funding.

The stakeholder interviews of mission cities were conducted as six online group interviews in October-November 2024. In total, 26 experts participated in city-specific group interviews that ranged from 30-60 minutes (Table 2). Furthermore, 3-5 project's experts participated as interviewers. All the interviews were recorded, and the key findings were summarised as notes.

Table 2. Number of interviewees in the group interviews.

Mission city	Number of interviewees
Espoo	3
Helsinki	8
Lahti	5
Lappeenranta	2
Tampere	6
Turku	2

The interviewees brought into the discussions a diverse range of expertise, for example on:
- climate actions (incl. coordination, emission reductions),
- environmental protection (emissions, noise),
- transport planning (e.g. infrastructures, public transport, modelling),
- urban planning,
- active mobility (walking and cycling) promotion and coordination,
- wellbeing (e.g., planetary)

A two-hour stakeholder workshop was organised on 13th of December 2024 in collaboration with NetZeroCities project. The aim of this participatory online workshop was to present and validate the generic action portfolio and discuss the content and input data of the preliminary model. In total, 24 participants from Finnish Climate Mission Cities, ministries and NZC actors participated the workshop along with six project members. The workshop entailed an introductory part presenting key findings, followed by two interactive working sessions using a Miro board. The first session focused on gathering feedback on the generic action portfolio, including missing relevant instruments as well as potentially irrelevant ones. The second session addressed the modelling approach and focused on gathering insight on how easy it would be for cities to collect the necessary initial modelling data and what kind of use and need the model might have in the cities. The agenda of the workshop is shown in Appendix 1.

3.3 Modelling

Key purpose of the model

The open-source health impact model used is designed to be integrated with greenhouse gas emission calculation models or other models that provide quantitative information on emissions or active mobility. The model combines the WHO HEAT model (WHO, 2024; https://heatwalkingcycling.org) for the health benefits of active mobility and the THL model (Tuomisto et al., 2015; https://en.opasnet.org/w/Health_impact_assessment) for calculating the burden of disease from air pollution. It assesses various health impacts, including the effects of active mobility on mortality, the impact of air pollution on mortality and respiratory infections, and the effect of active mobility on traffic accidents.

Main sources and the logic of the model

The model utilizes the WHO HEAT model's information and calculations by running it on the web and applying it to the local situation in a target city. Health coefficients are derived from the output files to establish the relationship between active mobility and specific health impacts. The THL's burden of disease model, based on attributable fractions, is used to calculate the proportion of the disease burden attributable to air pollutant exposure. The model combines these two approaches and operates on the Kausal platform, requiring input nodes such as CO_2 emissions from road traffic and district heating, active mobility data, population, and discount rate. The full documentation of the health model is presented in Appendix 2.

Relevance for active mobility

The model incorporates the health benefits of active mobility, such as walking, cycling, and electric cycling, by assessing its effect on reducing mortality through increased fitness. It also considers the potential negative impacts of active mobility, including increased exposure to air pollution and the risk of traffic accidents. The HEAT model is used to produce city-tailored estimates of the magnitude of health effects in relation to active mobility, expressed as the time spent on active mobility in the adult population. The model provides insights into the overall health impact of active mobility, considering both its benefits and risks, which can inform decision-making, and policies related to promoting active transportation in urban environments.

In summary, the open-source health impact model combines the WHO HEAT model and the THL burden of disease model to assess the health impacts of active mobility and air pollution. The model incorporates various factors such as CO_2 emissions, active mobility data, population, and discount rate to calculate the health coefficients and attributable fractions. It provides a comprehensive assessment of the health effects of active mobility, considering both its benefits in reducing mortality through increased fitness and its potential risks due to increased exposure to air pollution and traffic accidents. The model's findings can support decision-making and policy development aimed at promoting active transportation while minimizing its negative impacts on public health.

4. Sustainable mobility actions with health co-benefits

The following sections present the key findings: 1) from the analysis of the Finnish mission cities' Climate City Contracts (CCC) and Sustainable Urban Mobility Plans (SUMPs) and 2) from the brief literature review of the impacts of sustainable mobility actions with heath co-benefits. The latter focused mostly on review articles and on finding quantitative evidence on the potential impacts for the basis of the modelling exercise.

4.1 Policy Document analysis

Climate City Contracts

First, the individual mobility and transport actions presented in the CCCs of the Finnish mission cities were mapped into the elements of Behavior Change Wheel (BCW).

A total of 51 actions were discovered from the city plans. At first, one main source of behaviour was determined for each action. Then each action was categorized into either intervention function or policy category. Eleven (22 %) of the actions were too vague for determination or categorization. Four of them were from the same city (Tampere), which informed in the plan that the actions would be determined in more detail during 2024.

The findings (Table 3) revealed that 1) the concepts of outcomes and actions seemed to be mixed and unclear, 2) in the sources of behavior the actions targeted mostly on psychological capabilities such as increasing knowledge and on physical opportunities such as improving infrastructure, 3) only one action targeted at motivation indicating that motivation as a source of behavior was not seen critical for the desired change, 4) the actions appeared quite vague for the practical implementation, and 5) the variability of the selected actions seemed quite narrow considering the size and heterogeneity of the target group, which in most cases was the inhabitants of the whole city.

Table 3. Number of actions mapped to the sources of behaviour, intervention functions and policy categories of BCW.

City	Sources of behavior						Intervention functions									Policy categories						
	C		O		M																	
	Ph	Ps	Ph	So	Ref	Aut	Edu	Per	Inc	Coe	Tra	Res	Env	Mod	Enb	Com	Pla	Gdl	Fis	Reg	Ser	Leg
Espoo	1	4	7		1								6			1	4				2	
Tampere	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Lappeenranta			4										2		2							
Turku		1	2										1			1	1					
Lahti		8	4	2			1	1					2		4	1	2	2		1		
Helsinki*		1	4	1									3				2	1				
Total	**1**	**14**	**21**	**3**	**1**		**1**	**1**					**14**		**6**	**3**	**9**	**3**		**1**	**2**	

na = Detailed actions not yet determined.

** Preliminary information through personal communication.*

Second, the individual mobility and transport actions presented in the CCCs of the mission cities were mapped against the multiple levels of Social Ecological Model (SEM).

From the total of 51 actions 47 were mapped against SEM. The four actions listed in Tampere were excluded because they were not detailed enough for mapping. The findings in Table 4 show that the actions in CCCs focused mainly on policy level. All cities but one described also community level actions and some cities institutional actions. However, very few or no actions were planned at the individual or interpersonal level.

Table 4. Number of actions mapped to the levels of SEM.

City	Individual	Interpersonal	Institutional	Community	Policy
Espoo	1	-	1	4	7
Tampere	na	na	na	na	na
Lappeenranta	-	-	3	-	5
Turku	1	-	-	1	2
Lahti	-	-	3	6	6
Helsinki*	-	-	-	1	6
Total	**2**	**0**	**7**	**12**	**26**

na = Detailed actions not yet determined

** Preliminary information through personal communication*

Sustainable Urban Mobility Plans (SUMPs)

The analysis showed that the cities had made their SUMPs at different time points from 2017 (Helsinki) to 2024 (Turku). In some plans, the time span was indicated clearly but in others it seemed more unclear. Overall, the actions in SUMPs were much more detailed and pragmatic than in CCCs. In most cities the actions were also classified under specific developmental themes and/or goals. As a result, the number of actions was far greater than in CCCs. Due to the differences in presenting the actions and high number the actions, mapping against BCW or SEM was not conducted.

4.2 Climate impacts of Sustainable Mobility Actions

From the perspective of climate change mitigation, sustainable mobility actions aim at reducing the travel with the modes producing GHG emissions. This can be accomplished by making less trips, shifting to more sustainable modes, reducing trip lengths, or increasing the energy efficiency of travelling, e.g. by new technologies and services.

The climate impact of transport and mobility action depends on three aspects:

- The amount of travel in kilometres reduced or shifted to another transport mode.
- The specific energy consumption of the means of transport used (amount of energy needed per kilometre).
- The carbon intensity of the energy used. The intensity is low, for example, for renewable electricity and hydrogen, and high for conventional fossil fuels and electricity generated from coal. For the active modes (walking and cycling), the intensity is zero.

The following chapters present (quantitative) climate and health impacts of some key transport and mobility actions, measures or policies identified relevant by systematic academic reviews or a wider range of research projects or case studies. The actions are categorised under the themes identified relevant from the literature.

Promoting active transport

Actions promoting active transport (walking and cycling) aim usually to modal shifts from car travel to active modes. **Infrastructure, service, and information provision improvements** are the most used instruments. Based on the previous research and international and national experiences, it has been recognised that high-quality routes and their good maintenance, modal hierarchy in planning and investments considering equally all modes of transport, organising bicycle parking, experiments encouraging the use of active modes (e.g. in workplaces, schools and hobbies), and campaigning, sharing information about the benefits and opportunities offered by active modes of transport for residents, and especially municipal decision-makers, are the best ways to promote walking and cycling.

A systematic review of the effect of **infrastructural interventions to promote cycling** (Mölenberg et al. 2019) included 31 studies conducted within urban areas in high-income countries. The interventions included focused on the opening of cycling lanes, the installation of a city-wide cycling network, and the improvement of existing cycling infrastructure. Most of the evaluations found changes in favour of the intervention, showing that the number of cyclists using the facilities increased (median relative change compared to baseline: 62%; range: 4 to 438%), and to a lesser extent that cycling behaviour increased (median relative change compared to baseline: 22%; range: - 21 to 262%).

Another previous research (see e.g., Auvinen et al. 2020) reported a variety of figures between 0-30% for the quantitative increase in cycling volumes on **new or improved lanes**. A large part of the increase in cycling volumes may be due to route changes. The modal shifts have rarely been identified, and if measured, and the shifts have been small, for example from driving to cycling 2-8% and from public transport to cycling 6-24%. Also 4-8% shift from walking to cycling has also been observed.

Further, a very recent systematic review by Roaf et al. (2024) on multi-component actions or interventions combining infrastructure change with **behavioural or social programmes** showed most impact on active travel levels. Policy makers were reminded that to ensure the optimal effectiveness of interventions that only include behavioural or social strategies they should also be accompanied with environmental and infrastructural strategies and should receive long-term funding to achieve population-level impacts. Interventions involving **e-bikes**, and **bike-sharing** schemes were also highly impactful.

Still another recent review identified, compiling evidence from 19 studies across the globe on modes replaced by **bike sharing**, that the overwhelming majority of trips substituted were from sustainable transport modes, particularly public transport (PT) and walking (70% on average), with only a small share being from private car use (around 10% on average). Nevertheless, the study also noticed a substantial variation in car replacing rates, with some systems reporting much higher car reductions than others (Teixeira et al. 2021).

From the local perspective, in the Helsinki region, respondents to the bike sharing user survey 2017 reported that shared bikes replaced especially longer walking trips and short public transport trips, but also trips made by bus and private bike. The shared bike was chosen for its speed and convenience (e.g. no public transport waiting times). Approximately 10% of the shared bike trips replaced car trips (Gruzdaitis and Tenhula 2017).

As regards **bike parking**, there are some indications that improvements especially in the railway stations have increased the share of cycling among trips from home to railway stations, for example up to 20 % (in the US) and up to 29 % (in the Netherlands) (Auvinen et al. 2020), but the results are very location specific.

Tactical urbanism is a city or citizen-led method of rapid, low-cost project implementation that applies techniques designed to enhance the built environment and foster community engagement and place-making. Tactical urbanism projects are physical urban interventions that are often interim and pop-up in nature, to catalyse long-term change for more liveable streets and spaces. They provide an opportunity to re-imagine the look, function, and role of public spaces by quickly applying best practice street design principles to real-world situations. The climate impacts of Tactical Urbanism are indirect. For example, based on **the living streets experiments** in Ghent, Belgium, (NZC, 2024) closing streets from cars and turning the streets into liveable places nudges people to adopt more sustainable modes of mobility. The experiments demonstrate that structural changes are possible and that resistance to change can be overcome one street after another. In Ghent, the Living Streets has been a part of a broader paradigm change in mobility planning, which has had a significant influence on the modal split: growing share of cycling and public transport, reduction in car traffic.

Mobility Management refers to the promotion of sustainable transport modes and managing the demand for car use by offering services with the final objective of changing travellers' attitudes and mobility behaviour. At the core of mobility management are "soft" measures such as information and marketing campaigns, awareness raising, mobility education, mobility info points, and school and company travel plans. "Soft" measures most often enhance the effectiveness of "hard" measures within urban transport (e.g., new tram lines, new bike lanes or charging infrastructure). Compared to "hard" measures, mobility management measures do not necessarily require large financial investments and may have a high cost-benefit ratio in a short time frame (EPOMM 2024).

Based on a literature review (Pohjalainen 2016), mobility management in workplaces has produced good results, reducing the share of private car use by 2–38 percentage points. Projects in which various measures have been used over a long period have been the most effective. Mobility management in schools has reduced the share of private car use by 1–22 percentage points and campaigns by 1–50 percentage points. Information and guidance measures have reduced the share of private car use by 1–35 percentage points. Personal guidance targeted at small groups has been the most effective. More extensive, regionally implemented mobility management measures have reduced the share of private car use by 2–19 percentage points.

Reducing car use (Modal shift)

The main aim of the actions reducing car use is to **prevent unnecessary car trips**. For example, urban vehicle access regulations (UVARs) are means to reduce the number of vehicles entering a given geographical area. These can include **regulatory measures** (e.g. low-emission zone), financial measures (e.g. congestion charge) or **spatial measures** (e.g. creation of a superblock or reallocation of road space to create a pedestrian zone). UVAR measures can be put in place for several reasons, one of which is to reduce GHG emission. Others are to create more liveable space, to encourage more walking or cycling, to address delivery issues such as congestion or kerb space access, to reduce air pollutant emissions (e.g., Particulate Matter (PM), NO_x), to reduce speed and/or noise, to reduce motorised traffic levels, through traffic, congestion and/or injuries (NZC platform).

These negative incentives, so called sticks as opposed to carrots put restrictions on vehicle access to given areas, while maintaining access for people and for goods. Implementation of the measures requires close cooperation with citizens and stakeholders to ensure they understand the purpose of the restrictions and that no equity issues arise.

The existing evidence from a scoping review on the effects of **road pricing** on transportation and health equity (Hosford et al. 2021) suggests road pricing has mostly net positive effects related to a reduction in car trips, air pollution, asthma attacks, and road traffic collisions, and increases in life expectancy. Frequency and ease of social interactions were found to be negatively impacted, with fewer visits to family and friends. The population groups that generally fared better across transportation and health outcomes were those with higher incomes, men, and people between the ages of 35–55. Across space, there are benefits for both the areas inside and outside the cordon boundary, but to a greater degree for the area inside. Overall, the evidence base is limited by a narrow set of health-related outcomes and a lack of longer-term studies.

Based on the experiences from Sweden, the Stockholm and Gothenburg **congestion charging** implementations, there is evidence that the traffic volumes in the congestion charge area will decrease. In Stockholm, passenger car trips decreased overall by 25%. Almost half of this are work trips that shifted to public transport. In Gothenburg, the number of business trips made by car decreased by 9% and the number of leisure trips by 7%. The number of trips made by public transport increased by 4.5–6.5%. For leisure trips, the changes were smaller. The number of cycling trips also decreased (13–36%), but the worse weather conditions in the later phase might have affected the result (Auvinen et al. 2020).

A recent Evidence Review report (Williamson et al. 2022) drawing on recent review studies, selected national and EU databases and expert knowledge of the authors, found that well-designed, carefully implemented and stringently enforced **Low Emission Zones (LEZs)** can make a significant contribution to improving air quality in urban areas. NO_2 concentration reductions of around 40% are not only theoretically possible but have been demonstrated in practice. Reductions of around 20% have already been achieved and may be more achievable in a wider set of circumstances. In terms of Particulate Matter (PM10 and PM2.5), the potential for reduction by LEZs is smaller. This is related to both the fact that the proportion of locally measured PM concentrations associated with exhaust emissions is much smaller than for NO_2 and also that a larger proportion of the diesel fleet will already have Diesel Particulate Filters (DPFs) fitted, due to earlier Euro standards. However, in some circumstances, such as in countries with older vehicle fleets (and especially, e.g., municipal buses), LEZs will still have a significant positive impact on reducing PM emissions. LEZs can also positively improve air quality in areas outside the Zone and prior to full implementation (pre-compliance).

Another review based on the recent research on the life satisfaction and air quality impacts of Low Emission Zones (Sarmiento et al. 2023) showed similarly that they improve air quality despite increases in ozone and pollution spillovers. However, LEZs cause also transitory yet long-lasting reductions in life satisfaction and consequently well-being effects of restricting mobility may outweigh those of improved health.

As regards building new public transport infrastructures, there is some evidence (Auvinen et al. 2020) that after **construction of a new or upgrading of the existing urban rail line** the use of public transport will increase. It seems, however, that without other supportive measures, the majority of users may transfer from other forms of public transport. One good example of a package of measures comes from Bergen, Norway, where building a new tram line during the 2010s, was supported with a high-service bus network, increased congestion charge and compacted urban structure along the tram line.

An example from Tampere, Finland, shows that 1-2 years after the implementation the new tram line in 2021 (the first one in the city), the number of public transport trips has increased more than expected. Trips inside the city have grown relatively more than in the wider Tampere region. The car traffic volumes in the city centre have decreased, but the impact of the tramline alone is difficult to assess, since the volumes have decreased on many other main streets and roads in the city region as well. The number of pedestrians and cyclists has increased on three of the four examined streets in the city centre (Tampereen Ratikka 2024).

As regards **parking management and fees**, the meta-analysis of 50 studies including modelling (Lehner and Peer, 2019), shows that the theoretical estimate of the price elasticity of parking on commuter trips ranges from -0.63 to -0.41, and on other journeys between -0.71 ... -0.14. The parking measures in the central area would seem to affect transport volumes (the search time for a place is reduced), more efficient use of parking spaces, and to direct long-term parkers (e.g. commuters) to park further away from the centre or to use other modes of transport.

Technology measures

Electrification of the urban bus fleets is an effective measure to increase the energy efficiency of urban transport systems. Urban buses are responsible for about 8% of the road transport GHG emissions in the EU (UITP 2019). Buses with internal combustion engines are responsible for emissions of fossil carbon dioxide (CO_2) as well as air pollutants particulate matter (PM) or nitrogen oxides (NO_x). Thus, zero emission buses, have a significant potential in the reduction of transport related emissions in urban areas. Electric buses use an electric propulsion engine, and the energy is provided either by batteries (Battery electric vehicles, BEV) or, mainly in older installations, by overhead wires (trolleybus) or inductive systems embedded in the road. Different charging technologies are available for electric buses: manual plug-in connection and automatic connections, like pantograph-type connections from the top or the bottom of the vehicle. Moreover, different BEV charging approaches can be used, including overnight depot charging, alone or supported by opportunity charging (e.g. at the end of the line or at stops) during the daily use (NZC, 2024).

Benefits of the electric bus fleets:

- Large scale deployment of electric buses helps to improve air quality, as these vehicles do not emit exhaust emissions while operating and strongly reduce brake emissions.
- Zero emissions buses make less noise comparing to internal combustion engines, so they help to reduce noise emissions.
- Reduced air and noise emissions help to offer healthier and more attractive lifestyles to residents of urban areas.
- More silent vehicles and reduced vibration of vehicles (in particular electric ones) provides improvement of working conditions for bus drivers and other on-board staff.
- Even though the initial costs are high (electric and fuel cell buses are more expensive and require charging and/or refuelling infrastructure) they offer decreased energy and maintenance costs, delivering a positive total cost of ownership in comparison to internal combustion engine solutions.
- Improvements done on a bus system of a city (e.g., bus stop design, vehicle design, cleanliness and comfort) can have a positive impact on passengers' perspectives and the modal shift. The improvements attract citizens to the network, increasing ridership and therefore revenues for public transport companies.

4.3 Health impacts of Sustainable Mobility Actions

Glazener et al. (2021) have clarified the connections of transport and health by developing a conceptual model. In the model transport itself is affected by land use and built environment, transport infrastructure, transportation mode choice and transport technologies and disruptors. **Transport can,** in turn, **affect health through four beneficial** (green spaces and aesthetics, physical activity, access, mobility independence) **and ten detrimental pathways** (contamination, social exclusion, noise, urban heat islands road travel injuries, air pollution, community severance, electromagnetic fields, stress, greenhouse gases). Ultimately, health with extrinsic and intrinsic modifiers can affect morbidity and premature mortality. In the same publication Glazener et al. (2021) present a literature review on the health outcomes of transportation according to the 14 pathways. Based on the findings they concluded a significant overlap and interaction between the pathways and thus advocate for systemic rather than simplified single-strategy approach for quantifying and promoting health through transportation.

Mizdrak et al. (2023) utilized the conceptual model of Glazener et al. (2021) in outlining the health impacts of sustainable mobility actions. Their systematic review was an update of Mueller et al. (2015) and thus excluded studies prior to 2014. Total of 87 full-text articles were included. Majority of studies were implemented in a single city or region (n=64) or a single country (n=11). Only seven studies covered regions from multiple countries.

Health impacts were assessed with diverse methods in wide range of scenarios such as implementing transport plans and policies; changing land use, infrastructure and travel modes; and conducting social and technological innovations. Comparative risk assessment with Integrated Transport Health Impact Model and WHO's HEAT tool were the most popular assessment methods. Different indicators and measures were used in quantifying the health impacts and most studies included more than one outcome in the assessment.

According to the findings 1) **the most common pathways in health impact assessment were physical activity, road injury and air pollution**, 2) the quantification of health impacts differed within specific pathway, 3) the impacts of the same scenario varied in different settings and with different indicators, 4) majority of studies quantified the impacts in total population without focusing on different subgroups and 5) only few studies seemed to have been conducted from specific policy needs and 6) the number of studies on the health effects of transportation was grown notably.

Due to the large number and heterogeneity of included studies the review did not attempt to make systematic analysis of the results. It only provided an update of studies quantifying the health impacts of transport scenarios focusing on changes in travel modes. As a conclusion, the review calls for using health impact modelling in the future assessment and promotion of active transport. In the assessment, the inclusion of full range of pathways associated with transport is suggested as well as the extension to different population groups due to known inequality in both health and transport.

A Systematic Review of Zukowska et al. (2022) on **transport policies, which increase physical activity of the whole of society** identified three main transport policy areas with 60 individual policy actions that had a direct or indirect effect on physical activity (PA). These were: **convenient transport infrastructure development, active travel promotion and shift of transport mode**. More than half of the policy actions identified (53%) had a positive effect on PA. The review concludes that PA levels can be increased by implementing policies that provide convenient, safe, and connected walking and cycling infrastructures, promote active travel and give strong support to public transport. There is also clear evidence that **active travel policies work best when implemented in a comprehensive way** (very often as a combination of several policies). This may include infrastructure and facility improvements as well as educational programmes to achieve substantial shifts towards active modes of travel.

Xiao et al. (2019) have compiled systematic review and meta-analysis on the **impact of new public transit on physical activity levels**. The results show that building new public transit options is associated with a statistically significant increase in light to moderate physical activity levels. This is equivalent to increasing walking and other light to moderate physical activity by about 30 minutes per week, relative to baseline. No significant effect was found for the moderate to vigorous physical activity outcome.

In Finland, a comprehensive report on the health effects of transport in the whole country and in 11 cities has been published in 2021 (Lehtomäki et al. 2021). Three pathways to linking transportation and health were examined: particulate matters, noise, accidents and physical activity. According to the findings the transportation caused altogether 16,200 **disability adjusted life years** (DALYs) in 2015 and active transport brought significant health benefits of -31,400 DALYs by preventing premature deaths in Finland. Another large study in Finland involving 16,778 public sector employees focused on the longitudinal association of changes in active commuting with changes in **work ability** and **recovery from work** (Kalliolahti et al. 2023). The results showed that to achieve small changes in work ability requires tens of weekly kilometres of active commuting. No association was found with the increase in active commuting and better recovery from work.

5. Generic Action Portfolio

During the past decades, numerous research projects, initiatives and case studies have identified and defined action areas, individual actions and instruments relevant for promoting sustainable mobility. Furthermore, an academic branch of research has identified mobility related interventions promoting physical activity and other health related aspects (see section 4). Based on a critical review of these sources of information and insights from the interviews of the Finnish Mission Cities, a comprehensive list of sustainable mobility actions with potential health co-benefits was developed. The list is presented in the Appendix 3 of this document.

The list of actions was further refined to identify those with available evidence and quantitative impact data, such as review articles summarizing the results of multiple cases or interventions. The choice of the approach was guided by the second goal of the project: to develop a model to assess the co-benefits of selected measures. The development of the model is dependent from the quantitative values on the impacts of measures and activities.

The following Table 5 presents the selected set of actions, which can be considered as the generic action portfolio of sustainable mobility measures with health co-benefits. Actions have been categorised under four wider themes: (1) **Promoting active transport**, (2) **Reducing car use**, (3) **Technology Actions**, and (4) **Planning**. It is important to highlight, that to promote active transport and reduce car use, some of the selected actions involve using incentives (both positive and negative) that can be tailored to specific target groups to encourage the desired behavioural change. The portfolio offers the mission cites a check list in planning activities with integrated climate and health impacts and benefits. The actions in *Italic* were included to the list as a result of the project workshop, in which the Finnish Mission Cities could propose further important actions to the preliminary portfolio. Of the added actions, research evidence on the impacts has not been analysed. The portfolio also serves as the starting point for the modelling exercise of this work.

The findings from the literature and from the interviews indicate that the combination of actions (action/solution packages) is more impactful that individual actions.

Active modes, i.e., walking and cycling, combine physical activity and transport, and, thus, promote health, equality, and sustainability. However, to become more common, walking, cycling and also public transport must be easy and attractive. Experiments and a well-designed urban structure form the foundation for increasing active travel.

Table 5. The Sustainable Mobility Action Portfolio with health co-benefits.

Focus	Action	Further details
Promoting active transport	Infrastructure changes	Constructing new cycling infrastructure, bike parking
	Tactical Urbanism	Physical small-scale, citizen-led urban interventions that are often interim and pop-up in nature, to catalyse long-term change for more liveable streets and spaces.
	Bike sharing schemes	E.g., city bikes
	Provision of subsidies for bikes and e-bikes	E.g., company bike benefits
	Behavioural interventions and Mobility Management	Workplace travel plans, campaigns, nudging, marketing, branding, *education (e.g., in schools)*
	Renewal of urban spaces	*Creating attractive urban spaces and environments for walking and cycling*
	Maintenance	*(Winter) maintenance of walking and cycling lanes*
Reducing car use (Modal shift)	Low emission zone	An area that restricts the use of polluting vehicles through both priced and non-priced strategies
	Parking management	Setting parking fees, services, restrictions
	Congestion charging	A fee or a tax for private cars to enter or drive within certain areas, typically city centres
	New tram/rail lines	Constructing new public transport infrastructure
	Increasing the service level of public transport	*Designing multimodal hubs, parking / bike & ride services, shorter headways in public transport services*
	Reallocation of urban space	*Transport calming, allocating the road space for active modes*
Technology Measures	Electrification of bus fleet	Replacing traditional diesel or gasoline-powered buses used in public transport with electric buses
Planning	Sustainable Urban Mobility Plans (SUMPs)	
	Local development plans for cycling and walking	

6. The Novel Modelling approach

The objectives of the novel modelling approach were to:

- Give local governments a functional model for a jump start to quantify impacts of some common practical actions.
- Select transport actions that have relevance in both reducing greenhouse gas emissions and improving public health.
- Offer first estimates of the critical parameters and results based on those, so that governments can see the order of magnitude impact without much local data.
- Describe the data sources and quality of information used. This is important for understanding the reliability of the results and also for directing further data collection.
- Categorise things into relevant groups to gain more insight about accessibility, cost distribution and other variations in the population.
- Show the potential impacts of individual level incentives on the transport system level developments.
- Help municipalities to view transport as a single holistic system rather than a collection of unrelated modes of travel chosen by individuals.

The model developed in this project was based on several previous open-source codebases. The core model was based on NetZeroPlanner, a tool provided for European Mission cities for making Climate City Contracts. The code is being developed by Kausal and is offered as a demo site free of charge for self-service. The tool contains a causal network model for estimating emissions and costs of building, transport, electricity, waste, and other sectors. The transport model was adopted for further development.

On the model's demo site, the user can adjust the population size of the model from *All settings*. This makes it possible to scale the effects to relevant local conditions. The purpose is to help understanding the magnitudes of the many aspects in the model. Typical Finnish and European values are used for other input data. A full model version is needed for adjusting the data.

The health effect module was based on two parts. WHO HEAT model for health impacts of walking and cycling was adopted as the key data source. The HEAT model itself was not directly used as a component; instead, several model runs were performed for the whole of Finland and cities in Finland to learn about the behaviour of the model that could be parameterised and thus transferred to the new model. The HEAT model was found out to behave quite linearly, making it straightforward to estimate health factors from the model. These factors can then be multiplied by the amount of active mobility by transport mode and scale to the population size and thus get estimates of health effects. Pathways included are health benefits of physical activity, increased exposure to air pollutants while in traffic, and accident risk. Mortality was the endpoint considered. Deaths are monetised by using the value of statistical life, a standard method in economic assessments and used by WHO HEAT.

The other part was a disease burden model developed by Finnish Institute for Health and Welfare (THL) and published as an online tool running on R software[6]. It estimates health effects of air pollution from several sources. It is looking at health effects in the whole population, unlike the HEAT model that only looks at the increased air pollution exposure while in traffic.

The combined health module was first developed for the city of Lappeenranta in 2024, and it was further developed in this project to include additional traffic-related actions from the portfolio. The model is available free of charge for self-service. Inquiries can be sent via https://kausal.tech.

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[6] https://en.opasnet.org/w/Health_impact_assessment

However, installing the system on an own server requires advanced IT skills. Therefore, there is also a demo version available for the time being at https://dut-transport-nzc.paths.kausal.tech.

The model is designed for city-level use so that city-specific input values can be used in the model. However, the test model was developed for the whole Finnish population. Therefore, it should be remembered that most of the actions in the model cannot in practice be implemented in the whole of Finland with the same intensity and effect as in a single city. For example, congestion charges or park-and-ride facilities are practical only in the few largest cities. For these reasons, the results of the test model should not be treated as actual estimates of the Finnish situation. However, the model illustrates the order of magnitude of health effects and helps visualise and understand which issues are large and which are much smaller.

The model is a deterministic causal model. It does not explicitly deal with uncertainties, although sensitivity analyses can be performed with several actions by choosing stronger or weaker implementation. There exists a prototype version that uses Monte Carlo simulation as an explicit way to deal with uncertainties.

The impact calculations are performed by comparing different scenarios. Typically, the active scenario has all actions on, and the impact of an action is defined as the difference with that scenario and another one where the action is turned off. Because some actions have causal interactions (i.e., they strengthen or weaken each other's effect), the sum of the impacts of all actions is not identical to the difference between the active scenario and the baseline scenario where all actions are turned off. Figure 6 shows an example of a causal chain from an action to an outcome. Each of the intermediate nodes in the chain can be clicked open to examine, what is the impact of the action on the node. It is also possible to open the page of each node for more details. All actions are connected to the same causal network that contains all the computational details of the model. In Figure 7, the green actions increase active transport or shift trips from cars to other transport modes. There are also other kinds of actions not shown, such as electrification of the fleet, which reduces emission factors and thus air pollutants and CO_2 emissions.

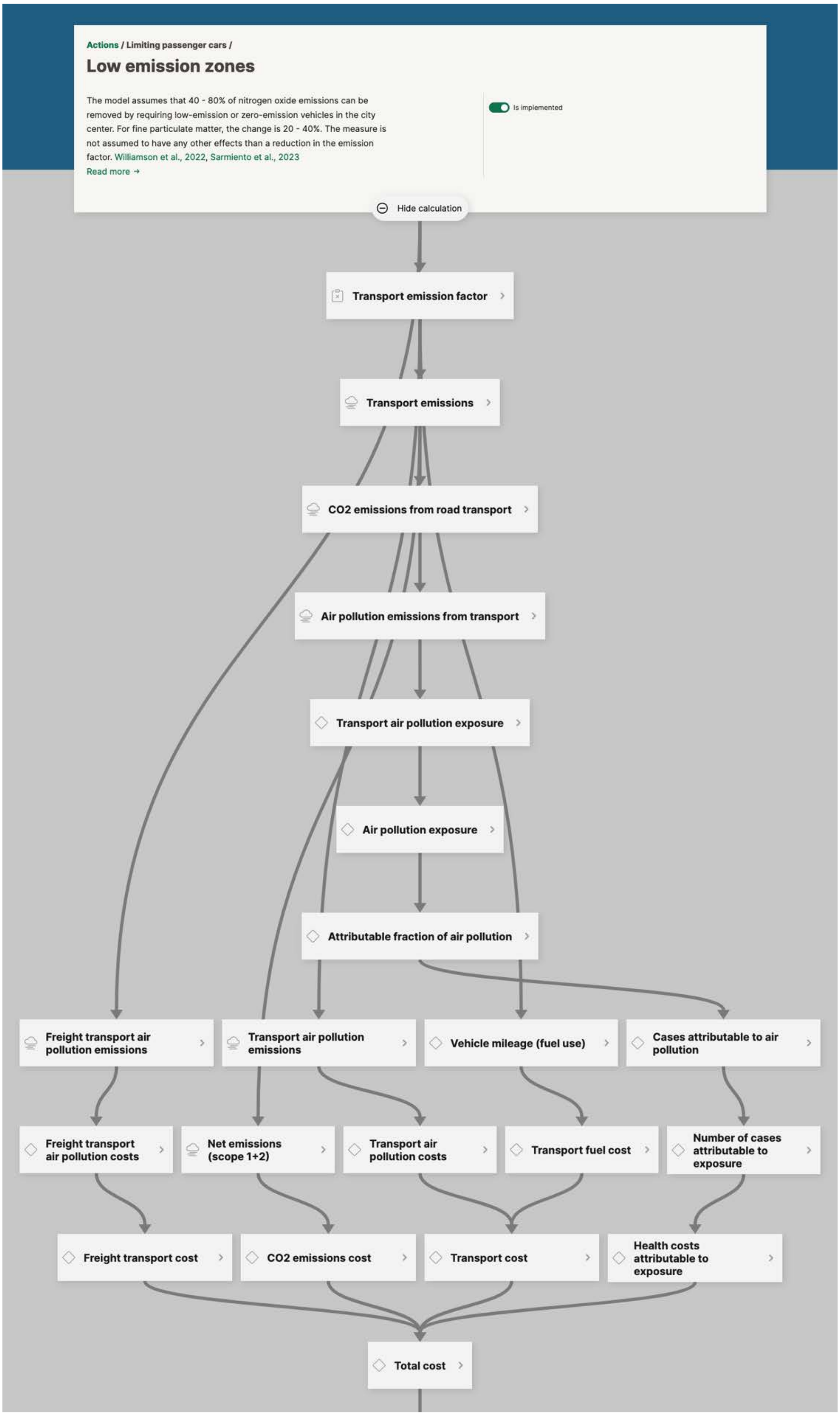


Figure 6. An example of a causal chain originating from an action (Low Emission Zone) and resulting in a final outcome (Total cost). Each action is a part of a full causal network.

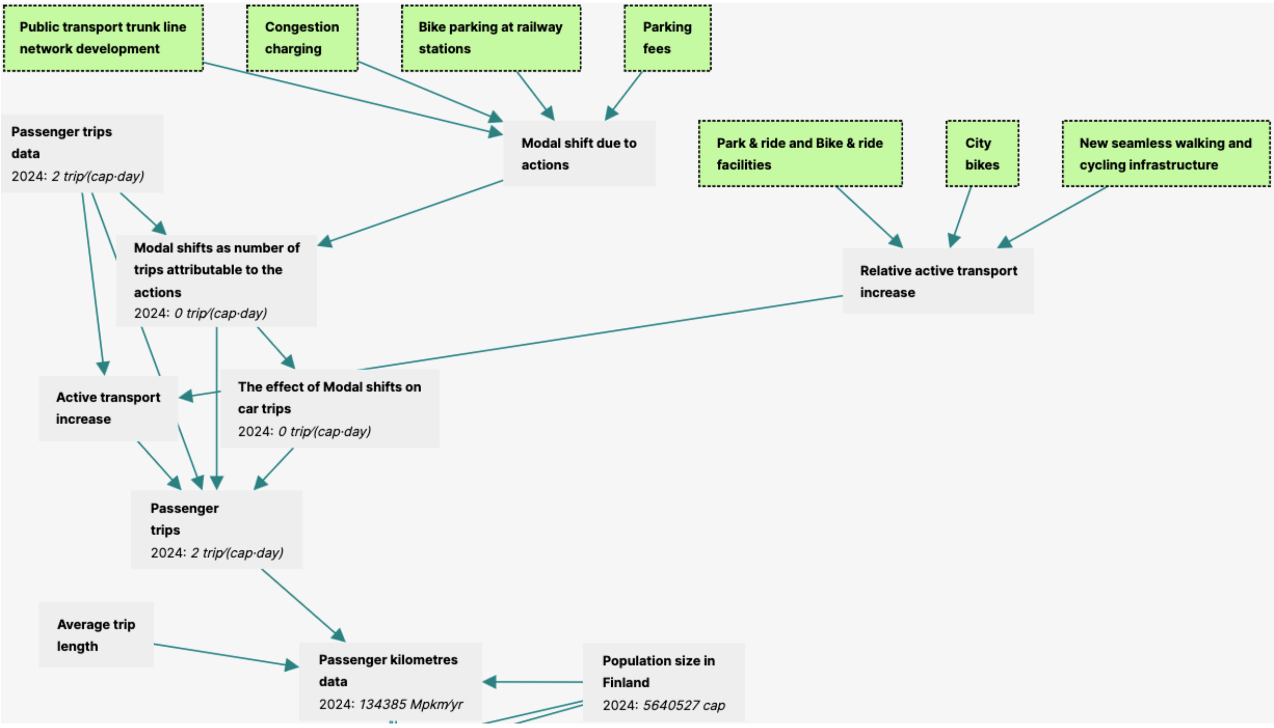


Figure 7. A detail of the full causal network. Most actions (green nodes) either move trips from cars to other transport modes or increase active transport by making it more suitable.

In Figure 8, there is an example graph from a node page. Aggregated costs have several dimensions, which means that the costs are categorised into several bins based on cost type and which stakeholder group gets the burden or benefit. There is a powerful filtering functionality, which makes is possible to deep dive into the details of the model and understand the specific behaviour of each part of the model.

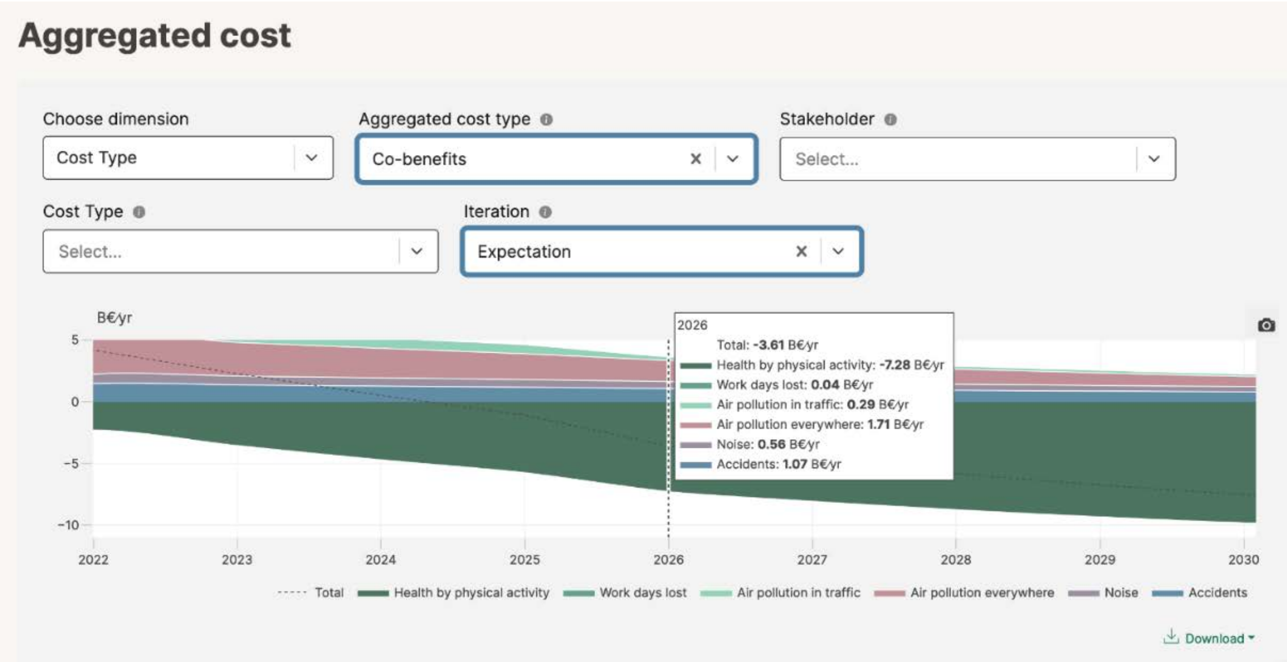


Figure 8. Overall magnitude of the health outcomes related to road traffic and active transportation. Physical activity is the major contributor to better health (negative costs).

Physical activity was found out to be the largest pathway producing health benefits. Many of the health risks, such as accidents, noise, or air pollution exposure while in traffic, are clearly smaller than physical activity. Air pollution emissions from the traffic is the second largest category causing health effects.

The user can study the scenarios in several ways. They can choose between ready-made scenarios or create their own by turning individual actions off or on. For some actions, they can also perform sensitivity analysis by pulling the sliders (Figure 9). This affects the magnitude of action implementation and is an easy way to adjust the model with city-specific information.

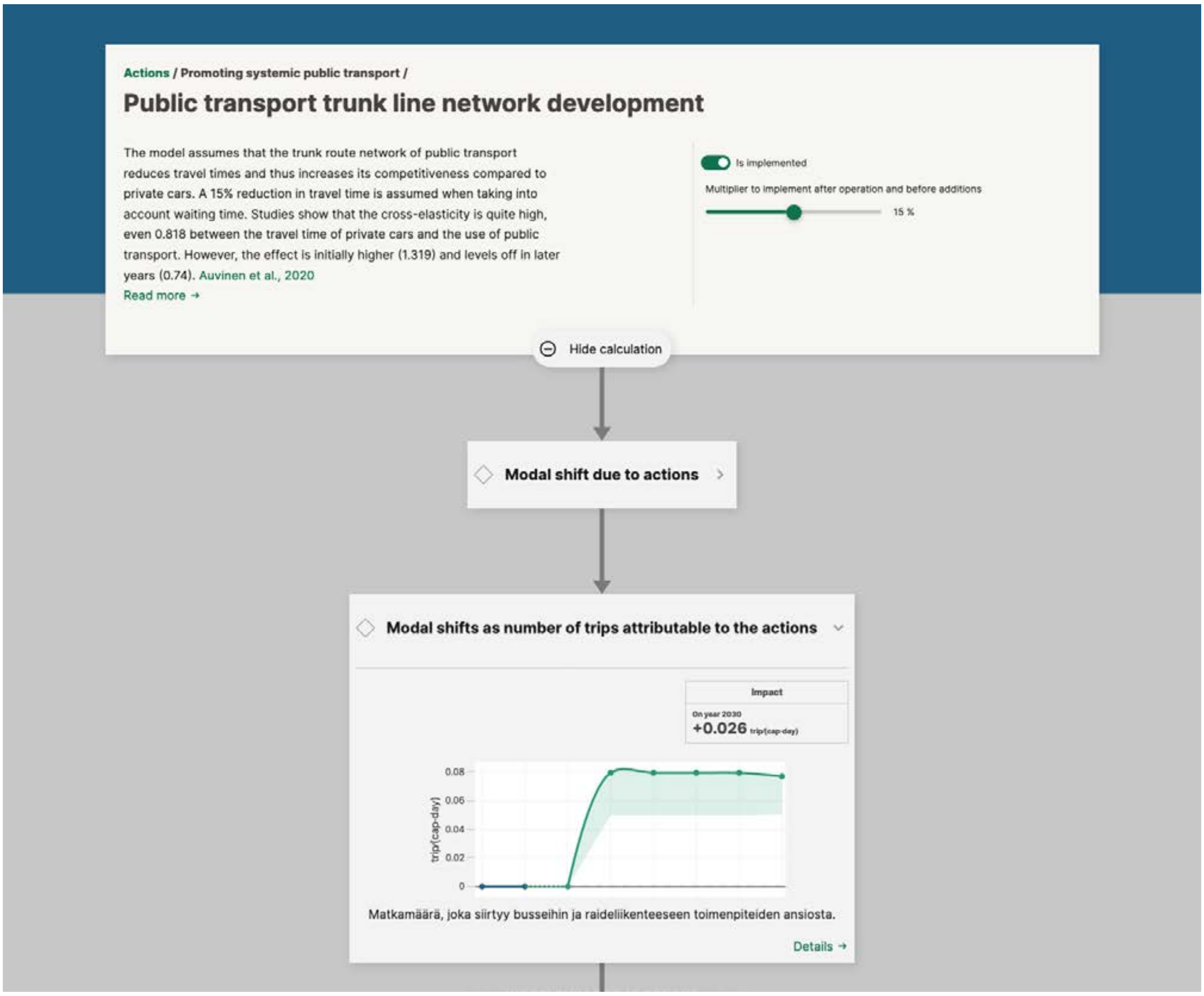


Figure 9. The impact of an action on an intermediate node in the causal chain. The dark green line shows the situation when all actions are on, and the light green area shows the impact if this particular action is turned off. The action can be adjusted with a slider by the user.

All health and other effects considered in the model are converted to monetary units in the end. For some but not all actions, there are also implementation cost estimates available. In those cases, it may be meaningful to make benefit-cost calculations, but not all actions can be assessed in the same way due to missing information.

A short list of actions (Table 6) was selected for quantitative modelling from the long list produced in the project. Inclusion criteria were mostly practical, notably the availability of effect estimates, potential to reduce emissions and improve health, and assumed potential for implementation in municipalities.

Table 6. Actions in the computational model. These are not identical to the portfolio actions in Table 5 mostly due to data availability and practical modelling reasons.

Focus	Modelled action	Portfolio action	Type of measure	Level of intervention
Promoting active transport	New seamless walking and cycling infrastructure	Infrastructure changes	Physical infrastructure	Community
	Bike parking at railway stations	Infrastructure changes	Physical infrastructure	Community
	City bikes	Bike sharing schemes	Service provision	Community
Promoting systemic public transport	Park & ride and Bike & ride facilities	Increasing the service level of public transport	Service provision	Community
	Public transport trunk line network development	Increasing the service level of public transport	Physical infrastructure, service provision	Community
Limiting passenger cars	Congestion charging	Congestion charging	Fiscal measures	Policy
	Parking fees	Parking management	Fiscal measures	Policy
	Low emission zones	Low emission zones	Regulation and legislation	Policy / Community
	Increased car occupancy	-	Communication and marketing	Individual
	Reduce all motorised transport	-	Undefined	Policy
	Modal shift from cars to other modes	-	Undefined	Policy
Actions affecting health only via air pollution	Electrification of cars	-	Physical infrastructure	Community / Individual
	Electrification of buses	Electrification of bus fleet	Physical infrastructure	Community / Institutional
	Electrification of trucks	-	Physical infrastructure	Policy
	Replace fossil electricity	-		Community / Institutional

Categories are used in the model to understand the nuances of the transport system and to see how costs and benefits are distributed within the population (Table 7). The model is built in a way that if detailed data is not available, categories can be dropped out without a need to change the model itself. Usability of the model in different contexts is improved by using a generic structure to describe a transport system, so that it is relevant for most cities in Europe. Input data is made more generalizable by normalizing it by population size when relevant.

Table 7. Categories that can be used in the model to improve the granularity of the transport activities and service levels. These categories are not necessary, and most cities only have transport activity data split by transport modes (cars, walking, cycling etc.).

Dimension	Category	Description
Population subgroup	Toddlers (always with an adult)	Population subgroups are useful in understanding the service availabilities: not everyone has a possibility to use a car or a bus independently.
	Children (can walk and cycle independently)	
	Adults without own car	
	Adults with a car in their control	
	People that need support in moving around	
	Unclassified	
Trip length	Short (<2 km, easy to walk)	Modal shifts happen more easily with short trips. On the other hand, urban planning may have tools to reduce the need for long trips.
	Medium (< 6 km, easy to cycle)	
	Long (> 6 km)	
	Unclassified	
Transport service level (fabrics in the finger model)	Walking city	The city area and its transport services limit the opportunities of citizens to more around. Some solutions are more costly in one area than in another.
	Public transport city	
	Car city	
	Unclassified	
Activity period	Rush hour (07-09, 14-18)	Feasibility of transport services depends on the overall activity during that time. Also, effects and solutions of congestion concentrate on a few hours.
	Silent hours (21-06)	
	Average hours (all others)	
	Unclassified	

7. Building Transformative Capacity to support the action implementation

Building transformative capacity can be considered as a pathway entailing several steps. These steps entail 1) increasing the willingness and commitment to promote change, 2) creating deeper understanding of the current state of sustainable mobility, 3) carrying out strategic planning, 4) implementing actions and carrying out experiments as well as building reflexivity and developing evaluation, and 5) establishing the new practices (Figure 10).

Figure 10. Pathway steps to build transformative capacity and support action implementation in cities.

Based on prior literature (e.g., Tuominen et al. 2021) and interviews of the representatives of the Finnish Mission Cities, many of the key factors needed to build capacity to support action implementation are currently in use in the Finnish Mission cities. For example, the cities have long-term strategies, such as climate strategies, Transport System Plans and Sustainable Urban Mobility Plans (SUMPs), as well as short-term plans, including annual planning. However, while the role of sustainable and active mobility is central, particularly in urban climate strategies, it is less evident in health and well-being, recreation, and education strategies. It seems that the role of wellbeing and health is acknowledged but not yet well integrated in mobility management and SUMPs as recently pointed out also by Kasraian et al. (2024).

Without knowledge of the current state of the transport system, i.e. different transport modes, future planning and implementation of actions are difficult. In this regard, the cities have been active in monitoring for example the shares of different transport modes and traffic volumes. Here, the role of National Travel Survey is crucial, as it provides an overview of mobility across Finland including information on demographic, regional and temporal variations in passenger trips. In cities, the monitoring process also includes evaluating the progress of both their strategic and tactical actions. Municipalities also carry out local travel surveys and manual and mechanical transport counts e.g. on cycling volumes. Monitoring of cycling volumes is more common in larger cities than in the small municipalities. 68 percent of the Finnish municipalities don't monitor the cycling volumes (Turunen 2023)

Implementing activities, particularly if they challenge status quo, can be challenging, which makes the role of experimentation and piloting crucial. Majority of interviewed city representatives highlighted the importance of project funding in developing and experimenting new activities. The funding for experimenting and implementing activities comes from several sources, e.g., government and internal budget funding for infrastructure projects and external project funding. This puts pressure on managing vast project portfolios. Furthermore, gradual, systematic development work may seem as incremental and slow but as pointed out by one of the interviewees: “*We’ve managed to nudge many things in the right direction; we should celebrate the small victories*”.

Development and pilot projects are beneficial only if they lead to new learning. While the interviewed cities already leverage best practices and promote learning, further emphasis, and models for evaluating, collecting, and sharing information are needed, ensuring that these practices become ingrained in daily operations. The need for impact evaluation and modelling the benefits, including the health-related co-benefits of sustainable urban mobility actions, was highlighted by several interviewees, particularly to ensure and convince local decisionmakers in acting.

As well known, the actions that strengthen the climate neutrality of cities and well-being of citizens through sustainable transport and mobility are linked to many operational sectors and departments in the city organisations, such as infrastructure construction, traffic management, recreation and sports, public health, and education. This often means that such actions have no organisational home base, and the responsibility has scattered across the sectors. This may hamper the intersectoral dialogue and collaboration which are essential for transformational change in complex systems. While some of the cities have established a position for a sustainable mobility coordinator and many have a cross-sectoral team to plan and implement activities, there is still room for improvements. Challenges lay in ensuring sufficient, long-term funding for coordination activities, which mainly currently rely on project funding. Another general feature is limited or missing involvement of stakeholders working with health promotion and wellbeing, particularly from local wellbeing services counties. Many cities have health promotion activities, but they are often implemented as own projects, and not so much linked with active transport activities. Integrating all the above actors and activities in coordination would be beneficial in fostering the health-related co-benefits of sustainable mobility actions.

7.1 A tool for transformative capacity building related to sustainable and active mobility

Below is presented a tool for cities to support their action implementation. This tool, based on the NetZeroCities Climate Transition Map and the Local Transformative Capacity Framework (Tuominen et al. 2022), consists of five pathway steps (Figure 11) and eleven four-stage criteria (Tables 8-12) for identifying and evaluating progress related to transformative capacity building for sustainable and active mobility. The cities can use the tool both for self-evaluation and capacity building, and it can used also for comparisons across cities.

Step 1. Willingness and commitment to promote change

Promoting an active lifestyle requires the long-term commitment of key stakeholders. A cross-sectoral team should be established within the city organization to plan and implement sustainable and active mobility activities that involve multiple units. The most important person in the team is the mobility coordinator. The task of municipal decision-makers is to ensure the adequacy of the team’s financial and human resources. The implementation of changes is carried out in cooperation with stakeholders. Therefore, it is important to identify key stakeholders, establish a cooperation body for the actors, and ensure its regular operation (Table 8).

Table 8. Evaluation criteria for Step 1.

An internal cross-sectoral team promoting active modes	Coordination of actions	Engaging external stakeholders
1. The team has been established but does not cover all essential sectors. 2. The team has been established and is comprehensive. 3. The team has been established, is comprehensive, and its activities are linked to decision-making. 4. The team's activities have become an established part of the municipal organization.	1. The need for a coordinator for active mobility has been identified. 2. The position of coordinator for active mobility has been established, but funding is not secured. 3. The position has been established and filled, with short-term funding secured. 4. The position has been established and filled, with long-term funding secured	1. Key stakeholders have been identified. 2. A collaborative body of stakeholders has been established. 3. The collaborative body operates regularly and interactively. 4. The activities of the collaborative body have the approval of the municipal council.

Step 2. Understanding of the current state of sustainable mobility

Systematic monitoring of the state of the transportation system is essential for all modes of transport, their shares, as well as traffic volumes. Without knowledge of the current situation, future planning is not possible. Additionally, a modal hierarchy, decided at the municipal level, is needed. This hierarchy is used in planning and resource allocation, and its implementation is systematically monitored (Table 9).

Table 9. Evaluation criteria for Step 2.

Regular and continuous monitoring volumes of active transport	Applying modal hierarchy
1. A monitoring plan is in place. 2. A plan is in place and resources have been allocated. 3. Monitoring is conducted every three years or less frequently. 4. Monitoring is comprehensively conducted annually.	1. A plan for the modal hierarchy has been made. 2. The plan for the modal hierarchy has been approved by the council. 3. The modal hierarchy is used as a planning tool occasionally. 4. Annual transport investments are made in accordance with the modal hierarchy.

Step 3. Strategic planning

In promoting sustainable and active lifestyles, long-term, future-oriented work on active and sustainable mobility is an important part of the change. This work should also take into account other local, mutually supportive strategies, such as climate and urban strategies, health and well-being, recreation, and education. The short-term implementation plans of these strategies are also essential pillars of future work on active and sustainable mobility (Table 10).

Table 10. Evaluation criteria for Step 3.

Developing long-term programs for active mobility and integrating them with key municipal strategies	**Planning annual implementation of active mobility projects as part of strategic development**
1. The long-term development program has been created and is aligned with the municipality's other strategies. 2. The development program has been approved by the municipal council. 3. The progress of the program is systematically monitored. 4. The long-term development program is regularly updated.	1. An annual implementation program based on the long-term development program has been developed. 2. The implementation program has been approved, and key projects have been funded. 3. The progress of the program and projects is regularly monitored. 4. The results of the annual implementation programs are utilized in updating the long-term development program.

Step 4. Actions, experiments and evaluation

Implementing activities is not always simple, straightforward, or easy. Creating systematic approaches for rapid experimentation, implementing not only individual actions but also larger project entities, as well as impact assessment support change and provides information on the effectiveness and usefulness of the actions (Table 11).

Table 11. Evaluation criteria for Step 4.

Systematic support for experimentation	**Management of multidisciplinary project and funding portfolios**	**Evaluation of impacts**
1. Individual experimental projects are implemented annually. 2. The themes of the experimental project portfolio are planned for several years ahead. 3. The themes and funding of the experimental project portfolio are planned for several years ahead. 4. The themes and funding of the experimental project portfolio are planned for several years ahead in collaboration with other sectors.	1. Potential funding sources for experimental and development projects have been identified. 2. The suitability of various funding sources for the municipality's project activities has been assessed. 3. Key project and funding portfolios, along with their responsible persons, have been identified. 4. The review and possible update of project and funding portfolios are conducted systematically (annually).	1. Results and feedback are collected from individual experiments and projects. 2. The results and key lessons from individual experiments and projects are compiled and communicated to stakeholders. 3. A systematic approach is developed for compiling results and evaluating the impacts of experiments and projects. 4. The results, impacts, and lessons from experiments and projects are compiled annually and communicated within the municipality and to key stakeholders according to the established approach.

Step 5. Establishing the new practices

Development projects and experiments are useful only if they lead to new learning. To utilize best practices and promote learning, clear models for observation, collection, and sharing are needed so that practices become part of daily operations (Table 12). Cross-administrative, sectoral, and cultural cooperation to promote an active lifestyle will be achieved if the roles of different actors in the cooperation are clear.

Table 12. Evaluation criteria for Step 5.

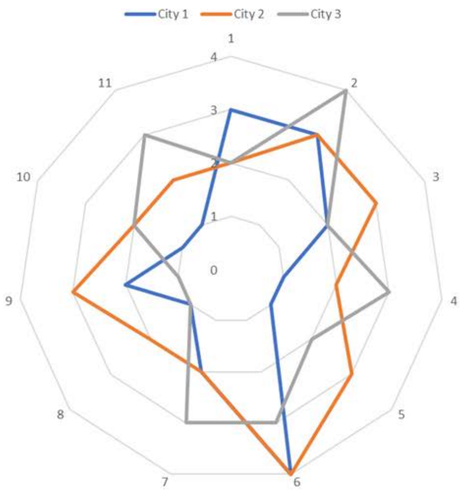
Identifying and utilisation of best practices and lessons learned
1. There is a model in place for identifying, collecting, and sharing best practices from development and experimental projects. 2. Resources have been allocated for utilizing and/or replicating best practices. 3. The results, lessons, and models from experiments are utilized in the daily work of the municipality and other actors. 4. The results of experiments are used in long-term planning.

The key steps and activities of the tool are summarised in Figure 11.

STEP	FOCUS	ACTIVITIES
1. Willingness and commitment to promote change	Municipality	▪ A cross-sectoral team promoting active mobility and physical activity ▪ Coordinator for Active and Sustainable Mobility: Coordination and Resourcing of Actions
	Stakeholders	▪ Identifying and Engaging Key Stakeholders to Promote Change
2. Understanding of the current state	Measuring and monitoring	▪ Regular and continuous monitoring of active modes volumes
	Applying modal hierarchy	▪ Integrating and adhering to the transport mode hierarchy in planning and resource allocation
3. Strategic planning	Strenghening future orientation	▪ Developing long-term programs for active mobility and integrating them with key municipal strategies ▪ Planning annual Implementation as part of strategic development
4. Actions, experiments and their evaluation	Systematic planning and implementation	▪ Implementation of prioritized activities ▪ Systematic support for experimentation ▪ Management of broad project and funding portfolios ▪ Evaluation of impacts
5. Establishing new practices	Learning and embedding learnings	▪ Identifying and sharing best practices ▪ Strengthening cross-sectoral collaboration and learning ▪ Utilizing and integrating learnings into daily practices

Figure 11. Key steps and activities.

The status and progress of a city can be mapped using the evaluation matrix, as illustrated in 12.



1. Cross-sectoral team promoting active modes
2. Coordination of actions
3. Stakeholder engagement
4. Regular monitoring of transport volumes for active modes
5. Modal hierarchy in planning and resourcing
6. Long-term promotion programs for active modes
7. Annual implementation planning for active modes as part of strategic development
8. Systematic support for experimental activities
9. Management of multidisciplinary project and funding portfolios
10. Evaluation of the impacts
11. Identification and utilization of best practices and lessons learned

Figure 12. An example of an evaluation matrix related to transformative capacity building and action implementation in cities.

8. Radical innovative solutions

There are currently three major transformations happening simultaneously in transport systems: automation, servitization, and electrification. Automation and servitization are particularly influenced by digitalization and the development of artificial intelligence. These transformations can bring significant changes to the available modes of transportation and the temporal, effort-related, and economic costs of mobility, from both an individual and societal perspective. For individuals, for example, automatic driving can eliminate the effort of driving and allow travel time to be used for leisure and productive purposes. This could lead to an increase in car usage and increased sedentary travel. On the other hand, diverse mobility services might encourage people to give up using their own cars and travel more actively. Changes in modes of transport and their user experiences alter people's perception of the accessibility of various activities, e.g., commuting, shopping, hobbies, meeting people, and where it is possible or worthwhile to travel (Lehtonen et al. 2024).

Furthermore, changes in accessibility affect where and when various activities are performed. They also influence the attractiveness of different areas in terms of living, working, or other regular activities. In the long term, changes in attractiveness are also reflected in the built environment through relocation and construction decisions. New transportation technologies and services can also require or free up space in the built environment, for example, by affecting the number and placement of necessary parking spaces or pathways (Lehtonen et al. 2024).

The impact mechanisms of new technologies and services are complex and multifaceted, and research results on their impacts are sometimes contradictory, making it challenging to foresee the impacts. Based on the recent study by Lehtonen et al. (2024), at least the following new transport technologies and services are relevant for future considerations: automated cars, robotaxis, automated public transport, shared mobility and peer-to-peer rental services and mobility as a service (MaaS). A newly published findings by Militão et al. (2025) indicate that multimodal mobility bundles such as MaaS can effectively nudge choosing sustainable travel modes over private cars especially if financial incentives and mix of transport modes are provided.

Interestingly, already well before automated cars, it was estimated that city regions would clearly benefit from subsiding MaaS systems and thus reduce societal (air pollution, greenhouse gas emissions, urban space) and individual costs (fuel and capital costs of cars) and reach a more sustainable transport system (Tuomisto and Tainio, 2005). Any automation would further increase the efficiency of the transport system and thus increase the societal benefits and reduce the need for subsidies.

The theory of creative destruction (Schumpeter, 1942) describes how better and cheaper commodities enter the market and drive old, inefficient products to extinction. One could think that private cars would easily be replaced by MaaS and other better and cheaper based on creative destruction. However, the choice between a MaaS trip and a car trip is not a simple comparison, because typically the customer already has bought a car with a substantial amount of money. Therefore, the marginal cost of a car trip appears cheap, while the MaaS trip appears an extra cost on top of a car that already exists. In addition, there is remarkable resistance from the car and fossil fuel industry to prevent their own destruction. Therefore, it is not clear how long and effective this change prevention will be; and how much better new systems must be to replace the current modus operandi.

Gamification has been identified as a potential approach for promoting modal shift towards sustainable transport modes (Luger–Bazinger and Hornung–Prähauser 2021). For example, Crowdsorsa mobile app transforms monitoring the conditions of roads and city infrastructure into a challenge for users. Individuals are encouraged to become “citizen reporters” by sharing their experiences and contributing to improvements within their city. City of Helsinki has used Crowdsorsa app for surveying cycle path condition (City of Helsinki 2023). The app presents users with missions that involve collecting data, such as videos or photos, related to specific aspects of urban environments. These could include identifying road damage like potholes, mapping cycle paths, or documenting the presence of invasive plant species. Users select missions displayed on a map within the app.

Another example of an innovative solution to promote sustainable mobility is the personal carbon trading experiment from Lahti, Finland. In the two-year experiment, carbon trading was conducted via CitiCAP mobile application that automatically recognized users’ mode of transport and visualized travel emissions. The application calculated a personal carbon budget based on the user’s life situation. Those who stayed under their budget accumulated virtual credits, which could be exchanged for various products and discounts in the app’s marketplace. The CitiCAP mobile application was downloaded approximately 3,000 times and had up to 350 active users per week at its peak. More than one in three users (36%) who responded to the experiment’s surveys reported reducing their travel emissions thanks to the application (Lahti 2021).

As regards health promotion, Ferdman (2021) argues that active mobility modes such as walking and cycling are potentially beneficial to objective well-being, since they enable more and more diverse opportunities to develop and exercise our human capacities, compared to sedentary modes like driving and travelling in an autonomous vehicle (AV). Human capacities are considered here as capacities to know, create, achieve and be sociable while on the move. Adding the human capacities perspective may provide crucial information for policy makers when designing mobility environments and when choosing between alternatives. Hence, it is important to pay attention to the creation of interesting environments, such as streetscapes that contain a visual attraction every four seconds at eye level, remove unnecessary clutter, and design lighting for night-time usage.

An example of social innovation on health promotion is the Finnish national action programme aiming to establish a physically active culture in Finnish comprehensive schools. More than 90 per cent of Finnish schools participate in the programme and apply the developed Schools on the Move Concept. The concept consists of different services related to making the school day more active. The services have been divided into three areas: creating an active culture, developing the pedagogy and increasing movement. By adding physical activity to the school day, the programme does not promote just the health and wellbeing of pupils but also improves the learning outcomes and school enjoyment and creating a peaceful working atmosphere (Schools on the Move 2024).

In future, the radical innovations might gain wider potential to contribute the climate and health impacts of transport and mobility. Currently, based on international and domestic experiences (see section 4), it has been recognized that high-quality routes and their proper maintenance, traffic network planning that equally considers all modes of transport, the arrangement of bicycle parking, experiments encouraging the use of active modes of transport (e.g., at workplaces), as well as campaigns and information sharing about the benefits and opportunities of active modes of transport to residents and especially to municipal decision-makers, are the best ways to promote walking and cycling.

9. Conclusions

The project produced three key results, which correspond to the goals set in the beginning of the project:

1. A generic action portfolio of sustainable urban mobility actions with health co-benefits,
2. A model to assess the co-benefits of selected sustainable urban mobility actions, and
3. A tool supporting the implementation of the actions through transformative capacity building.

The collaboration in the project with the Finnish Mission Cities revealed that all the cities plan and implement already widely many types of sustainable mobility actions. For all the of cities either Sustainable Urban Mobility Plans (SUMPs) or Climate Neutrality Plans for Mobility guide the activities. Many of the cities have also extensive plans for health promotion, but those are often separate from sustainable mobility activities. The structural reform of health and social services in Finland (2023) obligates the wellbeing services counties, municipalities and other regional actors to closer cooperation in health promotion. This may eventually enhance the integration of planning and implementation of local and regional activities promoting both health and sustainable mobility. Long term commitment of the key decision makers is, however, required for better integration of climate and health actions.

The analysis of Climate City Contracts (CCCs) of the Finnish Mission Cities revealed that the range of actions included in the contracts was rather limited, and the descriptions of these actions were rather vague for practical implementation, despite the contract's aim to guide cities' actions and investments to reach climate objectives. Knowing that all Finnish Mission Cities having well-developed plans for sustainable mobility, it appears that the consistency between the CCCs and these plans could be further improved in the future.

Recommendations

To further promote sustainable mobility actions with health benefits, considerations of health benefits could be included as an integral part of future SUMPs, CCCs and other relevant plans. The revised TEN-T Regulation, which entered into force in July 2024, provides an opportunity for this since it designates 431 European cities as urban nodes and sets out specific requirements for them in order to promote seamless traffic flows from, to and across urban nodes on the TEN-T network. One of the requirements is that urban nodes should adopt a Sustainable Urban Mobility Plan and collect and regularly submit to the Commission data on urban mobility indicators.

In addition, a common European-wide assessment method/model for health benefits of sustainable mobility actions could help to recognize the importance of integrated actions at the local level and maybe also allow for comparisons across cities while considering the local contexts. The assessment model developed in this project could serve as a starting point for a generic, wider scale model development. Such an assessment model, highlighting the co-benefits of certain sustainable mobility actions, could also support cities in overcoming decision-making and implementation challenges of actions getting mixed reception.

Based on the results of the project we can provide the following general recommendations for the planning and implementation of sustainable mobility actions with potential health co-benefits. First, it is important to consider different types of actions simultaneously, i.e., policy and solution mixes, since those seem to deliver the largest impacts.

Second, in the health impact assessment, a wider range of pathways outside the most frequently used physical activity, air pollution and road injury should be considered. In doing so, it is important to recognize that the pathways may alter between population groups: increasing physical activity through transportation may be a relevant pathway for health in some people but decreasing social isolation may be a far more relevant pathway in another group of people. Specification of the target population is thus as crucial in promoting health through transport actions as in "general" health promotion. It also helps to identify the most inclusive, feasible and effective intervention options to influence people's transportation behaviour. However, research proves the complexity of the relationship and interdependency of pathways between transportation and health. The effective response to this challenging problem lies not in a single but multilevel systems approach with cross-sectoral collaboration. In practice, this means that simultaneous actions are needed at all socio-ecological levels (individual, interpersonal, institutional, community, policy) by the multifaceted actors of the whole system.

Third, impact assessments and models should take the transport system level approach, since in assessing the benefits and costs of actions often touch more than one mode of transport. For example, cycling is often emphasised in policies and actions, but walking is actually more potential source of health benefits, since walking is often more relevant option to travellers than cycling. It is the most resilient mode, enabling multimodal transport chains.

To conclude, previous research has shown that sustainable mobility actions targeting to increase in active modes and modal shifts from private cars to sustainable modes do not provide extensive contribution to climate change mitigation. However, this study and modelling exercise have indicated that the wider benefits of those actions come from health and wellbeing impacts of individuals. The developed model doesn't include all the potential actions proposed by the generic portfolio, and consequently further research and development work is still needed to widen the scope and utilise the whole potential the modelling approach has to offer for promoting urban sustainability transitions.

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Appendices

Appendix 1. Agenda of the online workshop 13.12.2024

- Welcome (Anna Huttunen, NZC and Anu Tuominen, VTT)
- Findings from the NZC policy workshop (Anna Huttunen, NZC)
- Strengthening the climate neutrality of cities and well-being of citizens through sustainable transport and mobility project (Anu Tuominen, VTT)
- Preliminary results of the project Mission cities' CCCs and SUMPs (Minna Aittasalo, UKK Institute)
- Effective measures: Traffic and health benefits (Henna Sundqvist, VTT)
    - Workshop session 1
- Modeling: Health benefits of traffic (Jouni Tuomisto, Kausal)
    - Workshop session 2
- Final discussion and summary, next steps

Appendix 2. Full documentation of the health model

Model General Structure

An open-source health impact model was used. It is particularly suitable for integration with a greenhouse gas emission calculation model. Linking to other models is also possible if they provide quantitative information on greenhouse gas or air pollutant emissions from combustion processes or active mobility of the population (walking, cycling, and electric cycling). The model is based on two previous models: the WHO HEAT model for the health benefits of active mobility and the model developed at the National Institute for Health and Welfare (THL) for calculating the burden of disease from air pollution. These models were combined so that the new model can assess several health impacts:

- The effect of active mobility on reducing mortality through increased fitness.
- The effect of active mobility on mortality due to increased exposure to air pollution.
- The effect of active mobility on increasing traffic accidents.
- The effect of fine particles on increasing total mortality.
- The effect of nitrogen oxides on increasing total mortality.
- The effect of fine particles on increasing respiratory infections measured by the number of sick days.

HEAT Model for Active Mobility

The HEAT model is quite extensive, and a lot of background information has been built into it, for example, on regional and local population and morbidity. WHO maintains the HEAT model at https://heatwalkingcycling.org. Currently, version 5.3.0 is in use.

In the active mobility submodel, the information and calculations of the HEAT model were utilized by running the actual HEAT model on the web, applying it to the local situation of the city in question, and using the output files to calculate the so-called health coefficient, i.e., the number by which one daily minute of active mobility at the population level translates into a specific health impact.

The advantage of this approach is that the background assumptions and nuances of the model can be simplified into a clear implementation that can be transferred to another platform. The limitation, on the other hand, is that the health coefficients cannot be directly used for the situation of another city without first verifying their applicability. Before using the health coefficients, it was verified that the effects in the HEAT model are indeed in a straightforward relationship with the amount of active mobility.

Air Pollution Burden of Disease Model

THL's burden of disease model is based on calculating attributable fractions. The attributable fraction refers to the proportion of the observed total amount of a health effect that can be attributed to a specific exposure. In other words, the attributable fraction of the disease burden would disappear if the exposure ceased completely. The attributable fraction (AF) is calculated from the formula AF = (RR-1)/RR, where RR is the relative risk caused by the exposure.

THL's model is described in detail (with its source code written in R included) in Opasnet at https://en.opasnet.org/w/Health_impact_assessment. The necessary parts of this code were translated into the Python language used by the Kausal platform.

The advantage of the model based on attributable fractions is that it is relatively easy to transfer to new situations, if local information on morbidity and population is available. The variables it uses are transparent and thus easier for an external expert to evaluate than the numbers produced by the HEAT model, which require knowledge of the model's internal logic.

It is important to note that the risk ratio produced by epidemiological studies does not necessarily accurately indicate the number of premature cases, because they usually compare follow-up time rather than the number of cases between the exposed and control groups. For example, fine particles cause an increase in heart attacks, just like other risk factors such as obesity or high blood pressure. However, it could be that fine particles cause heart attacks at a younger age than other risk factors. However, this is impossible to study because there is no marker that would reveal the cause of an individual patient's heart attack. In this hypothetical situation, however, the number of life years lost would be in proportion to the risk ratio observed in the study. But the number of deaths caused by fine particles would be smaller than the attributable fraction because these patients would die younger and lose more years at once. A detailed description of this bias can be found in Hammitt's article (James K. Hammitt, Peter Morfeld, Jouni T. Tuomisto, Thomas C. Erren. Premature Deaths, Statistical Lives, and Years of Life Lost: Identification, Quantification, and Valuation of Mortality Risks. Risk Anal. 2020 Apr; 40(4): 674–695. doi.org/10.1111/risa.13427).

Actions in the Health Model

New seamless walking and cycling infrastructure. The model assumes that the main walking and cycling routes can be improved through new construction or significant upgrades to existing routes, including quality enhancements, separation of different modes of transport, lighting, and pavement improvements. The impact of these changes is measured through traffic counts and surveys before and after implementation, with cycling volumes on new or improved routes increasing by 8-140%, largely due to route changes. When cycling volumes are measured across larger areas, the growth rates are typically between 0-30%. Modal shifts from car or public transport to cycling have been small or sometimes non-existent, ranging from 2-8% for car to cycling and 6-24% for public transport to cycling, while a 4-8% shift from walking to cycling has also been observed. Output node: relative active transport increase.

Bike parking at railway stations. Improving bicycle parking, particularly at train stations and other public transport stations, can increase the share of cycling when transitioning from home to the station. In the Netherlands, the share of cycling from home to train stations has reached 29 percent by investing in bicycle parking, while in the United States, the share is 4 percent, with the best stations reaching up to 12 percent. Research data is available from both leading cycling countries, such as the Netherlands, and countries with less cycling, such as the United States, so the information can be related and applied to Finnish conditions. The effectiveness of bicycle parking measures is conditional on the bicycle routes, for example, from residential areas to train stations, being in good condition. Output node: modal shift fraction due to actions.

City bikes. Assuming the availability of city bikes increases cycling by 20% overall. The estimate is not based on research, which is why the user can change the estimate using the slider. Output node: relative active transport increase.

Park & ride and Bike & ride facilities. It is assumed that park-and-ride facilities increase bus and train trips by a user-selected percentage, and a corresponding number of trips are reduced from car trips. The same percentage is used for trains and buses, and this should be taken into account in the estimate. The default value is a 15% increase. Output node: relative active transport increase.

Public transport trunk line network development. The model assumes that the trunk route network of public transport reduces travel times and thus increases its competitiveness compared to private cars. A 15% reduction in travel time is assumed when taking into account waiting time. Studies show that the cross-elasticity is quite high, even 0.818 between the travel time of private cars and the use of public transport. However, the effect is initially higher (1.319) and levels off in later years (0.74). Output node: modal shift fraction due to actions.

Congestion charging. The model assumes that congestion charges increase the cost of driving by an average of 20% (more during peak hours, but different times are not considered separately). For public transport, the cross-elasticity is quite high (on average 0.248) and moderate for active modes of travel (0.105). The model could be refined if separate data on short trips were available, as active mobility is focused on them. Output node: modal shift fraction due to actions.

Parking fees. The model assumes the same cost changes and cross-elasticities as in congestion charges. Output node: modal shift fraction due to actions.

Low emission zones. The model assumes that 40 - 80% of nitrogen oxide emissions can be removed by requiring low-emission or zero-emission vehicles in the city center. For fine particulate matter, the change is 20 - 40%. The measure is not assumed to have any other effects than a reduction in the emission factor. Output nodes: transport emission factor, freight transport air pollution emissions.

Reduce all motorised transport. The model assumes a general reduction in the need for motorized traffic due to various reasons: urban planning, remote work, and other measures that do not appear elsewhere in the model. Output node: motorised transport change.

Modal switch from cars to other modes. In the model, a user-selected percentage of car trips are shifted to other transport modes. The distribution follows the default value of the NetZeroPlanner, which is 60% to trains, 30% to walking, and 10% to buses. Output node: passenger kilometres switched.

Car occupancy increased. How many % increase there is in the average number of people in a car. Output node: relative transport efficiency.

Electrification of passenger cars. The model assumes that the share of the electric vehicle fleet increases in an S-curve shape towards a mature situation, which is 35% according to the default value of the NetZeroPlanner. Output node: fully electric car share.

Electrification of buses. Fraction of buses that is replaced with electric buses each year. Output node: fully electric bus share.

Truck fleet electrification. The model assumes that the share of the electric truck fleet increases in an S-curve shape towards a mature situation, which is 100% for vans and 60% for trucks according to the default value of the NetZeroPlanner. Output node: fully electric truck share.

Replace fossil electricity. The decarbonization of electricity production reduces indirect (scope 2) emissions for the electric vehicle fleet. The model assumes a 35 percentage point shift from fossil-based electricity production to emission-free production, as per the default value of the NetZeroPlanner model. Output node: electricity shares.

Intermediate Nodes Used by the Combined Health Model

The combined model operates on the Kausal platform and can be included in the scenario tools used on the platform. The following nodes are required between the health module and the main model:

- Road traffic CO2 emissions (or other emission node with breathing zone emissions)
- District heating CO2 emissions (or other high stack emissions)
- Active mobility
- Population
- Discount rate

Description of Model Nodes

Here, each node is described only in general terms. The calculations implemented in the nodes are described in more detail in the actual online model, which can be found e.g. at https://dut-transport-nzc.paths.kausal.tech or at the source code level at https://github.com/kausaltech/kausal-paths/blob/main/configs/modules/health.yaml

Traffic Emissions Emission Factor. The initial data was obtained from the default values of the NetZeroCities project calculation Excel.

Relative Proportion of Traffic Emissions. The relative proportion of traffic emissions compared to CO2 emissions, which gets a ratio of 1. Input nodes: Traffic Emissions Emission Factor

Traffic Air Pollutant Emissions. Traffic air pollutant emissions calculated from CO2 emissions and other emissions proportioned to it according to the emission factors. Input nodes: Relative Proportion of Traffic Emissions

Fossil Power Plant Air Pollutant Emission Factor. The initial data was obtained from the default values of the NetZeroCities project calculation Excel.

Relative Proportion of Fossil Power Plant Emissions. The relative proportion of fossil power plant emissions compared to CO2 emissions, which gets a ratio of 1. Input nodes: Fossil Power Plant Air Pollutant Emission Factor

Fossil Power Plant Air Pollutant Emissions. Air pollutant emissions from large power plants operating on fossil fuels, calculated from CO2 emissions and other emissions proportioned to it according to the emission factors. Input nodes: Relative Proportion of Fossil Power Plant Emissions

Intake Fraction of Air Pollutants. The proportion of air pollutant emissions that eventually end up being inhaled by someone. The data was obtained from the article by Sebastien Humbert, Julian D. Marshall, Shanna Shaked, Joseph V. Spadaro, Yurika Nishioka, Philipp Preiss, Thomas E. McKone, Arpad Horvath, and Olivier Jolliet. Intake Fraction for Particulate Matter: Recommendations for Life Cycle Impact Assessment (2011). Environmental Science and Technology, 45, 4808-4816.

Breathing Volume. Breathing volume per day. A nominal reading is used, which must be the same as when calculating the intake fraction.

Exposure to Traffic Air Pollutants. Exposure to air pollutants as a long-term average concentration in the breathing zone. The exposure is allocated to the population considered by the model, although part of the exposure occurs outside the study area. Input nodes: Traffic Air Pollutant Emissions, Intake Fraction of Air Pollutants, Breathing Volume, population Output nodes: Air Pollutant Exposure

Exposure to Air Pollutants from Large Fossil Fuel-Burning Power Plants. Exposure to air pollutants as a long-term average concentration in the breathing zone. The exposure is allocated to the population considered by the model, although part of the exposure occurs outside the study area. (only district heating currently) Input nodes: Fossil Power Plant Air Pollutant Emissions, Intake Fraction of Air Pollutants, Breathing Volume, population Output nodes: Air Pollutant Exposure

Air Pollutant Exposure. Total exposure to air pollutants from all sources.

Active Mobility Average Speed. The average speed of active mobility is obtained from the article by Kelly et al. 2014. Also Heli Lehtomäki et al. 2021. Health Effects of Transport in Finland and the Largest Cities. Reports of the Finnish Environment Institute 16 / 2021

Active Mobility Distance. The estimates from Lehtomäki's report, which are based on the National Travel Survey (HLT2016), are used.

Time Spent on Active Mobility. Input nodes: Active Mobility Distance, Active Mobility Average Speed

Active Mobility Health Coefficient. The WHO HEAT model was used to produce a city-tailored estimate of the magnitude of health effects in relation to active mobility. The coefficient is expressed as the time spent on active mobility in the adult population. For walking, the age group of 20-79 years is considered, and for cycling, 20-64 years.

Cases Prevented by Active Mobility. Input nodes: Active Mobility Health Coefficient, Time Spent on Active Mobility Output nodes: Total Case Count Attributable to Exposures

Incidence. Incidence of diseases and effects relevant to environmental exposures

Attributable Fraction of Air Pollutants. The proportion of the disease burden explained by air pollutant exposure. Input nodes: Air Pollutant Exposure

Total Case Count. The total case count in the target population is obtained by multiplying the background incidence by the population size. Input nodes: Incidence, population

Cases Attributable to Air Pollutants. The proportion of the total case count attributable to fine particles and nitrogen oxides. Input nodes: Attributable Fraction of Air Pollutants, Total Case Count Output nodes: Total Case Count Attributable to Exposures

Total Case Count Attributable to Exposures. The total includes both the case counts of air pollutants and active mobility. Positive numbers are disease cases, negative numbers are prevented cases. Input nodes: Cases Attributable to Air Pollutants, Cases Prevented by Active Mobility

Premature Deaths. Premature deaths caused by fine particles, nitrogen oxides, and traffic accidents, and prevented by active mobility. Input nodes: Total Case Count Attributable to Exposures

Disease Burden per Case. The disease burden caused by one case for different responses.

Disease Burden Attributable to Exposures. The disease burden attributable to exposures in the target population. The cases of physical activity, air pollutants, and traffic accidents refer to premature deaths attributable to these exposures. Mortality and lost workdays, on the other hand, refer to cases caused by air pollutants, although this is not specifically stated at this point. Input nodes: Disease Burden per Case, Total Case Count Attributable to Exposures

Statistical Value of Mortality Risk. The default value of the HEAT model is used.

Health Costs Attributable to Exposure. Currently, the cost of sick leave is not calculated, only deaths. Input nodes: Premature Deaths, Statistical Value of Mortality Risk

Discounted Health Costs. Input nodes: Health Costs Attributable to Exposure Parameters: Discount Rate

Appendix 3. Long list of sustainable Mobility Actions with health co-benefits

Measure	Most recent systematic reviews, meta analysis and other reviews	Target	Type of Measure
Congestion pricing	Hosford 2021	Restricting/ reducing car use	Fiscal measures
Congestion pricing	Auvinen et al. 2020	Restricting/ reducing car use	
Parking fees		Restricting/ reducing car use	Fiscal measures
Cycling experiments		Promote active mobility	Service provision/ Mobility Management
Company bikes		Promote active mobility	Service provision/ Mobility Management
Company PT tickets		Promote sustainable urban mobility	Service provision/ Mobility Management
Smart Cards for PT		Promote sustainable urban mobility	Service provision/ Public Transport
PT subsidies (fees)		Promote sustainable urban mobility	Fiscal measures
Multimodal ticketing	Geis & Schulz 2026	Promote sustainable urban mobility	Fiscal measures
Electification of bus fleet	European Commission 2020	Promote sustainable urban mobility	Technological solution
Electification of (municipality) car fleet		Promote sustainable urban mobility	Technological solution
New PT routes		Promote sustainable urban mobility	Service provision/ Public Transport
New cycling infrastructure	Mölenberg 2019,	Promote active mobility	Physical infrastructures
New cycling infrastructure	Auvinen et al. 2020	Promote active mobility	
New walking infrastructure/ urban spaces		Promote active mobility	Physical infrastructures
Separation of walking and cycling infra		Promote active mobility	Physical infrastructures
Bike parking	Auvinen et al. 2020	Promote active mobility	Physical infrastructures
Bike lane/ Walking lane winter maintenance		Promote active mobility	Physical infrastructures
Tactical urbanism actions*/ Attractive walking, cycling en	Tactical Urbanism_NetZeroCities Kn	Promote active mobility	Physical infrastructures
Tactical urbanism actions*/ Attractive walking, cycling en	Yu et al. 2024	Promote active mobility	
Tactical urbanism actions*/ Attractive walking, cycling en	Living Streets of Ghent	Promote active mobility	
Safe cycling and walking routes (to schools)		Promote active mobility	Physical infrastructures
Networks of (outdoor) sports venues		Promote active mobility	Physical infrastructures
Lighting		Promote active mobility	Physical infrastructures
Park & Ride facilities		Promote sustainable urban mobility	Physical infrastructures
Bike & Ride facilities		Promote sustainable urban mobility	Physical infrastructures
Mobility hubs		Promote sustainable urban mobility	Physical infrastructures
New railway/tram lines	Xiao 2019	Promote sustainable urban mobility	
New railway/tram lines	Auvinen et al. 2020	Promote sustainable urban mobility	
Campaigns (e.g. Bike to work)	Pohjalainen 2015	Promote active mobility	Communication/ Marketing
Marketing (e.g. PT or Cycling Brand)	Pohjalainen 2016		Communication/ Marketing
Communication	Belanger-Gravel 2021	Promote active mobility	Communication/ Marketing
Info days/Info points		Promote active mobility	Communication/ Marketing
Sustainable Mobility Ambassadors		Promote active mobility	Communication/ Marketing
Cycling courses / cycle repair courses (also support to companies to organise)		Promote active mobility	Service provision/ Mobility Management
Sustainable Urban Mobility Plans (SUMP)	Policies: Winters et al. 2017	Promote sustainable urban mobility	Transport, Urban, Environmental planning
Local transport, transport system and urban plans		Promote sustainable urban mobility	Transport, Urban, Environmental planning
Transport safety plans		Promote sustainable urban mobility	Transport, Urban, Environmental planning
MAL plans, integrated planning (PT, walking, cycling, urban form)		Promote sustainable urban mobility	Transport, Urban, Environmental planning
Local walking development plans		Promote active mobility	Transport, Urban, Environmental planning
Local cycling development plans		Promote active mobility	Transport, Urban, Environmental planning
Walk to school guidelines (liikkuva koulu tmv.)		Promote active mobility	Guidelines
Sustainable procurement guidelines		Promote active mobility	Guidelines
Parking Management/ Car parking restrictions	Parking and SUMP_Topic Guide	Restricting/ reducing car use	Regulation and Legislation
Parking Management/ Car parking restrictions	Park4SUMP	Restricting/ reducing car use	
Low Emission Zones	Williamson et al. 2022	Restricting/ reducing car use	Regulation and Legislation
Low Emission Zones	Sarmiento et al. 2023	Restricting/ reducing car use	
Speed limits/ Car transport calming	van Erpecum et al. 2024	Restricting/ reducing car use	Regulation and Legislation
City bikes	Teixeira 2021	Promote active mobility	Service provision
City bikes	Auvinen et al. 2020	Promote active mobility	
E-scooters	Wang 2023	Promote active mobility	
E-scooters	Badia & Jenelius 2023	Promote active mobility	Service provision
E-scooters	Abduljabbar et al. 2021	Promote active mobility	
Car sharing	Vélez 2023	Restricting/ reducing car use	Service provision
Workplace Mobility Plans	Maheswari 2022	Promote sustainable urban mobility	
Workplace Mobility Plans	DeGruyter 2018	Promote sustainable urban mobility	Service provision/ Mobility Management
Public Transport (PT) service level improvements		Promote sustainable urban mobility	Service provision/ Public Transport
Increase of PT departures		Promote sustainable urban mobility	Service provision/ Public Transport
PT trunk line network development		Promote sustainable urban mobility	Service provision/ Public Transport
First/last mile services/Integration with PT services/	Kosmidis 2023	Promote sustainable urban mobility	Service provision/ Public Transport
Transport policies	Zukowska 2022		
Built environment	Aldred 2019		
Built environment	Tcymbal 2020		
Built environment	Zhang 2022		
Interventions to reduce car use	Cleland 2023		
Impacts on wellbeing	Ferdman 2021		
Stakeholder experiences	Lawlor 2022		
Health impacts	Mizdrak2023		
Health impacts	Glazener 2021		
Climate Neutrality	Christidis 2024		
Active travel interventions	Roaf 2024		