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Measures to foster active mobility and co-benefits for climate and health in Vienna*

von

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Abstract

Physical inactivity is ever-rising globally, with far-reaching consequences for both the environment and human health. In Austria, around 38% of the population is “insufficiently active”. Motorised transport, in particular car travel, reinforces the issues of physical inactivity and deepens the dependency on fossil fuels, which exacerbates the threat of global climate change. Fostering active mobility (AM, i.e. walking and cycling) and discouraging individual motorised transport (IMT) hold potential to yield synergetic effects, so-called co-benefits, for climate and health, which can act as additional incentives for decision makers to adopt climate change mitigation measures in the field of mobility.

This thesis assesses the health and climate effects in the event of a shift in passenger transport mode choice towards active mobility stemming from the implementation of defined measures in a future scenario in the city of Vienna. A literature screening is conducted to select four measures to foster AM among the Viennese population and discourage IMT. The selected measures are then implemented in the system dynamics model Metropolitan Activity Relocation Simulator (MARS) to derive the future scenario “all measures 2030” and calculate climate effects (i.e. changes in CO_2-emissions against a business-as-usual scenario and the baseline). Furthermore, additional estimates of CO_2-emissions are performed. Specific outputs of the MARS model serve as inputs for a Comparative Risk Assessment (CRA). The CRA is utilized to estimate effects on health (i.e. changes in burden of disease, expressed in disability-adjusted life years, DALYs) compared to the year 2013 as a baseline.

With the introduction of the selected measures (road calming, improvement and expansion of cycling routes, increase of parking fees and limitation of parking spaces) the share of people in Vienna who are “sufficiently active” increases to 65% compared to 38% in the baseline due to more people participating in cycling and walking. More than 1,600 DALYs are saved in 2030 compared to 2013. The measures proposed could save approximately 1,100 DALYs in the future scenario for ischemic heart diseases alone, which translates to a 9% reduction. Considering overall burden of disease in Vienna (all causes), about 0.7% of total DALYs could be saved. Walking trips account for more than half of DALYs saved, which indicates the importance of walking as an active travel mode. Additionally, CO_2-emissions in the Viennese passenger transport sector are reduced by up to 226,500 tonnes per year, which translates to a reduction of up to 61% of emissions stemming from IMT affected by the mobility behaviour changes. The findings show that the selected measures to foster AM and discourage IMT yield high benefits for both climate and health and are effective in realizing the ambitious goals formulated by the Viennese Urban Development Plan (STEP 2025). Combining “pull” and “push” measures, as applied in this thesis, and implementing interventions in bundles, seem to be of great importance in facilitating lasting mobility behaviour changes. Evaluating measures to foster active mobility and reduce the attractiveness of IMT, and their effects on climate and health, can create compelling arguments for the implementation of climate change mitigation measures.

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List of abbreviations

AM	Active mobility
AT	Active travel, used interchangeably with AM
CRA	Comparative Risk Assessment
CAPs	Climate-altering pollutants
CO_{2equ}	Carbon dioxide equivalents
CVD	Cardiovascular disease
DALYs	Disability-adjusted life years
DRF	Dose-response function
ERF	Exposure-response function
GHG	Greenhouse gas
HIA	Health impact assessment
IMT	Individual motorised travel / transport
IPCC	Intergovernmental Panel on Climate Change
NCD	Non-communicable disease
PA	Physical activity
PI	Physical inactivity
PM	Particulate matter
PT	Public transportation
vkm	Vehicle-kilometres
WHO	World Health Organization

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1. Introduction

1.1 Background

Physical inactivity is on the rise globally. Kohl and colleagues have dubbed physical inactivity as a “global pandemic” (Kohl et al., 2012), with far reaching consequences for human health and the environment. Globally, around 23% of adults fall under the World Health Organization (WHO)-category of “insufficiently active”, meaning they engage in less than 150 minutes of moderate intensity physical activity per week (WHO, 2010). The share of “insufficiently active” children and adolescents between the ages of 11 and 17 is even higher, at around 81% globally (WHO, 2018). In Austria, around 38% of the population is “insufficiently active”, with women and young adults particularly at risk (Putz, 2009).

Physical inactivity has substantial effects on human health. Lee and colleagues found that around 6 to 10% of major NCDs (non-communicable diseases) worldwide can be attributed to physical inactivity (Lee et al., 2012). Morbidity associated to physical inactivity burdens not only the health systems, but also society and individual quality of life and creates economic costs (Kohl et al., 2012). Physical inactivity and sedentary behaviour (time spent sitting) are ever-rising, potentially driven by “rapid urbanisation, mechanisation, and increased use of motorised transport” (Hallal et al., 2012).

The prevalent dominance of motorised forms of transport, especially individual motorised transport (IMT, car travel), reinforces the issues of physical inactivity, as well as air pollution, and deepens the dependency on fossil fuels. This dependency on fossil fuels amplifies climate issues through the emissions of carbon dioxide (CO_2). Mobility accounts for around 29% of greenhouse gas emissions in Austria in 2017, 99% of those stems from road traffic (UBA, 2019). However, mobility is also of great importance not only for transportation of goods, supplying energy and raw materials, but also for commuting to work, running errands, care work and leisure purposes. Batty and colleagues state that “Transport has significant and long-lasting economic, social and environmental impacts, and is thus an important dimension of future sustainability” (Batty et al., 2015). Thus, exclusively curbing mobility is not the solution. Other, more sustainable and healthy options than individual motorised travel need to be considered in order to address the complex and manifold issues that arise. Active mobility (AM), i.e. walking and cycling, offer potential to address these concerns. Active mobility has the capability to influence the physical activity levels of a large part of the population. Measures to foster active mobility and discourage individual motorised travel may increase physical activity (PA), while decreasing carbon dioxide emissions and air pollution from car travel, and hence yield synergetic positive effects, so-called co-benefits, for climate and health. While the effects of interventions for climate change mitigation have a spatial and temporal offset, health co-benefits of certain climate change mitigation measures can be realized more directly and often more quickly, thus making them more tangible for decision makers (Watts et al., 2015; APCC, 2018).

Cities are of great importance in this context. The WHO estimates that by 2030 more than 80% of the population in Europe will be living in cities (WHO, 2017). At the same time, cities provide comparably short distances between living, working, leisure, amenities, etc., a high population density (meaning that measures may reach a high share of the population) and already existing infrastructure, thus offering great potential for the implementation of measures fostering active mobility and decreasing the attractiveness or viability of individual motorised travel.

There is a plethora of proposed measures to foster active mobility and decrease car usage. Evidence of effectiveness of measures is scarce, however. Studies assessing impacts of active mobility on human health tend to focus on policy goals rather than on the specific set of measures to reach a mode shift. In this thesis emphasis is put on the means to reach a mode shift, incorporating a dynamic transportation (and land-use) model called MARS (Metropolitan Activity Relocation Simulator) from the Institute of Transportation (Research Unit Transport Planning and Traffic Engineering, Vienna University of Technology). A hypothetical future scenario is developed, in which a set of four measures is implemented. The occurring shift towards active mobility (i.e. walking and cycling) entails effects on human health, which are estimated using a Comparative Risk Assessment (CRA), and on carbon dioxide emissions, which are obtained from the MARS model and from own calculations.

1.2 Research question and aim of thesis

This thesis addresses the question of the effects of an increase in active mobility on climate and health in the city of Vienna, Austria. More specifically, it focuses on the combined climate and health effects from a set of selected measures to foster walking and cycling among the Viennese population and decrease the attractiveness of individual motorised travel (IMT).
Thus, the main research question is:

- *What are the combined health and climate effects of a shift in transport mode choice towards active mobility (i.e. walking and cycling) in a future scenario in Vienna, stemming from the implementation of defined measures?*

The climate effects of concern are carbon dioxide (CO_2)-emissions stemming from the passenger transport system of Vienna.
The health effects of concern are effects on specific diseases obtained from an increase in physical activity, resulting in a higher share of the Viennese population falling under the category of “sufficiently active”. While other impacts on health, such as air pollution, traffic injuries and fatalities or noise, are discussed, they are not considered in the estimates of health effects in this thesis.
As emphasis is put on specific measures and their effectiveness in increasing participation in active mobility and decreasing individual motorised travel, and their subsequent effects on health and climate, three supporting research questions are formulated:

- *What are effective and/or promising measures to foster active mobility and/or decrease the attractiveness of individual motorised travel as described in academic literature, strategic papers and national plans?*
- *What are the effects of a set of four selected measures to foster active mobility and/or decrease the attractiveness of individual motorised travel on modal split and transport mode choice in a future scenario in Vienna compared to the baseline and a business-as-usual scenario?*
- *Based on that, what are the effects on human health and CO_2-emissions in a future scenario in Vienna compared to the baseline?*

1.4 Thesis outline

The thesis is structured as follows: After the introduction (chapter 1) and outlining the relevancy for social ecology (chapter 2), the "State of the art" chapter (chapter 3) provides an overview of the interlinkages between climate change, health, transport and active mobility. Several case studies on climate and health co-benefits are presented to show evidence of the interlinkages between mobility, climate and health in the city of Barcelona, Spain, and the city of Vienna, Austria.

Chapter 4 ("Material and methods") explains the methods applied and data sources used. It is subdivided into four subsequent methodological steps: First, the literature screening is outlined and the selection criteria for measures selection are defined. Then, the Metropolitan Activity Relocation Simulator (MARS) and its outputs, which are used for the calculation of climate effects and a Comparative Risk Assessment (CRA) are described. Alongside carbon dioxide estimates stemming from MARS, own calculation methods are outlined. Finally, the methodical approach of the CRA applied, which is used to quantify the health effects of the selected measures, is described in depth.

In chapter 5 the main results of the literature screening are presented and discussed. The chapter includes a detailed table of measures to foster active mobility assessed.

Chapter 6 ("Empirical results") combines the presentation and discussion of the empirical results obtained from MARS and own calculations. Finally, chapter 7 draws conclusions of the thesis in terms of climate and health effects and effectiveness from measures to foster active mobility, and provides an outlook of further research needed.

Supplementary information on calculation details, data sources and results can be found in the appendix.

2. Relevancy for Social Ecology

The Viennese School of Social Ecology addresses the interactions between social and natural systems to provide the scientific basis for a sustainable societal transformation. It acknowledges that society depends on the natural environment, while both society and nature interact and co-evolve over time. The society-nature interaction model establishes a conceptual framework for those interactions and locates the human population, infrastructure and livestock as hybrids of the two domains (Fischer-Kowalski & Weisz, H., 1999). In this framework, the mutual interactions of the societal and natural domains are central. “Therefore, the natural and cultural spheres of causation partly overlap in society” (Fischer-Kowalski & Weisz, H., 2016: p.22), as shown in the conceptual model of society-nature interaction in Figure 1.

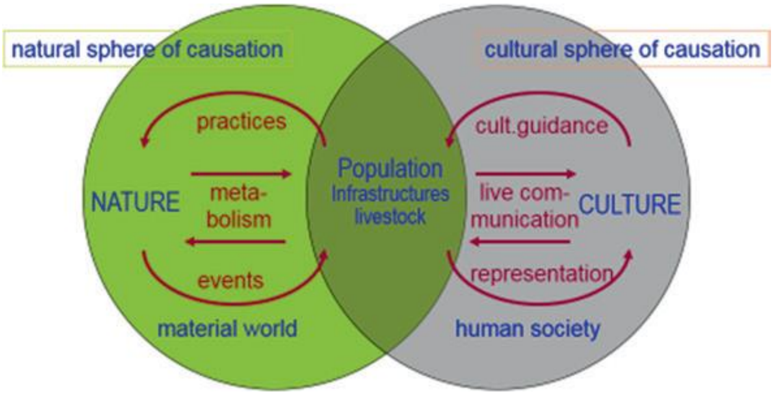

Figure 1. Conceptual model of society-nature interactions from the Viennese School of Social Ecology (Fischer-Kowalski & Weisz, H., 2016, p.21)

According to this understanding, transport and its infrastructure are considered as hybrids in terms of being a product of the cultural sphere of causation, while also being part of the biophysical realm or the natural sphere of causation. Transport modes, mobility behaviour and related lifestyles as part of culture affect the biophysical realm, for example through the construction of infrastructure, energy use or the output of emissions. Changes in the biophysical environment (such as the construction of public transport stops) may produce feedback-loops, which in turn affect mobility behaviour, e.g. the development and expansion of public transport (PT) in areas formerly lacking PT access. According to the society-nature interaction model, measures with the aim to manage mobility (in response to changes in the biophysical realm) can be defined as programmes. Programmes may lead decisions and actions of the collective, and may lead to changes in behaviour and lifestyles (if certain conditions are met), which then again affect the biophysical realm.

In order to describe the society-nature interactions, the Viennese School of Social Ecology offers two concepts - social metabolism and colonization of nature/natural processes (Fischer-Kowalski & Weisz, H., 2016; Haberl et al., 2002; Fischer-Kowalski & Weisz, H., 1999; Fischer-Kowalski & Haberl, 1993). The concept of social metabolism applies the concept of biological metabolism, which describes biochemical processes that allow organisms to reproduce themselves, to society. Biological metabolism encompasses inputs – material and energy needed by the organism, which are transformed internally – and outputs, for example excrements, which are emitted into the environment. In analogy to the biological metabolism, the concept of societal metabolism comprehends society as an entity that depends on a continuous throughput of material and energy, transforms those inputs internally, and creates outputs in various forms in order to reproduce its biophysical structure. The biophysical part of society consists of "stocks", accumulation of material and energy, which are in constant exchange: input enters stocks, may be transformed internally, and output leaves stocks and subsequently may leave society. Stocks within the system need some form of maintenance, in the form of continuous inputs of material, energy or labour (Fischer-Kowalski & Erb, 2016). The concept of social metabolism can be applied to different scales. It can be applied to a nation, or a specific sub-part, such as the transport sector. In the context of mobility, inputs may be materials needed to construct infrastructure (roads, subway stations, etc.) or vehicles (cars, bicycles, etc.) for mobility purposes, as well as energy, most commonly energy stemming from fossil fuels to construct and fuel vehicles, among others. Outputs generated include emissions (CO_2-emissions and other air pollutants) from motorised forms of transport.

The concept of colonization of nature describes the precise and systematic interventions in natural systems and processes with the aim to fundamentally alter them and keep them in a specific state to yield benefits for society (Haberl et al., 2002; Fischer-Kowalski & Weisz, H., 2016). This distinguishes the interventions made from outputs, such as emissions, which can be considered unintended side-effects (Fischer-Kowalski & Haberl., 1993). The interventions are usually linked with continuous inputs from society to maintain the desired condition of systems and processes. In the context of mobility, colonization manifests in the alteration of the biophysical environment. The construction of infrastructure, such as roads, is a prime example of human colonization with the purpose of allowing the population to be mobile. "If a road is built, plants are purposively eliminated from this because they would impede mobility - the concrete used is no 'emission' into the environment, but a means to social purpose" (Fischer-Kowalski & Haberl, 1993, p.430).

Emissions, such as carbon dioxide emissions, are unintended side-effects of social metabolism and colonization, and are a driving force of climate change. Addressing emissions using an “end-of-pipe” approach is inadequate, as “All input flows in a social system ultimately exit the system as output flows” and “A dissipative system cannot be blocked from behind; to reduce emissions and waste, one must reduce the input into the system” (Fischer-Kowalski & Erb, 2016, p.43). Hence, in the context of mobility and transport, transport modes and mobility behaviour need to change in order to reduce CO_2-emissions effectively. In order to do so, the framework conditions, as well as the programmes imposed by society, need to be transformed. Measures to foster active mobility and decreasing the attractiveness or viability of individual motorized travel, enabling a shift away from car travel towards more sustainable modes of transport (i.e. walking and cycling), offer opportunities to alter the inputs into society, and therefore the outputs leaving the system.

Since the human population can be located as “hybrids” between the natural and the societal realms within the society-nature interaction model, human health can be viewed as the state of the population (Weisz, U., 2015; Weisz, U., & Haas, 2016). Measures to foster active mobility hold potential to not only curb social metabolism (i.e. material and energy use and related greenhouse gas emissions), but also affect human health positively (Watts et al., 2017; IPCC, 2018; APCC, 2018). While the long-term benefits of reducing greenhouse gas emission have a spatial and temporal offset, benefits for human health are more immediate, tangible and can act as additional incentives for decision makers and stakeholders to adopt measures to foster active mobility. Thus, human health serves as socio-ecological, valuable argument in the sustainability debate and for policy making regarding sustainability issues (Weisz, U. & Haas, 2016).

3. State of the art

This chapter gives an overview over the current state of the art on the topic of active mobility, and interlinkages to climate change, health and transport.

Climate change affects health in numerous ways. In the face of the threat of human-induced global warming and its noticeable impacts today, the topic is emerging in both the scientific and political domain (Watts et al., 2015, 2017, 2019; APCC, 2018). There is consent that climate change will affect human health mostly negatively (Haines et al., 2006; McMichael et al., 2006; Confalonieri et al., 2007; Smith et al., 2014; Watts et al., 2015; Watts et al., 2017; APCC, 2018; Watts et al., 2019). The effects are manifold and complex and range from direct impacts due to heatwaves, floods and other environmental catastrophes to indirect impacts such as the spread of disease-transmitting vector-organisms and population displacement.

Figure 2 provides an overview of pathways between determinants and health effects of climate change ("exposure pathway"). It also shows leverage points for climate change adaption and climate protection measures ("countermeasures"), including combined effects on emission reduction and health ("health related co-benefits") (Fig. 2, APCC, 2018).

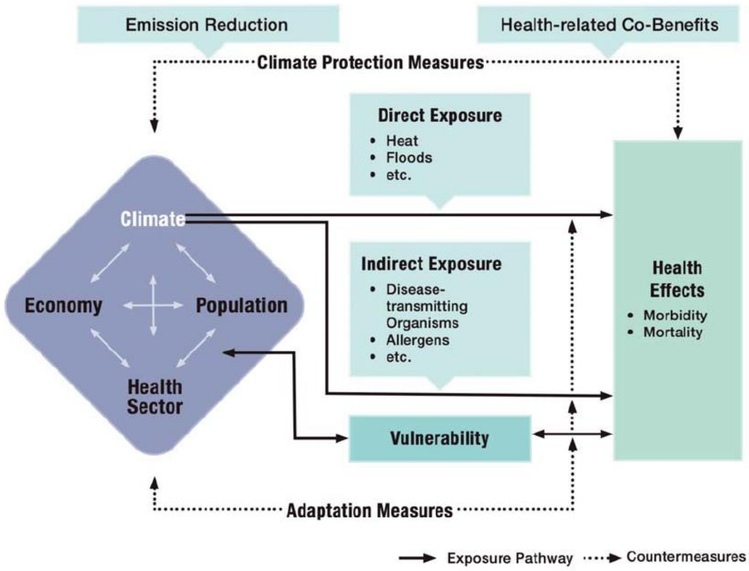

Figure 2. Exposure pathways of climate change-related determinants of health and entry points for countermeasures (APCC, 2018, p.11).

Measures to change mobility and mobility behaviour have the potential to affect CO_2-emissions substantially, while also entailing effects on human health, producing such "co-benefits" for health.

3.1 Mobility, climate change and health

Mobility affects both climate and health in numerous ways. Mobility in its current form facilitates what Kohl and colleagues have dubbed the "global pandemic of physical inactivity", since car travel is the dominant form of transportation and does not rely on physical activity (Kohl et al., 2012; Pérez et al., 2017). The still increasing number of cars affects the population's health due to an ever-rising physical inactivity, traffic injuries and fatalities, noise, social isolation and air pollution, and due to greenhouse gas emissions (de Nazelle et al., 2011). The observable effects of climate change are global, with a spatial and temporal offset, whereas the effects of physical activity, traffic injuries and fatalities, noise, air pollution and social isolation are short-term and mostly localised.

Since most cars (more than 95% of motor vehicles, Xia et al., 2013) are still reliant on fossil fuels, the dependency on this finite resource is reinforced. The WHO describes the travel behaviours of current forms of mobility as "entrenched", creating "large barriers to change", and depicts individual motorised travel as "micro-environments", with cars still acting as symbols of power, status, freedom and individuality (Hosking et al., 2011).
There is a dire need to address the manifold challenges of mobility, particularly in cities. The WHO states that "[…] cities may be one of the most important places, as the challenges are concentrated there and at their most visible. Accordingly, cities are places where new solutions can have a significant impact and show the path towards a more liveable, just, healthy, safe and sustainable world for all" (WHO, 2017, p.15). In cities, the potential for active mobility is particularly high due to comparably short distances and readily available infrastructure (Wolkinger et al., 2018). It is becoming increasingly clear that it is necessary to re-structure urban mobility fundamentally in order to combat health and climate issues and achieve a sustainable transportation system.
An opportunity for restructuring urban mobility is active mobility. Active mobility or active travel includes any form of mobility that relies (partially) on physical activity for transportation. It is mostly used to describe walking and cycling, though other forms of mobility such as skateboarding, or roller skating can also be considered active mobility. Depending on the definition and the scope, the usage of public transportation can be considered as active mobility as well, since it is necessary to walk / cycle to a station and from the station to the desired destination. Fostering active mobility in a population may lead to beneficial effects on climate and health, but also in some cases to detrimental effects on health (see page 22 and 23). It is important to note that the connections between health and mobility are manifold, complex and not fully understood (Watts et al., 2019; APCC, 2018). The following sections aim to give an overview of the effects of (active) mobility on climate and health and to discuss the importance of so-called co-benefits of active mobility.

3.1.1 Climate and health effects of current modes of mobility

Transportation is one of the biggest contributors to greenhouse gas (GHG)-emissions worldwide and accounts for about 16% of global GHG-emissions in 2016 (WRI, 2020[1]), and its growth in energy use is higher than for any other sector (Hosking et al., 2011). The transport sector in Austria is one of the largest GHG emitters with a constant increase, accounting for almost 29% of the country's GHG-emissions (UBA, 2019). Approximately 99% of those stems from road traffic, most of which are CO_2-emissions (UBA, 2019). Individual or private motorised travel (car travel) and specifically vehicle miles travelled are important contributors to emissions and air pollutants. Around 18% of total national GHG-emissions stem from passenger transport, in particular from car travel (UBA, 2019). At the same time, in Europe almost half of all car journeys are less than 5 km (Xia et al., 2013; Wegener et al., 2017) and hold great potential for a substitution with active travel modes, such as walking and cycling. However, over the past three decades, active mobility or active transportation has declined in most developed countries (Giles-Corti et al., 2010).
Neves and Brand find that around half of all car trips in Cardiff, Wales (UK) are less than three miles (around five kilometres) and active mobility (i.e. walking and cycling) could realistically replace 41% of those short car trips, saving around 5% of CO_2-emissions from individual motorised travel (Neves & Brand, 2019).

[1] See URLs

Transportation systems offer opportunities for climate change mitigation and at the same time direct benefits for health (i.e. health co-benefits of climate change mitigation, APCC, 2018; Watts et al., 2019). On one hand, substitution of high-emission transport systems that rely on the combustion of fossil fuels with low-emission transport systems, such as e-mobility, and absolute decreases in individual motorised forms of transport may aid greenhouse gas emission reduction and may reduce traffic-related air pollution ("decarbonisation of the vehicle fleet", Watts et al., 2017). On the other hand, an increase in active travel modes such as walking and cycling, and to a certain degree public transportation, offers great opportunities to improve health, namely physical activity levels, "with all the attendant benefits in terms of reduced risk of cardiovascular disease, selected cancers, dementia, and diabetes, as well as improvements in mental wellbeing" (Watts et al., 2017, p.8). Benefits of physical activity in adults include reduced all-cause mortality, reduced rates of coronary heart disease, high blood pressure, metabolic syndrome, type 2 diabetes, breast and colon cancer, and even depression (Lee et al., 2012).

The Intergovernmental Panel on Climate Change (IPCC) stresses the importance of "designing transport systems that promote active transport and reduce use of motorised vehicles, leading to lower emissions of CAPs[2] and better health through improved air quality and greater physical activity" (Smith et al., 2014, p.714).

Promotion of active travel reaches a broader spectrum of the population than for example individual workplace-based interventions and it has become an important agenda for policy makers. Adverse effects of participating in active mobility, such as an increase of the inhalation of small particulate matter (PM_{10} and $PM_{2.5}$) during active travel, or traffic injuries and fatalities, need to be considered if possible to assess the overall health effects of active travel (Hosking et al., 2011). Measures to protect against those negative effects are needed to accompany measures to foster active mobility (Haines et al., 2009).

Figure 3 summarizes important effects on health that arise with the participation in active mobility. The figure is a graphical summary based on Hosking et al., 2011. The effects are then described in greater detail.

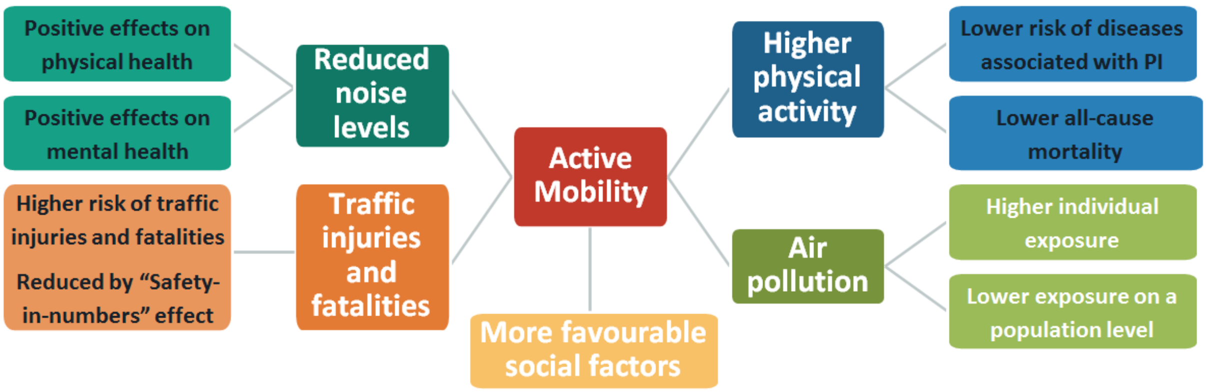

Figure 3. Summary of important effects of active mobility on human health.

[2] Climate-altering pollutants

Higher physical activity

Each hour spent in a car per day is found to statistically increase the likelihood of obesity by 6%, whereas each kilometre walked per day was found to reduce the risk of obesity by 4.8% (Frank et al., 2004). Generally, countries with the highest levels of active mobility (i.e. walking and cycling) have shown the lowest (self-reported) obesity rates (Pucher et al., 2010).

Participating in active mobility rather than individual motorised travel leads to a higher physical activity in everyday life. The American Heart Association recommends 30 minutes or more of moderate-intensity physical activity on most days of the week (Haskell et al., 2007). The WHO recommends doing at least 150 minutes of moderate-intensity physical activity or at least 75 minutes of vigorous-intensity physical activity during a week, or "an equivalent combination of moderate- and vigorous intensity activity" for the age group of 18 to 64 years (WHO, 2010).

It was found to be easier for people to participate in active mobility and thus integrate physical activity through walking or cycling in their everyday life than to add physical activity in their leisure time (Wegener et al., 2016; WHO, 2017). Active mobility is furthermore affordable and practicable for most people (without reduced mobility). Hence, active mobility holds great potential to increase physical activity on a population level. Also, people participating in active mobility were found to be more active overall, suggesting that there is no substitution of leisure-time physical activity with active mobility (Wegener et al., 2016; Woodcock et al., 2009).

Several studies have estimated the health benefits of physical activity to have the greatest impact on health for people participating in active mobility (de Nazelle et al., 2011; Rojas-Rueda et al., 2012; Mueller et al., 2018). Benefits were found to be largest for those who were physically inactive at baseline (Mueller et al., 2018), and people over the age of 45 years (de Hartog et al., 2010; Rojas-Rueda et al., 2012; Xia et al., 2015).

Regular physical activity leads to risk reductions for coronary heart disease, type 2 diabetes, breast and colon cancer, obesity, depression and other chronic disorders (Lee et al., 2012). Furthermore, physical activity impacts all-cause mortality (Andersen et al., 2000; Woodcock et al., 2011). Andersen and colleagues found a 28% risk reduction for all-cause mortality for people cycling to work regularly, resulting in about three hours of additional physical activity per week, compared to people who did not reach this amount of mobility in their daily lives (Andersen et al., 2000).

Air pollution

The transport sector is one of the most important contributors to air pollution, which the WHO describes as "the single greatest environmental health risk facing European cities" (WHO, 2017, p.23). Air pollution is responsible for more than three million deaths across the world annually, and causes a number of health problems (OECD, 2014). It is estimated that in the European region the economic cost of air pollution impacts amounts to US$ 1.6 trillion (WHO, 2017). In Austria, thousands of deaths can be attributed to air pollution annually, and air pollution reduces the life expectancy of Austrian citizens by half a year to one year on average (APCC, 2018).

Pollutants stemming from private motorised travel include small particulate matter (PM_{10} and $PM_{2.5}$), as well as carbon monoxide (CO), oxides of nitrogen (NO_x), ground-level ozone, volatile organic compounds (VOCs) and benzene (Hosking et al., 2011; Xia et al., 2013). In particular PM_{10} and $PM_{2.5}$, particles of less than 10 µm and 2.5 µm in diameter, are considered as hazardous pollutants, as they are able to "penetrate deep into the respiratory system, bypassing usual defences against dust" (Hosking et al., 2011, p.22). Exposure to those airborne

particulates are related to premature mortality, cardiovascular and respiratory disease and cancer (Hosking et al., 2011; Krzyżanowski et al., 2005).
Nitrogen oxides (NO_x) summarize the nitrogen-compounds NO and NO_2. They possess acid-forming properties and can result in mucosal irritations. They have been present in political discourse for a longer period of time and substantial progress with regards to NO_x-reductions has been made (Krzyżanowski et al., 2005).
Individuals participating in active travel, namely walking and cycling, suffer from a higher exposure to air pollution due to increased inhalation and possibly longer trip duration (de Nazelle et al., 2012). Exposure to vehicle emissions, such as CO and VOCs, seem to be highest while participating in car and bus travel, while car travel may lead to a reduced PM exposure if windows are closed (Kaur et al., 2007).
However, the health benefits due to a higher physical activity that arise from participating in active mobility are found to outweigh the adverse effect due to air pollution and traffic injuries (de Nazelle et al., 2011; Mueller et al., 2015; Maier, 2015; Tainio et al., 2016; Woodward & Samet, 2016), irrespective of geographical contexts (Mueller et al., 2018).
It is necessary to differentiate between air pollution impacts on individual participants of active mobility and impacts on the general population through ambient air pollution. As participation in active mobility increases, on a population level the exposure to ambient air pollution may decrease, since car trips are increasingly substituted with active mobility, thus lowering car usage and associated pollutants on a broader scale (Woodcock et al., 2009; Xia et al., 2015; Wolkinger et al., 2018). Hence, the negative effects that may arise for the individuals participating in active mobility could potentially be negated even further, as ambient air pollution decreases. This reduction in air pollution due to a shift towards active mobility results in "reductions of all-cause mortality, respiratory disease, CVD, cancer, adverse birth outcomes, activity-restriction days, and productivity-loss", whereas "Air pollution estimates for the active traveller, however, resulted in increases of described health outcomes" (Mueller et al., 2015, p.107). Both the impacts on the active traveller, and the impact on the general population, are estimated to be rather small in comparison to the effect physical activity has on human health (see Mueller et al., 2015).

Traffic injuries and fatalities and the “Safety-in-Numbers” effect

Road traffic is responsible for more than three thousand deaths daily across the world (Peden et al., 2004; WHO, 2018), for around 1.35 million global deaths and up to 50 million injuries annually (WHO, 2018). In 2004 road traffic incidents were the ninth leading cause of death globally (Hosking et al., 2011), in 2018 the eighth leading cause (WHO, 2018). There are significant differences in traffic injury and fatality risks among countries and across cities, suggesting differences in interventions for safety or differences in the transportation "culture" (Pucher & Buehler, 2008). The WHO states that "despite the scale of the problem, road traffic injury is considered largely predictable and preventable with the right measures" (Hosking et al., 2011, p.25). People who participate in active mobility (walking and cycling) are exposed to a higher risk of traffic injuries and fatalities than people driving cars (Pucher & Dijkstra, 2003; Wegman et al., 2012; Zegeer & Bushell, 2012). Public transportation can be regarded as a comparably safer mode of transport (Dhondt et al., 2013). However, overall, estimated health risks of traffic injuries and fatalities are minor in comparison with health benefits from an increase in physical activity (see above).
The so-called "Safety-In-Numbers" effect describes the phenomenon that the more people walk and/or cycle, the safer walking and cycling is per person (Elvik, 2009; Jacobsen, 2003). This possible "protective factor" (de Nazelle et al., 2011) could reduce the risk of traffic injuries

and fatalities with increasing participation in active travel. Jacobsen (2003) estimates that a doubling of people walking would lead to a 32% increase in total traffic injuries and a 34% reduction in individual's risks (Jacobsen, 2003). A reduction in the volume of motorised traffic may also lead to a reduction in accidents (Niewenhuijsen & Khreis, 2016). Switching to safer modes, such as PT, may reduce traffic incidents (Dhondt et al., 2013). However, measures to improve the safety of pedestrians and cyclists, such as designated cycling paths or road calming measures, still should be put in place to accompany measures to foster active mobility and reduce private motorised travel (Haines et al., 2009).

Reduced noise levels

There is limited evidence of the effects of noise level on health, in particular as to how noise levels change with a higher participation in active mobility, although motorised travel is the biggest source of community noise (Hosking et al., 2011). Elevated noise levels are associated with annoyance, sleep disturbances, higher stress levels and reduced cognitive performance (in particular in children) (WHO, 2011). Also, environmental noise exposure has been found to impact the cardiovascular system (Münzel et al., 2018). The WHO estimates that in the western part of Europe, at least one million healthy life years are lost annually due to traffic-related noise (WHO, 2011). Sleep disturbance (approx. 903,000 DALYs) and annoyance (approx. 587,000 DALYs) account for the largest share of healthy life years lost. In Austria, noise exposure in urban areas is responsible for around 24,000 healthy life years lost every year, and in Vienna around 94% of the population is exposed to high noise levels from road traffic (EEA, 2020[3]).

Pedestrians, cyclists and people using public transportation (especially subway, Neitzel et al., 2009) may suffer from a higher exposure to noise on an individual level (compared to travel in a car with closed windows). Conversely, overall noise levels may decrease as more people participate in active travel, as well as through specific interventions and measures such as an expansion of 30km/hr zones. Further research is needed to assess how participation in active mobility affects the individuals participating and ambient noise levels.

Noise may furthermore have an indirect effect on health by deterring people from participating in active mobility (van Lenthe et al., 2005). Reducing noise levels by discouraging people from using private motorised travel may increase attractiveness of active mobility, thus impacting physical activity, air pollution exposure, and more.

More favourable social factors

Aside from effects on physical aspects such as physical inactivity or accidents, transportation and mobility play a role in social situations and social determinants of health. "Transport also impacts on patterns of access to services and social interaction, which in turn can affect social determinants of health (health equity) and mental health" the WHO states (Hosking et al., 2011, p.21). Providing access to safe, reliable and efficient forms of mobility, including walkable neighbourhoods and access to cycling routes, as well as public transportation, is important to combat so-called "transport poverty" (Lucas et al., 2016). Transport poverty describes the lack of opportunities for transport and mobility. Groups that are more likely to suffer from transport poverty are low-income households and households without cars. Those who are affected by transport poverty lack alternatives to private motorised travel, such as public transport services, or the quality of the provided service is poor. Subsequently, they are at a higher risk to be involved in road traffic casualties and suffer from social consequences

[3] See URLs

(Lucas et al., 2016). Improving the safety of active travellers is likely to benefit more vulnerable groups (Hosking et al., 2011).

Current forms of mobility and the built environment may lead to a higher risk of social isolation and loneliness, due to a high dependency on car travel and "unwalkable" neighbourhoods (Newman & Matan, 2012). Designing neighbourhoods with walkability and cycling in mind is found to foster social interactions and facilitate building social networks in those neighbourhoods (Lund, 2002; Leyden, 2003). This "social capital", which is built up by social interactions and networks, was found to impact health as well, in particular mental health. Issues of unequal distribution of or exposure to air pollution also fall under this category. Sider and colleagues found that social disadvantage was associated positively with a higher exposure to air pollution (Sider et al., 2015). Reducing overall ambient air pollution may help alleviate the issue of unequal exposure.

Assessing such effects of increased active mobility on social factors and social determinants of health is difficult, thus knowledge on this topic is limited. Further research is needed to comprehensively assess the effects active mobility and reduced car travel may have on social factors.

3.1.2 Active mobility and its climate and health co-benefits

Considering the positive effects active mobility can have on climate and health, it is a viable and important strategy to combat both climate change and the "pandemic of physical inactivity" (Kohl et al., 2012). The promotion of active travel helps include physical activity in everyday life in an inclusive, accessible way for the population, while providing environmental benefits, in terms of long-term climate change mitigation effects and short-term effects on air quality and noise. As such, active mobility measures may lead to so-called co-benefits, or ancillary benefits. There is no common or shared definition of the term "co-benefit", even though it is now widely used in both scientific literature and strategic documents. Mayrhofer & Gupta state "the concept of co-benefits is not an economic concept or a prescriptive policy approach but should be understood as an idea, and it carries political weight in its definition, application and use." (Mayrhofer & Gupta, 2015, p.23). The IPCC defines co-benefits as "the positive effects that a policy or measure aimed at one objective might have on other objectives, irrespective of the net effect on overall social welfare" (IPCC, 2014). Giles-Corti and colleagues states that the term is used, "when benefits across multiple policy areas are considered concurrently" (Giles-Corti et al., 2010, p.124).

There is increasing evidence in both academics and politics that fostering active mobility and promoting a mode shift away from individual motorised traffic may lead to significant benefits to both climate and health. Various studies in European cities find a significant reduction in GHG-emissions from urban traffic (by up to 80%) in scenarios adopting policy packages, while reducing air pollution, noise, traffic injuries and fatalities, congestion and increasing physical activity levels (APCC, 2018), subsequently yielding co-benefits for human health. In section 3.2 some studies from the city of Barcelona and from the city of Vienna are described.

The occurring co-benefits of climate change mitigation measures can act as additional incentives for decision makers and stakeholders to adopt such interventions “and detrimental actions can be made less worthwhile” (APCC, 2018, p.42). However, in decision making health co-benefits are often not considered, and "the narrowly defined implementation costs of mitigation measures are the prevailing criteria for decision makers" (Wolkinger et al., 2018, p.2).

3.1.3 Political strategies and measures to foster active mobility

The WHO includes active mobility and its benefits in numerous publications and developed THE PEP (Transport, Health and Environment Pan-European Programme) to facilitate policy evaluation and knowledge exchange (WHO-UNECE, 2009). From 2007 onwards, the WHO has been developing an online tool, HEAT (Health Economic Assessment Tool) in collaboration with experts to estimate the value of a reduced mortality (in monetary terms, creating economic arguments) that results from walking or cycling as a mode choice (see Kahlmeier et al., 2017). HEAT enables policy and decision makers to conduct an economic assessment of the health benefits of walking and cycling without the need of expertise in the field of impact assessment. It can be applied in various situations, for example to access the impacts of new infrastructure developments, or to value the economic benefits from current levels of active mobility. The application is available for free on the web.

The European PASTA Project ("Physical activity through sustainable transport approaches"), carried out between 2013 and 2017, is a project which aims to put emphasis on the link between mobility and health by collecting and generating knowledge about the potential of active mobility and its effects on health. It encompasses seven European case study cities - Antwerp, Barcelona, London, Örebro, Rome, Vienna and Zurich. The project formulated a set of indicators to aid decision makers to understand the framework conditions in a city, and to establish a common and comparable way to measure and evaluate active mobility and active mobility measures. One of the main indicators to assess impacts of measures is the modal split, describing the distribution of all trips in a city for transport modes. Other indicators include funding, levels of physical activity or changes in air quality. PASTA also provides definitions and categories for classification of active mobility measures, which were used in this thesis (see chapter 5). In addition, PASTA identified successful and innovative initiatives to foster active mobility, such as the Cycle Superhighways in Copenhagen, Denmark (PASTA Consortium, 2017). Barriers (such as a lack of funding or a lack of political will in a city) and enabling factors of active mobility within the seven PASTA cities were also derived in co-production with mobility experts, decision makers and stakeholders (Wegener et al., 2016). Findings of the PASTA project also added to an updated version of the HEAT tool, which incorporates additional factors like air pollution levels. Several measures discussed in the PASTA project are incorporated into the catalogue of measures presented in chapter 5.

Active Mobility plays an integral role in Sustainable Urban Mobility Plans (SUMPs). A SUMP is a concept of planning that was adopted by the Action Plan on Urban Mobility, which was published in 2009 by the European Commission. The Action Plan on Urban Mobility proposes a number of measures in the field of urban transport. Alongside urban mobility topics such as freight distribution, intelligent transport systems or road traffic safety, sustainable urban mobility planning plays a key role in the Action Plan. The concept of SUMPs should be applied by local, regional and national authorities to promote a shift towards sustainable transport modes. Cross-sectional cooperation and the inclusion of citizens in decision making are key in the concept. SUMPs should be very adaptable to attain measurable goals and the concept provides a set of guidelines. In 2013, the European Commission published a follow-up report and review of the implementation of the Action Plan, the Urban Mobility Package. Focus lies on communication and sharing experiences, as well as show-casing best practices. The city of Vienna has published its own SUMP, the Urban Development Plan Vienna (STEP 2025, "Stadtentwicklungsplan") and its associated Urban Mobility Plan (MA18, 2015), which will be described later in depth.

Political focus often lies on the potential of e-mobility to combat air pollution and climate change. However, electronic cars still produce air pollution in the form of microplastic PM due

to tire abrasion like conventional cars (Sommer et al., 2018). Electric vehicles may even have higher tire-based emissions than conventional cars, since they exhibit a higher tire usage due to their higher weight and sharper braking (Grütter & Ki-Joon, 2019). Furthermore, e-mobility may lead to an increase in traffic injuries and fatalities due to their lack of sound, although artificial noise may be added to substitute the lack of a combustion engine at lower speeds. Additionally, health benefits from mode shifts to active travel from motorised individual travel (car travel) are much higher than mode shifts to improved vehicles (e.g. e-mobility) due to an increase in physical activity which would otherwise not occur (Woodcock et al., 2009). The APCC states in that regard that "technological transition from fossil fuel vehicles towards electric vehicles alone will not suffice to meet all the different goals as it fails to redress problems such as the risk of accidents, particulate pollution from tire and break wear as well as resuspension, noise, traffic jams and land use for road infrastructure" (APCC, 2018, p.43). The WHO states that "a shift to active transport (walking and cycling) and rapid transit/public transport combined with improved land use can yield much greater immediate health 'co-benefits' than improving fuel and vehicle effectiveness" (Hosking et al., 2011, p.1).
In order to attain a sustainable transportation system in the future, other forms of transportation besides e-mobility need to be considered. Fostering active mobility and decreasing the attractiveness of IMT thus hold great potential as a climate change mitigation measure with short-term, local, and more feasible ancillary benefits for health, producing additional incentives for decision makers and stakeholders to adopt such measures.

3.2 Selected case studies

3.2.1 Case study site Barcelona

Barcelona, despite offering a good public transport system, has a large motor vehicle fleet which leads to a rather large volume of traffic and results in one of the highest emission levels in all of Europe (Mueller et al., 2017). Since the year 2000 several mobility plans have been developed in Barcelona to facilitate active mobility and reduce individual motorised travel (IMT). Mobility plans implemented include a Road Safety Plan in 2000 and the current Mobility Plan (2013-2018). There are various interventions and measures put in place, such as an expansion of public transportation options, implementation of 30 km/hr zones, implementation of resident-only parking policies, improvement and expansion of cycling routes and public bicycle-sharing programs (e.g. *Bicing*, see Rojas-Rueda et al., 2011).
A study by Rojas-Rueda and colleagues addresses possible health impacts, both benefits and risks, resulting from the implementation of a bicycle-sharing program called *Bicing* (Rojas-Rueda et al., 2011). The program was introduced in 2007 and by 2009, around 11% of the population in Barcelona (182,000 residents) had subscribed to *Bicing*. Considering all-cause mortality as an endpoint (primary measure of outcome) in their study, they conduct a Health Impact Assessment (HIA)[4] including physical activity, air pollution and road traffic incidents as determinants of health. They also estimate carbon dioxide emission savings from changes in mobility. Assuming that 90% of new *Bicing* users switched from previous car travel, they assess the additional benefits that arise from an increase in physical activity for their study group, as well as additional risks from an increased exposure to particulate matter ($PM_{2,5}$, particulate matter smaller than 2.5µm in diameter) and road traffic incidents. They do not consider benefits that arise to the general population but focus on the health benefits from increased active mobility of the individuals participating. To estimate the health benefits arising from an

[4] See section 4.4.1

increase in physical activity, they use the approach from the Health Economic Assessment Tool (HEAT) from the World Health Organization (WHO) for cycling. Their results demonstrate that about 12 deaths within the *Bicing* population (182,000 residents, 25,400 regular users) were avoided each year as a result of increased physical activity. The health benefits obtained outweigh the negatives that arise from increased particulate matter inhalation and road traffic incidents. Annual carbon dioxide emissions were cut by more than 9,000 tonnes, which translates to around 0.9% of all motor vehicle emissions in 2009 in Barcelona. The results show evidence of benefits and risks and are comparable to other health impact assessment studies in so far, as they estimate the health gains to be substantially larger than the risks from air pollution and road traffic incidents, which is confirmed by several other studies (Rojas-Rueda et al., 2012; Maier, 2015; Mueller et al., 2015; Tainio et al., 2016; Woodward & Samet, 2016). Since they assume the shift to the *Bicing* program to occur largely from individual motorised travel (90%) rather than from public transport or walking, there may be a potential of overestimating the benefits obtained. Regardless, the results show that the introduction of such a bicycle sharing scheme could lead to substantial benefits for both climate and health due to increasing physical activity of its users and a reduction of carbon dioxide emissions.

Another study by Rojas-Rueda and colleague published in 2012 conducts a HIA for Barcelona for eight different scenarios on a shift from individual motorised travel to cycling and public transportation against a business-as-usual scenario (Rojas-Rueda et al., 2012). The scenarios differ in terms of traffic reductions (20% or 40% reductions), types of trips reduced and mode shifts (share of trips replaced by PT or cycling). Rojas-Rueda and colleagues differentiate between "inside Barcelona" and "outside Barcelona", which encompasses the greater Metropolitan area of Barcelona. They also choose all-cause mortality as health endpoint, as well as changes in life expectancy, and consider health effects from higher physical activity, air pollution exposure (for the individuals participating in active mobility) and road traffic incidents. In contrast to the previous study (Rojas-Rueda et al., 2011), they also include particulate matter ($PM_{2.5}$) exposure to the general population in Barcelona, thus adding potential health benefits to the population due to a reduction in ambient air pollution. They focus on the age cohort of 16-64 years and on those individuals, who shift to public transportation or cycling from car travel. For this incremental physical activity, they follow the approach presented in HEAT (see Kahlmeier et al., 2013, 2017). For air pollution exposure they differentiate between the "travellers" (individuals participating in active mobility) and the general population, using additional inhalation of particulate matter during active mobility trips, and potential impacts of air pollution reductions stemming from traffic reductions respectively. The resulting number of deaths avoided annually range from 26.88 to 76.15 (depending on the scenario) for the population considered (141,690 travellers). In all scenarios there is a net-benefit. Benefits from an increase in physical activity outweigh negative impacts from increased inhalation of $PM_{2.5}$ and increased risk to road traffic incidents. Effects on the general population from a reduction of air pollution on a greater scale are relatively minor in comparison to the effects of physical activity. Rojas-Rueda and colleagues additionally estimate carbon dioxide reductions due to a shift from IMT to other mode of transport in the Barcelona metropolitan area, which amount up to around 203,250 tonnes CO_2-emissions per year (1.25% of CO_2-emissions from the transport sector in the region of Catalonia).

A study from Pérez and colleagues in 2017 estimate health and economic benefits of active mobility policies between 2009 and 2013 in Barcelona, using the HEAT tool from the WHO. Comparing walking and cycling trips in those two years, they estimate that 86 premature deaths were prevented due to an increase in walking and 8.5 due to an increase in cycling (additional 83,493 pedestrian travellers and 19,864 cyclists), annually, and the average annual economic benefit between 2009 and 2013 was estimated to be around 58 million Euros. Additionally, Pérez and colleagues calculated trends in road traffic injuries in terms of annual percentage changes between 2009 and 2013.

Mueller and colleagues estimated changes in burden of disease associated with active mobility, applying the Urban and Transport Planning Health Impact Assessment (UTOPHIA) tool to Barcelona (Mueller et al., 2017). They estimate preventable morbidity, disability-adjusted life years (DALYs)[5] and corresponding economic effects in terms of indirect health care cost savings in the city, assuming a compliance with international exposure recommendations for exposures to physical activity (PA), air pollution (in the form of $PM_{2.5}$), noise, heat and green spaces. Comparing current exposure levels to those recommended, Mueller and colleagues calculate years of life lost (YLLs) and years lived with disability (YLDs) to obtain the summary measure DALYs. Additionally, they estimate health gains in monetary terms and willingness to pay (WTP) to avoid traffic noise impacts (i.e. annoyance and sleep disturbance). They show that Barcelona is currently not complying with any of the exposure recommendations and compliance would lead to a high reduction in burden of disease for all exposures considered, resulting in around 52,000 DALYs avoided annually, which translates to 13% of all DALYs each year. Furthermore, around 20 million Euro in direct health care costs could be saved each year, and WTP to avoid adverse noise effects amounts to over 7 million Euros each year. Mueller and colleagues state that – since they could not include a number of risk factors, such as socio-economic effects and other traffic-related air pollutants – benefits could potentially be higher. They conclude that traffic noise, physical inactivity and air pollution contribute the most to the burden of disease in Barcelona, and "healthy living could best be promoted by reducing Barcelona's burdensome motor traffic volume (i.e. a common source of noise, physical inactivity and air pollution) and promoting walking and cycling for transport in combination with improvements in public transport (i.e. active transport, a common mitigator of noise, physical inactivity and air pollution)". Moreover, they emphasize the need to implement mobility management measures like these jointly. Finally, they stress the importance of green spaces in mitigating noise, greenhouse gas emissions and other air pollutants, and their role in providing spaces for physical activity.

Although the studies mentioned in this section use different approaches, assumptions or scenarios to estimate health benefits and risks resulting from active mobility (measures), they have in common that benefits arising from additional physical activity outweigh the risks from air pollution exposure and road traffic incidents (if covered in the study). In either case, there is a net-benefit obtained, regardless of the approach. While three of the studies summarized used mortality as an endpoint and one study used morbidity (burden of disease), the net-benefit for health remained large. Two studies included benefits in monetary terms, demonstrating that the health benefits obtained may translate into tangible monetary savings. The studies agree that fostering active travel modes such as walking and cycling is an important step in achieving sustainable transport systems and is crucial in increasing public health. Effects on carbon dioxide emissions, if estimated, were ranging up to more than 200,000 tonnes saved per year (Rojas-Rueda et al., 2012).

[5] See section 4.3

3.2.2 Vienna case studies

Wolkinger and colleagues estimate the effects of the implementation of transport actions plans, and reaching their targets in three scenarios for Graz, Linz and Vienna (Wolkinger et al., 2018, see also Haas et al., 2016). They assess benefits for health (in terms of decreases in mortality and changes in disability-adjusted life years due to additional physical activity and reduced ambient air pollution for the general population) and GHG-emission reductions between the hypothetic scenarios and the baseline year (both for the year 2010, assuming the changes in mobility pattern were already present in that year), and additionally employed a (macro-)economic perspective. They link different modelling tools to analyse the three scenarios: (a) “Green Mobility” (GM), where policy targets formulated by transport action plans are almost achieved, (b) “Green Exercise” (GE), in which an additional change in mobility behaviour occurs, and (c) “Zero Emissions” (ZE), which uses the same modal shares as the GE scenario, but replaces the remaining conventional car trips with e-mobility (given that the power production occurs CO_2-neutral). In the GE scenario for the City of Vienna the share of cycling rises to 14%, the share of walking to 25% and the share of public transport to 41%, whereas the share of individual motorised travel decreases from 40% in the baseline to 18%.
Across all cities, the study reveals substantial reductions in energy use and GHG emissions, saving up to 1 million tons CO_{2equ} in the ZE scenario relative to the baseline. Increases in physical activity alone prevent a total of 891 deaths per year. Including reductions in ambient air pollution, decreases in mortality range from 27 to 58 deaths saved per 100,000 inhabitants and year in the GM and GE scenario respectively. Finally, the ZE scenario yields 76 prevented deaths per 100,000 inhabitants and year. In the GM scenario GHG emissions are cut by around 25% (0.3 Mt CO_{2equ}), in the GE scenario they are reduced by around 44% (0.5 Mt CO_{2equ}) compared to the baseline. The GHG emission savings are highest in the ZE scenario (1.2 Mt CO_{2equ}).
Wolkinger and colleagues show that simultaneous to achieving benefits for health and climate, health care costs can be reduced by up to 11 million Euros relative to the baseline per year. The authors further state that “additional costs for implementation and operation of public transport and bike or pedestrian facilities are mostly compensated by saved costs for motorized individual transport” as well. The macro-economic results indicate a strong positive effect on welfare, as well as slightly negative effects on GDP and employment. They conclude that reaching the targets formulated in transport actions plans of Graz, Linz and Vienna yields high benefits for health and climate, as well as economic benefits, which can act as additional incentives for policy makers to adopt said transport action plans.

In his Master’s thesis (carried out within the Social and Human Ecology Master Programme), Maier estimates the cimate and health effects from increased bicycle use in Vienna, according to the goals formulated in the "Stadtentwicklungsplan 2025" ("STEP 2025") regarding the future development of the modal split in the city of Vienna (Maier, 2015). This thesis is oriented on Maier’s Master’s thesis and adopts parts of its methodological approaches (see section 4.3 and 4.4).
Following the approach of Wolkinger et al. (2018), Maier assumes the changes in modal split from “STEP 2025” were already present in 2010 (which acts as the baseline). He estimates changes in burden of disease due to changes in physical activity levels and exposure to air pollution, and road traffic incidents resulting from a shift of car travellers to cyclists. The modal share of cyclists increases from 5% to 12% in the “STEP 2025” scenario. He focuses on the age cohort 20 to 69 years old and the following diseases in relation to physical inactivity: ischemic heart disease, ischemic stroke, colon cancer, breast cancer and diabetes mellitus type II. Also

considered are cardiopulmonary disease and lung cancer with regard to air pollution changes. Changes in the burden of disease are estimated by applying a Comparative Risk Assessment (CRA)[6] and are expressed in DALYs (disability-adjusted life years), i.e. healthy years saved in the “STEP 2025” scenario compared to the baseline. Furthermore, changes in CO_2-emissions stemming from a shift from IMT to cycling (and public transport) are estimated using CO_2-emission factors (related to motor vehicles) and considering vehicle kilometres driven (vkm).

The results show an overall positive effect on health corresponding to a net-reduction of almost 700 DALYs between the “STEP 2025” scenario and the baseline, which translates to a reduction in the overall disease burden of 1.38% (summarising effects of physical activity, air pollution and traffic incidents) in 2010. The single effect from increased active mobility results in about 800 healthy years gained in the “STEP 2025” scenario in comparison to the baseline, which is equivalent to a reduced disease burden of 2.35%. Ischemic heart diseases account for the biggest portion of DALYs saved (-3.24%).

Maier found a minor increase of health impacts of air pollution due to particulate matter inhalation (+0.49%) for the individual traveller cycling. He also observes a higher traffic incident rate (+13.83%), but no overall changes in the amount of fatal traffic incidents. While the rate of traffic incidents increased, the effect on DALYs is minor. However, Maier does not assume a "safety-in-numbers" effect, which could potentially lower the traffic incident risk with an increase in cycling (see Jacobsen, 2015).

Maier concludes that the beneficial effects on health that arise in the “STEP 2025” scenario drastically outweigh the detrimental effects resulting from an increased particulate matter inhalation and road traffic incidents, which is in line with other findings estimating health effects of active travel (see Section 3.1.1, e.g. de Nazelle et al., 2011; Mueller et al., 2015; Tainio et al., 2016).

Maier estimates CO_2-emission reductions in the City of Vienna to range from 35% to 56%, depending on assumptions used for occupancy rate and emission factor. Assuming a higher occupancy rate (more efficient use of IMT) and lower emission factors (technological progress), around 214.000 tonnes (56%) of carbon dioxide are saved in the “STEP 2025” scenario, which translate to around 11% of total road traffic emissions in Vienna (including freight transport).

[6] See section 4.4

4. Material and methods

According to the research questions, the thesis builds on three main steps, each using different methods and data sources.

In a first step, a research of literature is conducted to assess a wide range of measures to foster active mobility. While a common definition for "measures" is lacking, for the sake of this thesis a "measure to foster active mobility" encompasses any political intervention aimed at increasing active travel modes (such as walking and cycling, and to a lesser degree public transportation) and/or decreasing individual motorised travel (i.e. car travel). A catalogue of measures is compiled in chapter 5. Of those measures, four are selected according to defined criteria (see section 4.1).

Second, the selected measures are implemented in the system dynamics model MARS (Metropolitan Activity Relocator Simulator) to create a future mobility scenario for the Viennese population in 2030, i.e. for the Viennese passenger transport system, referred to as “all measures 2030” scenario.

MARS is used to show changes in modal split as well as calculate the climate effects, i.e. changes in CO_2-emissions (as well as NO_x and PM emissions) due to the implementation of the selected measures in the “all measures 2030” scenario against a business-as-usual scenario (“BAU 2030”), which are then compared to the baseline year (2013). In addition, based on modal split data of Vienna in 2013, own calculations of climate effects are carried out by following the approach used by Maier (2015, see section 4.3) to show changes in CO_2-emissions between the baseline year and the “all measures 2030” scenario, which are comparable with the results provided by Maier (2015).

MARS output in the form of changes in modal split also serves as input for step three by providing data on changes in the participation in active mobility of the Viennese population.

Eventually, in the third step, a Comparative Risk Assessment (CRA) is utilized to estimate the health effects of the selected measures, which refer to changes in the burden of disease for five health endpoints, expressed in disability-adjusted life years (DALYs) for the population of interest.

Figure 4 provides an overview over the methodological approaches of the thesis.

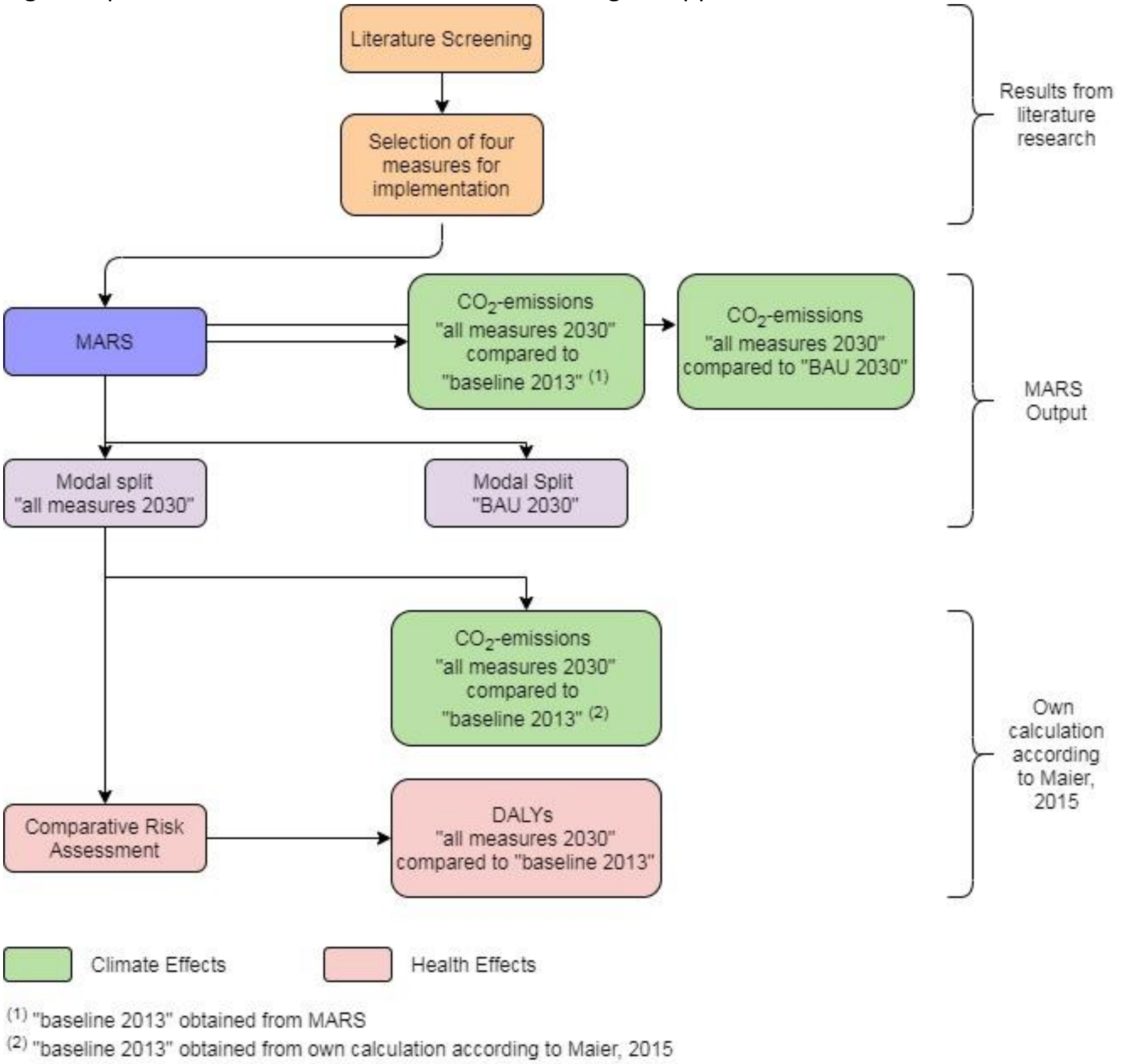

Figure 4. Workflow and methodological approach used in this thesis.

4.1 Screening of literature

A screening of literature on the topic of active mobility interventions and effects on health and climate is conducted to assess a wide range of measures to foster active mobility.

Screened literature includes international and national (Austrian) reports (“grey” literature), such as political strategy plans, publications from the WHO and from the IPCC. Scientific publications are compiled by using keywords in google scholar, such as “active mobility (measures)” and “active transport (measures)”. Additionally, some papers are added from references cited in the reviewed literature (“snowball”-principle).

Emphasis is put on national (Austrian) and regional (Viennese) literature. National literature includes the "National Action Plan Active Mobility" (Nationaler Aktionsplan Bewegung, Angel et al., 2013) from the Austrian Federal Ministry of Sports. Six working groups developed a number of goals and measures to reach said goals following recommendations from the WHO. One section of the National Action Plan focuses on mobility.

The Urban Development Plan Vienna (“Stadtentwicklungsplan 2025”, STEP 2025) and its associated Urban Mobility Plan (MA18, 2015) are published by the City of Vienna and paint a vision of a future Vienna, including targets and measures that will be undertaken by 2025. The Urban Development Plan Vienna itself encompasses seven thematic concepts (the built city, space for urban growth, centres and underused areas, business, science and research, open spaces, diversified mobility and social infrastructure) and one detailed concept on e-mobility. Focus is put on the detailed thematic concept "mobility", the Urban Mobility Plan Vienna. Additional Austrian and Viennese strategic plans include the Masterplan Cycling and the Masterplan Walking.

The selection of measures of interest follows specified selection criteria formulated in advance. The selection criteria include: (a) mentioned in numerous papers, (b) mentioned in papers from the WHO, (c) mentioned in national strategic plans (with a focus on Austria / Vienna), (d) described as promising or similar and (e) with evidences of effectiveness (if possible). Finally (f), the measures need to be implementable into the MARS model.

4.2 MARS – Metropolitan Activity Relocation Simulator

The Metropolitan Activity Relocation Simulator, MARS, is a dynamic, integrated Land Use Transport Interaction (LUTI) model based on causal loop diagrams and stock-flow modelling, which aims to assess impacts on transport mode choice, emissions, urban sprawl, economic development, etc., of selected transport and land use policies. The model was developed by Paul Pfaffenbichler from the University of Natural Resources and Life Sciences, Vienna and colleagues (see Pfaffenbichler, 2003; Pfaffenbichler et al., 2008; Pfaffenbichler et al., 2010).

It consists of two main sub-models, a transport sub-model and a land-use sub-model. The transport sub-model simulates passenger transport and encompasses trip generation, trip distribution and transport mode choice. Examples for transport and land use policies which can be assessed by MARS are new urban infrastructure, such as the construction of subway systems, changes in public transport fares and housing and business development. Considered modes of transport are motorised individual transport (car and motorcycle), public transportation (PT, divided into bus and rail) and non-motorised forms of transportation (walking and cycling). The time horizon can be freely selected but is usually set to 30 to 40 years into the future. The model factors in projections on demographic changes and technological advances among other region-specific assumptions (see below). Changes in the transport model are depicted in quarterly time steps.

The specific policy instruments considered in MARS are pedestrianization, new PT-infrastructure, PT fares, PT frequency, the construction of new roads, road pricing, parking charges, road capacity increase / decrease, fuel taxes and parking supply (Pfaffenbichler, 2003).

Final outputs of the MARS model include the modal split, a key indicator of transport statistics derived from mobility surveys (see EC, 2018[7]), which refers to number of trips and/or person or vehicle kilometres per means of transport in %, trip length and distribution, and emissions generated from transportation (CO_2, but also NO_x and particulate matter, PM).

The model is embedded in the System Dynamics Software Vensim® (www.vensim.com). Since the start of its development the MARS model has been applied in numerous national and international case studies for scenario testing, policy optimization and decision maker training (Pfaffenbichler et al., 2010, see Pfaffenbichler, 2017). MARS has already been calibrated for Vienna within the framework of the doctoral programme URBEM (“Urbanes Energie- und

[7] See URLs

Mobilitätssystem") in 2013. The underlying data and assumptions embedded in the MARS model for Vienna are described in depth in Pfaffenbichler, 2017.

4.2.1 Specific MARS run for passenger transport in Vienna

The MARS model was set to run from 2013 to 2030. The run itself was carried out by Paul Pfaffenbichler, who then provided the model outputs (see fig. 4). The run implemented four final measures to foster active mobility and discourage individual motorized transport to yield the scenario "all measures 2030". The implemented measures (road calming, improvement and expansion of cycling routes, increase of parking fees and limitation of parking spaces) are described in chapter 5.

Furthermore, the MARS model produced a future "business-as-usual" scenario ("BAU 2030"). The BAU-scenario includes policy assumptions and assumptions for modal split development based on observed trends and measures which are already put into place or to be implemented in the near future, such as the subway expansion project U2/U5 by Wiener Linien. It contains assumptions for populations growth in Vienna, fuel prices for petrol and diesel, transport emission factors, development of deployment, the number of jobs, levels of motorisation, and household income (see Pfaffenbichler, 2017).

Model outputs include the modal split (share of mode of transport) for both scenarios, additional pedestrian and cyclist trips per working day in the "all measures 2030" scenario compared to the "BAU 2030" scenario, as well as changes in emissions of CO_2, NO_x and particulate matter (PM) in the passenger transport sector between both future scenarios. MARS estimates for emission savings include the whole passenger transport system of Vienna (including public transportation, which amounts to approximately 4% of emissions of the passenger transport system) and parts of Lower Austria and Burgenland[8].

The modal split of the "all measures 2030" scenario was compared to the year 2013 as a baseline ("baseline 2013", chosen because of good data availability) for a Comparative Risk Assessment (CRA, see below) to estimate changes in burden of disease for five health endpoints (expressed in disability-adjusted life years, DALYs).

4.3 Estimation of CO_2-emission savings

Additionally to the CO_2-emission estimates provided by MARS, a second calculation is performed following the approach used by Maier (2015). Focus of these estimates are car trips (individual motorised travel, IMT) which are substituted by cycling and walking trips in the future scenario ("all measures 2030") compared to the "baseline 2013" in the City of Vienna.

In order to assess emissions associated with IMT, first the number of car trips per day is calculated using the modal split share of IMT, the mean number of trips per person per day and the number of persons in the age cohort selected (20-64 years). In a next step, the distance travelled by IMT per year is calculated by multiplying the number of car trips per day with the mean trip length and the number of days in a year. Taking into account a change in occupancy rate (number of persons in a car per trip), the number of car trips per day and subsequently the distance travelled is reduced by 12% (see Appendix 1). Finally, distance travelled by IMT is multiplied with emission factors taken from the "Handbook emission

[8] Eisenstadt (City), Eisenstadt-Rust-Mattersburg, Neusiedl am See, Neusiedl am See-Seewinkel, Wiener Neustadt (City), Wiener Neustadt (Countryside, North and South), Neunkirchen, Lilienfeld, Sankt Pölten (City), Sankt Pölten (Countryside, East and West), Hollabrunn, Mistelbach, Gänserndrof-Weinviertel, Tulln, Vienna surroundings West, Klosterneuburg, Korneuburg, Vienna surroundings North Gänserndorf, Gänserndorf-Marchfeld, Mödling, Shopping City Süd, Flughafen Wien-Schwechat, Vienna surroundings Southeast, Bruck an der Leitha, Baden.

factors for road transport" (HBEFA, ref cit. Maier, 2015) to assess the total amounts of CO_2-emissions in the "baseline 2013" and the future "all measures 2030" scenario.
Table 1 summarises parameters and data needed for the calculation approach (tab. 1). Assumptions for the mean trip length, occupancy rate and emission factors are adopted from Maier (2015).

Table 1. Parameters and data needed for the calculation of CO_2-emissions.

Parameters and data needed	"baseline 2013"	"all measures 2030"	Sources
Number of car trips / day	1,037,860	588,730	Own calculation
Modal Split share IMT [%]	32% [a]	16% [b]	[a]BMVIT, 2016 [b]MARS model
Trips / day / person	2.9	2.9	BMVIT, 2016
Age cohort 20-64	1,118,384 [a]	1,268,816 [b]	[a]Statistics Austria [b]Own calculation
Mean trip length [km]	5.9	5.9	MA18, 2013
IMT occupancy rate	1.3 [2010] [a]	1.5 [b]	[a]BMVIT, 2016, URBEM, after Wiener Linien [b]MA18, 2013
Emission factor IMT [CO_2 g / vkm]	165.538 [2010]	128.610	Handbook emission factors for road transport (HBEFA), ref cit. Maier, 2015

Analogous to Maier, four variants of substitution in the "all measures 2030" scenario are calculated (Maier, 2015):

- Substitution: Occupancy rate and emission factor correspond to those of the baseline. No technological progress or more efficient use of IMT are assumed. This scenario variant shows the effect of a 1:1 substitution of car trips with active mobility (cycling and walking).
- Substitution and higher occupancy rate: Occupancy rate increases in the "all measures 2030" scenario, emission factor corresponds to baseline.
- Substitution and lower emission factor: Occupancy rate corresponds to baseline, emission factor is assumed to be reduced in the "all measures 2030" scenario.
- Combined effects of higher occupancy rate and lower emission factors: Occupancy rate increases due to a more efficient use of IMT, emission factor decreases due to technological progress.

4.4 Comparative Risk Assessment (CRA)

4.4.1 Measuring the health effects of active mobility

In order to assess the effects of decision making on health, a procedure called Health Impact Assessment (HIA) was established. The WHO defines a HIA as "a means of assessing the health impacts of policies, plans and projects in diverse economic sectors using quantitative, qualitative and participatory techniques" and "a combination of procedures, methods and tools by which a policy, programme or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population" (European Centre for Health Policy, WHO, 1999, p.4). HIAs aim to provide estimates of health impacts, both positive and negative, which arise from interventions to mitigate harmful effects and foster health benefits (Joffe & Mindell, 2002).
Negev et al. (2012) discuss the importance of HIA as a "bridge between environment and health", fields with little interaction but common goals. They state that HIA can facilitate inter- and transdisciplinary and -sectoral processes, as well as the integration of health into policy making. It can promote a broader understanding about the goals and potential synergies among stakeholders in different fields. They further emphasize that the integration of HIA into decision-making processes may lead to institutional and procedural changes. While acknowledging the obstacles HIA and the increased implementation of this approach face, they urge to further develop HIAs to stress the value of inter-sectoral cooperation and to aid "transparent decision making" (Negev et al., 2012).
Within the framework of HIAs, the quantitative method of Comparative Risk Assessment (CRA) is of great importance. The CRA is defined as “the systematic evaluation of the changes in population health which result from modifying the population distribution of exposure to a risk factor or a group of risk factors” (Ezzati et al., 2004, p.31). CRA uses Relative Risks (RRs), the epidemiological method of Potential Impact Fractions (PIFs) and the measure value disability-adjusted life years (DALYs) to express changes in burden of disease. The following section describes the components and formulas used in the CRA.

Relative Risks (RRs)

The Relative Risk (RR) describes the ratio of risk of a health outcome (i.e. disease, injury, death) in an exposed group to the risk in an unexposed group. A RR of 1 means that the risk of the outcome is the same for exposed and non-exposed persons, a RR of below 1 means that the risk of the outcome is reduced by the exposure, whereas a RR of above 1 means that the risk of the outcome is increased by the exposure (Kreienbrock et al., 2012).
Exposure changes for active mobility are based on the categories “sufficiently active” and “insufficiently active”, as specified in the “Global recommendations on physical activity for health” by the WHO (WHO, 2010). Persons falling under the category of “sufficiently active” partake in more than 150 minutes of “moderate intensity physical activity” per week.
Literature provides robust evidence for changes in relative risks (RRs) attributable to physical activity for the five endpoints ischemic heart disease, ischemic stroke, breast cancer, colon cancer and diabetes mellitus type II. RRs are derived from Bull et al. (2014, see table 2) and are based on dose-response functions (DRFs) for these endpoints in terms of morbidity.

Table 2. Relative Risks (RRs) attributable to physical activity for five health endpoints (Bull et al., 2014).

Health endpoint (disease)	Exposure	RR
Ischemic heart disease	Insufficiently active vs. sufficiently active	1.44
Ischemic stroke		1.10
Breast cancer		1.13
Colon cancer		1.18
Diabetes mellitus type II		1.24

As an example – the risk of ischemic heart disease is 1.44 times higher for people who fall under the category of "insufficiently active" than for people who are "sufficiently active". Accordingly, the risk of ischemic stroke is 1.10 times higher for people who fall under the category of "insufficiently active" than for people who are "sufficiently active".

Potential Impact Fraction (PIF)

The Potential Impact Fraction (PIF) represents the proportion of disease cases (or deaths) in a population that would be avoided when risk exposure changes, i.e. increased active mobility in the "all measures 2030" scenario against the baseline situation ("baseline 2013") (see Barendregt et al., 2010; see Maier, 2015). The disease burden attributable to active mobility related risk factors for the selected endpoints are estimated by calculating the PIF. Therefore, information is needed on the distribution of the selected risk factors in percent in the population of interest (in this case, physical inactivity, expressed as the share of "insufficiently active" citizens in Vienna in the age cohort) and how those risk factors change through an intervention (in this case the four selected measures to foster AM and decrease the attractiveness of IMT). Additionally, Relative Risks (RRs) for the selected exposure and health endpoints are necessary (see above). The PIF is calculated after this formula:

$$PIF = \frac{(P - P^{*}) \times (RR - 1)}{P \times (RR - 1) + 1}$$

P is the number of persons who are "insufficiently active" in % in the population of interest before the intervention (in the "baseline 2013" scenario), P^* is the number of persons who are "insufficiently active" in % in the population of interest after the intervention (in the "all measures 2030" scenario). RR corresponds to the Relative Risks of the selected diseases (see above).

Disability-adjusted life years (DALYs)

The measured value of disability-adjusted life years (DALYs) summarises time lost due to premature death (years of life lost, YLL) and the time lived "in states of less than optimal health" (years of life lived with disability, YLD) (WHO, 2013). It is used to quantify burden of disease, combining morbidity and mortality, and was developed within the framework of the Global Burden of Disease Project (see Murray, Lopez & WHO, 1996).

Years of life lost (YLL) are estimated in relation to a standardised age specific life expectancy.

In this thesis the DALYs are used to express the effects of an increase in physical activity on the health endpoints ischemic heart disease, ischemic stroke, breast cancer, colon cancer and diabetes mellitus type II. Thus, the reduced YLD or (in other words) the healthy years gained due to decreased morbidity are considered.

4.4.3 Calculation details

The following chapter describes the approach used in this thesis in depth.

Comparative Risk Assessment (CRA) is used to estimate the health effects in the population of Vienna associated with changes in physical activity, stemming from the implemented measures described in chapter 5 in the “all measures 2030” scenario against the baseline (“baseline 2013”).

The calculation approach is similar to the method used by Maier for the Vienna case study (Maier, 2015). In this thesis, the selected endpoints are diseases associated with physical inactivity. Effects of increases in cycling and walking are expressed in disability-adjusted life years (DALYs) due to reduced morbidity, as in reduced DALYs or healthy life years gained, in the year 2030 (“all measures 2030”) compared to a baseline. The year 2013 is chosen as the baseline (“baseline 2013”) because of its data availability. Most of the data on the baseline is obtained from the “Mobilitätserhebung 2013/14” (BMVIT, 2016)[9].

Selected diseases (i.e. endpoints) associated with physical inactivity are ischemic heart disease, ischemic stroke, breast cancer, colon cancer and diabetes mellitus type II. The age cohort 20-64 years is selected as the part of the population most affected by the measures introduced, since recommendations for PA levels applied address this age cohort (WHO, 2010), and the HEAT tool for cycling focuses on this age cohort (Kahlmeier et al., 2013; Kahlmeier et al., 2017). Maier uses a similar range (20-69 years, Maier, 2015) and there is good data availability for this age cohort. In order to allow for consistency and comparability, the selected age cohort is applied to estimates for people participating in walking as well.

In order to allow comparison between the baseline (2013) and the future scenario, the modal splits (share of travellers using particular modes of transport) first need to be translated into additional cycling and pedestrian trips per working day (see Appendix 2). Subsequently additional cyclists and pedestrians per working day are compared to the baseline (see Appendix 3).

Because of data availability and the output generated by the MARS model, only working days are considered. It is assumed that the share of people participating in cycling in the selected age cohort is slightly higher than in the general population (see Maier, 2015 and Appendix 5). Using mean distance, mean speeds and mean number of trips (obtained from the “Österreich unterwegs 2013/14” Mobilitätserhebung, BMVIT, 2016) the number of minutes spent doing “moderate intensity physical activity” is estimated. Both walking and cycling are hereby considered “moderate intensity”. Since cycling can also be considered as “vigorous intensity physical activity” this may lead to an underestimation. However, cycling speeds differ greatly (amplified by e-bikes), so cycling is classified as “moderate intensity physical activity” in order to avoid overestimation.

Additional persons participating in cycling (see Appendix 3) (for around 210 minutes per week) and walking (for around 260 minutes per week) exceed the recommended threshold of 150 minutes per week of “moderate intensity physical activity” (own estimation, see Appendix 4) and are therefore sufficiently active after the introduction of measures in the “all measures

[9] “Bundesministerium für Verkehr, Innovation und Technologie“, now „Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie“

2030” scenario; assuming that those persons were insufficiently active in 2013 (i.e. participating in car travel in the baseline). The number and the share of people in the Viennese population who were insufficiently active at the baseline (“baseline 2013”) and are sufficiently active in the future scenario (“all measures 2030”) are estimated by adding the number of additional cyclists and pedestrians to the share of inherently “sufficiently active” persons. It is assumed that in addition to the incremental physical activity undertaken by cyclists and pedestrians, the same share of the population (38%, same as the “baseline 2013”) is inherently classified as “sufficiently active” in the “all measures 2030” scenario (see Appendix 7 and 8).
Population growth is considered in the calculation as provided by MARS. In order to show its contribution to the health impacts, the results are compared with an estimate omitting population growth. For this purpose, the additional cyclists and pedestrians are added to the number of “sufficiently active” persons in the baseline (“baseline 2013”) only, rather than the year 2030.
In a next step, the Potential Impact Fraction (PIF) for each selected disease is calculated, using Relative Risks (RRs) of those diseases associated to changes of exposure to physical inactivity (PI) (Bull et al., 2014). The PIF is calculated after the formula shown above (page 44).

The burden of disease in Austria in the year 2013 (“baseline 2013”), expressed in DALYs for the selected diseases, is translated into DALYs of the population of Vienna (see Appendix 9). In the data obtained from the Institute for Health Metrics and Evaluation colon and rectum cancers are summarised, however, changes in PA affect colon cancer only. Therefore, using data from Statistics Austria, the distribution of those cancers is estimated and applied to obtain DALYs associated with colon cancer (see Appendix 10). Likewise, diabetes mellitus consists of type I and type II, and changes in PA affect type II only. It is assumed that 90% of DALYs associated with diabetes mellitus stem from type II (Elisabethinen Linz, 2013; ref. cit. Maier, 2015).
Finally, health effects in terms of reduction in burden of disease (i.e. healthy life years gained) expressed in DALYs between the “all measures 2030” scenario and the “baseline 2013” year is calculated, using the following formula:

DALYs “all measures 2030” = DALYs “baseline 2013” x (1 – PIF)

All data sources and references used for the calculations of the burden of disease approach are compiled in table 3.

Table 3. Summary of data, assumptions and sources applied in the calculation of the burden of disease approach.

Data	Value	Notes	Source(s)
Modal Split "baseline 2013" Vienna	See results	Only working days considered	BMVIT, 2016
Modal Split "all measures 2030" Vienna	See results	Only working days considered	MARS output
Modal Split age cohort 20-64	6%	Share of age cohort 20-64 years of cyclists in Vienna, lack of new	Maier, 2015

years for cyclists, "baseline 2013"		available data, data from 2010, rounded (from 6,2%)	
Mean number of trips per person per day	2.9	For all modes of transport; for all people, both active and inactive; at any given working day	BMVIT, 2016
Residents in Vienna "baseline 2013"	1,741,246		Statistics Austria (STATcube, http://www.wien.gv.at/statistik/bevoelkerung)
Residents in Vienna "all measures 2030"	2,053,000		MARS output
Age cohort 20-64 "baseline 2013"	1,118,384		Statistics Austria (STATcube)
Age cohort 20-64 "all measures 2030"	1,268,816	For calculation method, see Appendix 6	Own calculation
Share of "sufficiently active" citizens in Vienna	38%	See Maier, 2015	Putz, 2009; Elmadfa et al., 2012
Number of "sufficiently active" citizens in age cohort for "baseline 2013"	424,986	For calculation method, see Appendix 7	Own calculation
Number of "sufficiently active" citizens in age cohort for "all measures 2030"		For calculation method, see Appendix 7	Own calculation
Mean distances per pedestrian trip per day in Vienna	1.2 km	Only working days	BMVIT, 2016
Mean distances per cycling trip per day in Vienna	3.4 km	Only working days	BMVIT, 2016

Mean walking speed	4 km/hr	Sources range from 3 km/hr to 6 km/hr	e.g. Woodcock et al., 2009; 2013; Rabl & Nazelle, 2011; HEAT tool
Mean cycling speed	14 km/hr	See Maier, 2015	Pfaffenbichler, 2011
Relative Risks for selected diseases associated with exposure (PA)	See Tab. 1	See Maier, 2015	Bull et al., 2014
Burden of disease in Austria at baseline ("baseline 2013")	See App. 9	Measure: DALYs (disability-adjusted life years) and deaths (mortality), all-cause and specific diseases.	Institute for Health Metrics and Evaluation (http://www.healthdata.org/gbd/data)

4.4 Limitations of this thesis

This chapter addresses the limitations of the applied methods and explains the assumptions made.

MARS model (assumptions) and climate effects (quantifying CO_2-emissions)

The Metropolitan Activity Relocation Simulator (MARS) operates with a number of underlying assumptions, which could not be explored in any detail in this thesis. Furthermore, only working days are considered within the MARS model. The selection of measures for implementation was restricted by the fact that only certain interventions are implementable into the model.

Importantly, the model was not developed to be applied to the estimation of health effects in a population. It was necessary to use the modal split rather than other highly differentiated and detailed outputs provided by MARS. Translation of the modal split into the time spent participating in “moderate intensity physical activity” required additional assumptions.

Furthermore, MARS compares the hypothetic scenario (“all measures 2030”) with another “business-as-usual” future scenario (“BAU 2030”). Comparison between two future scenarios is difficult and requires numerous assumptions, in particular for the estimation of health effects in the subsequent Comparative Risk Assessment (CRA), since it is challenging to project the current state of health in a population into the future.

Since MARS considers a bigger study area (see footnote 8) than the estimation method conducted after Maier (2015) the relative carbon dioxide emission savings differ vastly. Both the estimates from MARS and the calculation method after Maier are dependent on applied CO_2-emission factors and assumptions on occupancy rates. Harmonizing the scenario assumptions would have been possible but was out of the scope of this thesis. A comparison between results and with other empirical studies is only possible to a limited extent due to varying system boundaries, calculation methods, data sources and assumptions, particularly regarding future developments.

Mobility patterns

There is a basic lack of understanding individual mobility patterns and how they are influenced by interventions from decision makers (see de Nazelle et al., 2011), e.g. insufficient knowledge about who participates in active mobility and how often. It is often unclear if a rising number in participants stems from additional persons participating, or from existing participants undertaking additional trips (de Nazelle et al., 2011). In this thesis the former was assumed, since there is no data or knowledge about this situation available. Also, leisure time physical activity is not included in the estimates. However, no substitution of other forms of physical activity, including leisure time PA, by active travel is found (Woodcock et al., 2009), suggesting that people are becoming more active overall.

Health effects

In this thesis, the health effects of road traffic incidents are omitted. There is limited knowledge about the relationship between increased active mobility and road traffic accidents. Some authors estimate that with an increase in cyclists and pedestrians, the number of road traffic incidents increases, while other employ the "safety-in-numbers" effect (Elvik, 2009; Jacobsen, 2003), as well as reductions in traffic volumes, as described in section 3.1.1. Despite evidence of the occurrence of such a "safety-in-numbers" effect, the magnitude of its impact is difficult to estimate, and it is generally debated on how to include in a CRA. Overall, the effect of traffic incidents is found to be rather small in comparison to the effects of physical activity.

Health impacts of air pollution are omitted as well because it is out of the scope of this thesis. Air pollution affects the individual traveller participating in active mobility negatively and may affect the population on a greater scale positively due to a reduction in ambient emissions. Not only is the effect of air pollution on the individuals participating in walking and cycling found to be rather small in relation to the benefits obtained from an increase in physical activity, there may be some kind of leverage effect due to the reductions in ambient air pollution.

Additionally, several other determinants of health are not included because of a lack of available data, namely noise, stress or social factors. Several authors remark that with the inclusion of those determinants the health effects obtained from active travel could be even greater than estimated (Rojas-Rueda et al., 2011; Holm, Glümer & Diderichsen, 2012; Wolkinger et al., 2018).

Because of methodological issues and for simplicity reasons, mortality was not included as an endpoint.

Comparative Risk Assessment (CRA)

It has been necessary to translate the modal split derived from the MARS model into time spent participating in “moderate intensity physical activity” to conduct the Comparative Risk Assessment (CRA). During this translation of the output several assumptions are applied. To carry out the CRA itself a number of assumptions are necessary as well. The assumptions incorporated are taken from existing pieces of literature where it is possible.

In general, the outcomes of any CRA depend on the shape of the dose-response function (DRFs) or exposure-response function (ERFs) used. While curvi-linear DRFs are potentially biologically more-plausible (exhibiting greater benefits for people who were inactive at baseline and became moderately active, as well as lesser benefits for already active people, see Woodcock et al., 2011), linear DRFs are more robust, assuming equal health benefits for

people who are active and non-active at baseline, thus not requiring any knowledge about physical activity levels at baseline (Mueller et al., 2015).
Keeping those limitations in mind, the estimates provided by this thesis should be perceived as indicating the magnitudes of effects rather than providing robust absolute numbers.

5. Results from literature screening – Measures to foster active mobility

Policy measures to foster active mobility (AM) can encompass various sectors, political domains, actors and stakeholders. They range from mass media interventions to change the perception of active mobility, changes in the built environment such as creating separated bike lanes to fees for using specific streets or areas of a city. The PASTA-project (Physical Activity Through Sustainable Transport Approaches, BOKU, 2013-2017) provides a basic definition:

> "PASTA defines an active mobility measure as: An action which is undertaken in order to increase the level of active mobility (in a specified population), i.e. walking, cycling, and the use of public transport, in a city." (Wegener et al., 2016)

Furthermore, the authors subdivide measures into four different domains:

- “Strategic policy, comprising strategies, masterplans and programmes as key instruments for setting the urban agenda of a city’s development.
- Social environment, comprising measures aimed to change behaviour, encourage a shift in mobility culture and raise awareness for benefits of active mobility.
- Physical environment and infrastructure. This category includes all kinds of built infrastructures for walking, cycling and parking.
- Regulation and legislation. [This includes the introduction of fees and taxes, as well as vehicle bans].”

Batty et al. (2015) subdivide measures to foster active mobility along different categories, namely "push" and "pull". "Pull" measures in the context of active travel are defined as measures aimed at increasing the attractiveness of active mobility (walking, cycling, and public transportation) to "pull" people towards the usage of active mobility. "Push" measures are defined as measures aimed at decreasing the attractiveness of private motorised travel (car travel) through creating “conditions that make car usage either unattractive, difficult or impossible to undertake, thus forcing citizens to change their travel behaviours" (Batty et al., 2015, p.114). Push and pull measures are often implemented in tandem, as it is important to provide a reasonable alternative for private motorised travel, while simultaneously making private motorised travel unattractive.

5.1 Overview of important active mobility measures

This section aims to give an overview of the variety and importance of measure which were screened.

There is little evidence of the effectiveness of active mobility interventions. Several reviews (Möser & Bamberg, 2008; Scheepers et al., 2014) attest little evidence of effectiveness as well as inadequate or poor study designs in numerous studies covering active mobility measures. Scheepers and colleagues criticise the lack of information about statistical significance of modal shifts in various studies (Scheepers et al., 2014). Quantification of effectiveness of measures is difficult and the highly variable study designs and approaches used make comparison between studies difficult. Since measures are often implemented within bundles, separating the effects of single measures is difficult as well. Mass media interventions are an example of measures almost exclusively recommended to be implemented in a bundle with other interventions. Scheepers and colleague state that “[…] since evidence concerning the effectiveness of stand-alone mass media campaigns in increasing physical activity is modest and inconsistent overall […], it can be questioned if this positive effect on mode shift would

also have been found in the event only a mass media campaign was used" (Scheepers et al., 2014, p.278). Additionally, quantification of changes in mobility behaviour is challenging. Further research and better study design as well as before-after studies assessing the contextual situation are needed to assess the effectiveness of active mobility measures.
Table 4 provides a list of measures of interest from an in-depth literature research, including measures whose effects are not or hardly quantifiable and not implementable into the MARS model. Since they are deemed as highly important in different scientific papers and/or strategy plans, it is warranted to include them in this thesis. The measures are subdivided along the four domains (strategic policy, social environment, physical environment and infrastructure, and regulation and legislation), plus "enabling factors" provided by the PASTA-project (see above).

Table 4. Measures to foster active mobility from literature screening

Name of measure	Description	PASTA-domain	Notable source(s)
Intersectoral strategic planning	Planning across sectors, ministries and stakeholders to enable the implementation of subsequent measures	Enabling factor (*)	Heath et al., 2012; PASTA; WHO, 2018
Health-In-All-Policies (HIAP)	Emphasis on health aspect of active travel in communication, politics and decision making	Enabling factor (*), strategic policy	Horvath et al., 2013; PASTA
Local, regional, national mobility plans	Development of local, regional and/or national strategic mobility plans and action plans to raise awareness and promote behavioural changes as well as enable subsequent measures to foster active travel	Strategic policy	Heath et al., 2012; Urban Mobility Plan Vienna; PASTA; WHO, 2017
Availability and distribution of information on active travel and its benefits	Availability and distribution of information regarding the health benefits of active travel to raise awareness ("health literacy"); also, information that is accessible for decision makers and stakeholders to make informed decisions	Social environment	Urban Mobility Plan Vienna; PASTA; WHO, 2019
Availability and distribution of information on travel planning	Availability and distribution of sufficient travel information, e.g. via the app 'Wien Mobil' in Vienna	Social environment	Urban Mobility Plan Vienna; Batty et al., 2015
Mass media and social media campaigns	Campaigns aimed at distributing information and increasing the reputation of public transportation	Social environment	Batty et al., 2015; Heath et al., 2012;

	and active travel to establish them as a viable alternative transport option, regardless of socio-economic factors		Scheepers et al., 2014; WHO 2019
Inclusive PT	Public transportation is inclusive, barrier-free and accessible for everyone, e.g. construction of elevators	Social environment, physical environment and infrastructure	Urban Mobility Plan Vienna; PASTA; WHO, 2019
Addition of PT lines and networks	Additional public transport infrastructure, lines and networks, such as metro extension projects or new bus lines	Physical environment and infrastructure	Urban Mobility Plan Vienna
Increase of PT frequency	Increasing the frequency of public transport modes to decrease waiting times and increase capacity	Physical environment and infrastructure	Urban Mobility Plan Vienna
Smart coordination of PT	Decreasing waiting times during line and mode transfer via smart technology	Physical environment and infrastructure	Urban Mobility Plan Vienna
Reduction of PT fares	Reduction of public transport fares, annual tickets, etc.	Regulation and legislation	Batty et al., 2015
Walkable streets	Streets are designed for walkability through greening, advertisement aimed at and placed for pedestrians (rather than cars), connectiveness, safety improvements, inclusiveness for people with restricted mobility	Physical environment and infrastructure	Heath et al., 2012; Urban Mobility Plan Vienna; Masterplan Walking; National Action Plan Active Mobility; WHO, 2011; WHO, 2017
Strategy of "short distances" and "compact cities"	Higher density and less urban sprawl allow for shorter distances between residential, commercial and leisure areas	Physical environment and infrastructure	de Nazelle et al., 2011; National Action Plan Active Mobility; Masterplan Walking; PASTA; WHO, 2011; WHO, 2017

Increase of connectivity among different modes of transport	Increasing the connectivity among different modes of transportation allows for easier and faster mobility	Physical environment and infrastructure	Batty et al., 2015; Urban Mobility Plan Vienna; PASTA; WHO, 2017;
Bike sharing station availability, expansion of cycling hire facilities	Increasing the availability of bike sharing stations, as well as cycling hire facilities, i.e. "City-Bike" in Vienna	Physical environment and infrastructure	Urban Mobility Plan Vienna; Masterplan Cycling; PASTA
Expansion of Bike & Ride facilities	Expansion of Bike & Ride stations for linking cycling with public transportation	Physical environment and infrastructure	Urban Mobility Plan Vienna; Masterplan Cycling
Easier transportation of bicycles in PT	Allowing and increasing attractiveness and convenience of transportation of bicycles in public transportation, highly relevant for leisure travel and cycling tourism	Physical environment and infrastructure, regulation and legislation	Urban Mobility Plan Vienna; Masterplan Cycling
Car sharing station availability	Increasing the availability of car sharing stations, as well as car sharing services (e.g. "Car-2-Go") to discourage car ownership	Physical environment and infrastructure	Urban Mobility Plan Vienna
Expansion of Park & Ride facilities	Expansion of Park & Ride stations for linking car travel with public transportation, in particular in suburban areas or at the city border	Physical environment and infrastructure	Batty et al., 2015; Urban Mobility Plan Vienna
Financial and fiscal cycling incentives	Cycling is rewarded by financial and fiscal incentives, e.g. by the workplace	Regulation and legislation	Urban Mobility Plan Vienna; Masterplan Cycling; PASTA
Vehicle registration fees	Taxes and fees on purchase of new vehicles or purchase of a certain type of vehicle (e.g. diesel and petrol cars)	Regulation and legislation	Hosking et al., 2011
Car or road taxes	Taxation of ownership of cars or the usage of specific roads, e.g. "City-Maut"	Regulation and legislation	Batty et al., 2015
Fuel taxes	Taxation of diesel and petrol. Note: future scenarios predict an	Regulation and legislation	Smith et al., 2014

	increase in e-mobility, the effect of fuel taxes may be negligible		
Ban of vehicles in certain districts / only resident cars in certain districts	Banning vehicles from non-residents and non-suppliers from entering certain districts	Regulation and legislation	Nieuwenhuijsen & Khreis, 2016; WHO, 2017

(*) not a PASTA-domain

Intersectoral strategic planning is mentioned numerous times, not as a measure or intervention per se, but as an enabling factor or even basic condition for the success of subsequent measures to foster active mobility (Wegener et al., 2016; Heath et al., 2012). As Bull & Bauman state: "No single government ministry owns the problem [of physical inactivity] and controls the solution - integrated action and partnerships are required beyond the health sector" (Bull & Bauman, 2011, p.20). While awareness about the link between health and mobility is rising, "this coherence is rarely explicitly considered in transport strategies and SUMPs [Sustainable Urban Mobility Plans]. Practitioners in both public health and transport planning departments search for ways to raise AM [active mobility]; however, they usually do not collaborate and thus they do not benefit from possible synergies of integrated approach" (Wegener et al., 2017, p.22). The Health-In-All-Policies (HIAP, Horvath et al., 2013) approach is mentioned as an enabling factor as well. It aims to include health aspects and implications in decision making, regardless of the type of policy or ministry, to foster health and quality of life, as well as health equity of a population, and avoid harmful health impacts. The HIAP-approach acknowledges that determinants of health are not restricted to the traditional health system but are influenced by a number of decisions in policy making of stakeholders and ministries outside the health system (Horvath et al., 2013). Adopting the Health-In-All-Policies approach may allow stakeholders to identify co-benefits of their decisions (Kohl et al., 2012). Accepting the need for a HIAP-approach is required in order to allow the usage of instruments such as the Health Impact Assessment (HIA, see chapter 4) to properly select interventions to foster active mobility. Addressing and acknowledging the importance of those "enabling factors" is quintessential in tackling mobility issues to allow subsequent interventions to succeed.

The adoption of local, regional and national action and mobility plans is understood as one of the first steps to combat physical inactivity and carry out additional interventions. Action plans are tightly linked with intersectoral strategic planning. However, research suggests that there is significant global variation as well as a lack of operationability of those action plans (Kohl et al., 2012). Further, Kohl and colleagues state that "plans are not implementation, implementation is not strategy, and strategies are not evidence for population change" (Kohl et al., 2012, p.296). Regardless, adopting an action plan for active mobility is highly important to guide subsequent measures to foster active mobility and encourage intersectoral collaboration.

The notion of "walkable cities" is gaining more and more traction in policy making as a viable and attractive way to foster walking. The WHO states that "governments across the WHO European Region have recognized the need to prioritize physical activity in the city context. [...] The built environment has consistently been shown to affect the level of physical activity among the population; thus, there is much scope to use the setting of the city to increase

opportunities for physical activity" (WHO, 2017, p.9). "Walkable cities" put great emphasis on creating pedestrian friendly environments which are safe, attractive and a viable alternative to private motorised travel. Walkable streets are mentioned in numerous papers and mobility plans, including the Urban Mobility Plan Vienna. The WHO states that it is of great importance to transform pedestrian walkways to make them interesting, for example through green spaces or advertisement aimed at pedestrians rather than cars (WHO, 2017). Furthermore, walkable streets need to be connected and accessible, even for people with reduced mobility. In conjunction with walkable streets, the idea of "walkable cities" also encompasses short distances, employing the notion of "compact cities" or "compactness" (de Nazelle et al., 2011; Hosking et al., 2011; Newman and Matan, 2012; WHO, 2017). In order to allow citizens to walk most, if not all of their daily errands and trips, the distances between residential, commercial and leisure areas need to be shorter. Consequently, reducing urban sprawl and increasing density support keeping distances short (Newman & Matan, 2012).
Evidence suggests that built environment is an important prerequisite of active transportation (Younger et al., 2008; Frank & Kavage, 2009; Panter et al., 2016). Infrastructure investments have proven to be effective instruments in changing behaviour (Rissel, 2009; Panter et al., 2016). Moreover, they have been found to have a significant effect on those who were the least active, suggesting that changes in the built environment have "the potential to shift the population distribution of activity, rather than merely enabling those who are already active to do a little more" (Panter et al., 2016). In order to facilitate active travel, careful planning and investments in infrastructure are needed to create neighbourhoods that are safe and attractive for walking and cycling, as well as allow access to public transportation.

In order to reach a broad population and achieve a long-lasting mode shift, a shift in the perception of active travel and public transportation may be needed, as car travel and specifically car ownership is still seen as a symbol of status. Gatersleben & Appleton (2007) argue, that such cultural shift may occur once a "critical mass" of cyclists and pedestrians is reached, which signals others that active travel is safe, reliable and enjoyable (Gatersleben & Appleton, 2007).
In this context, mass media and social media campaigns, as well as the distribution of information about active travel and its benefits are of great importance. Raising awareness as well as reinforcing behaviour changes are necessary to achieve long-lasting mode shifts towards active travel.
In general, interventions or measures to foster active mobility should not be implemented by themselves, but in a bundle or package to facilitate success (WHO, 2011; de Nazelle et al., 2011; Mueller et al., 2018). De Nazelle et al. state that "bundles of strategies are often implemented together [...], making it difficult to isolate specific elements that may change travel behaviours but also suggesting that multi-pronged strategies are most effective at creating change" (de Nazelle et al., 2011, p.769). Specifically mass media or information distribution campaigns are mentioned as measures that accompany and support other intervention tools (Kahn et al., 2002; Scheepers et al., 2014). Scheepers and colleagues found that all the mass media campaigns assessed in their systematic review were implemented in combination with other measures (Scheepers et al., 2014). In line with this, Batty et al. argue, that "Push" and "Pull" measures need to be implemented in tandem to create long-lasting changes in mobility patterns (Batty et al., 2015, see above).
Measure implementation and success are often hampered by societal, cultural and political obstacles. Particularly “Push” measures, which aim to reduce or prevent car travel, are met with various challenges. Political commitment to those measures is necessary to facilitate

success, but political will is often lacking, since “politicians have to take into account societal opinions/requirements (where the motoring sector is highly vocal)” (Batty et al., 2015). The high political turnover and “resistance by the vested interests of powerful societal actors” (Batty et al., 2015, p.18) are obstructive factors, making political commitment challenging.
It is important to note, that public transportation and walking/cycling are competitive transport modes, rather than complementary. A shift from public transport to cycling is found to be easier for citizens than a shift from private motorised travel to cycling (Batty et al., 2015). Therefore, measures to foster public transportation may reduce "slow modes" such as walking and cycling, and vice versa. An appropriate package or bundle of strategies is necessary to avoid a stagnation of private motorised travel and facilitate a shift from car usage to other modes of transport.

5.2 Selected measures to foster active mobility

Table 5 provides an overview over the final four measures which were selected to be implemented into the MARS model (Metropolitan Activity Relocation Simulator, see section 4.2). The measures are considered as highly important by a number of sources (see tab. 5) and are comparatively easily implementable into the MARS model. They are subdivided into "pull" and "push" measures (after Batty et al., 2015, see above) and into the aforementioned PASTA-domains for further specification. Each of the selected measures to foster active mobility is then described in greater detail.

Table 5. Selected measures to foster active mobility, to be implemented into the MARS model

Name of measures	Description	Pull / Push measure	PASTA-domain	Notable source(s)
Road calming	Interventions for road calming, e.g. expansion of 30 km/hr zones in residential areas, physical separation from the road	Pull and push	Regulation and legislation, physical environment and infrastructure	Batty et al., 2015; Urban Mobility Plan Vienna; Masterplan Walking; Masterplan Cycling; PASTA; THE PEP
Improvement and expansion of cycling routes	Improvements of safety, expansion of cycling routes, e.g. construction of designated cycling paths, construction of long-distance cycling routes	Pull	Physical environment and infrastructure	Fraser & Lock, 2010; Pucher & Buehler, 2008; Urban Mobility Plan Vienna; National Action Plan Active Mobility; Masterplan Cycling; PASTA

Increase of parking fees	e.g. increasing fares for short- and long-term parking, increasing the cost of the "Parkpickerl" in Vienna	Push	Regulation and legislation	Batty et al., 2015; WHO, 2017; THE PEP
Limitation of parking spaces	Limitation of parking spaces, replacing car parking spaces with bicycle parking spaces or green space	Push	Regulation and legislation, physical environment and infrastructure	Batty et al., 2015; Urban Mobility Plan Vienna; PASTA; WHO, 2017

Road calming measures

Road calming measures, such as a reduction of the driving speed or changes in the built environment can be seen as both “push” and “pull” measures - pushing people away from private motorised travel and pulling people towards walking or cycling on calmed roads. They are of great importance in enhancing pedestrian and cyclist safety and in the individual perception of safety (de Nazelle et al., 2011). Traffic calming is found to be able to reduce traffic injuries by 15% to 25% (Elvik, 2001).

In Vienna road calming through 30 km/hr zones has been implemented since the 1980s. Other road calming measures introduced include one-way streets and transformation of streets into residential streets ("Wohnstraßen"), where cars are only allowed to pass through in walking speed. Several structural changes, such as "bumps", elevated sections on the roads forcing cars to slow down, and physical enlargements of sidewalks at crossroads ("Gehsteigvorziehung") were also introduced. Further interventions to calm roads in Vienna are mentioned in the Urban Mobility Plan from the STEP 2025 (MA18, 2015), as well as in the Masterplan Walking and Masterplan Cycling, to increase the attractiveness of active travel modes and increase the safety for its participants.

Road calming measures are implemented in the MARS model through a 20% reduction of road capacity in all areas of Vienna, leading to reduced driving speeds.

Improvement and expansion of cycling routes

Safe, convenient and interconnected cycling routes are necessary to facilitate a shift towards cycling as the main mean of transport. Already existing cycling routes need to be improved regarding safety and accessibility, for example via improved street lighting or physical and structural separation from the road which is used by cars. Safety issues are one of the biggest concerns for cyclists - only 23% of participants in the PASTA Project considered cycling to be safe "with regards to the risk of traffic crashes" (Raser et al., 2017; Götschi et al., 2017). In order to establish cycling as a viable alternative to motorised individual transport, safety needs to be addressed and ensured. In addition to the improvement of existing cycling routes, new infrastructure for cyclists needs to be created. Cycling infrastructure that allows cyclists to cover longer distances, e.g. following the example of long-distance cycle highways ("Cycle Superhighways") in Copenhagen (see PASTA Consortium, 2017), appear to have great potential.

Implementation in the MARS model is carried out through the assumption that detours, as well as the weighting of travel times for cyclists are reduced by 5% respectively.

Increase of parking fees

In order to make car usage unattractive, increasing parking fees is mentioned numerous times as a viable strategy (Batty et al., 2015; WHO, 2017). For policy makers it may be an unattractive intervention to implement, as it may be highly unpopular with some voters (Batty et al., 2015), which is also mentioned in interviews with stakeholders in the course of the PASTA project (Wegener et al., 2017). This may lead to a lack of political will to undertake such interventions. Additionally, the short political terms and high turnover of political actors contradict with the long-term commitment that is necessary to carry out interventions, especially those who aim to make car usage unattractive.

In Vienna parking fees are already applied in a number of districts (districts 1 to 12 and 14 to 18, as well as districts 19 and 20). Depending on the amount of time a car is parked the prices range from 1.05 Euro (for 30 minutes) to 4.20 Euro (for 120 minutes). District residents are eligible to acquire a permanent parking permit ("Parkpickerl") for their respective district (prices differ for districts), which allows them to park without the need to acquire the individual parking tickets.

The increase of parking fees is implemented into the MARS model comprehensively over the whole city area. The parking fees are increased by 1.00 Euro per parking process for short-term parking and by 5.00 Euro per parking process for long-term parking until 2030 relative to the baseline.

Limitation of parking spaces

Niewenhuijsen et al. argue that "cars, and related roads and parking space, use up a large amount of the already limited space in cities that could arguable be used for other purposes such as trees, parks and other greenness, which are often lacking in cities but are more beneficial to public health and well-being" (Nieuwenhuijsen & Khreis, 2016, p.252, see Nieuwenhuijsen et al. 2014). The city of Vienna acknowledges this, as well as the potential of limiting parking spaces to make private motorised travel unattractive and "push" people towards active mobility (Urban Mobility Plan Vienna). There is, however, a lack of political will to pursue a larger-scale reduction of parking spaces, since this measure seems to be highly unpopular with voters (see "increase of parking fees").

While limiting parking spaces is a useful instrument to make private motorised travel unattractive to the population, if the limitation (and an increase of parking fees as well) is not applied uniformly across the city area, it may lead to adverse effects, especially in suburban areas (Batty et al., 2015). Careful planning and co-packaging with other measures is necessary to avoid adverse effects.

In the MARS model limitation of parking spaces is assumed to have several consequences:

- Former parking areas are converted into green spaces and parking spaces for bicycles, which increases the attractiveness of walking and cycling by 10%. The weighting of travel times is reduced by 10%.
- Due to the reduction in available parking spaces in public areas trips to and from parking spaces are extended by 10%.
- Since car drivers increasingly switch to car parks and parking garages, the time spent searching for a parking space does not change.
- Due to the switch to car parks and parking garages, the share of fee-based parking processes is increased by 10%.

6. Empirical results

6.1 Changes in modal split

One of the main results provided by MARS are the modal splits (the share, usually in %, of travellers using a mode of transport) of the City of Vienna for both the scenario where the selected measures were implemented ("all measures 2030") and the "business-as-usual" scenario ("BAU 2030"). The modes considered are walking, cycling, public transport (PT) and individual motorised transport (IMT).

Figure 5 depicts the modal split of the baseline year ("baseline 2013", obtained from "Mobilitätserhebung 2013/14, BMVIT, 2016). Note that in this figure the category "other", which amounts to around 1%, is omitted.

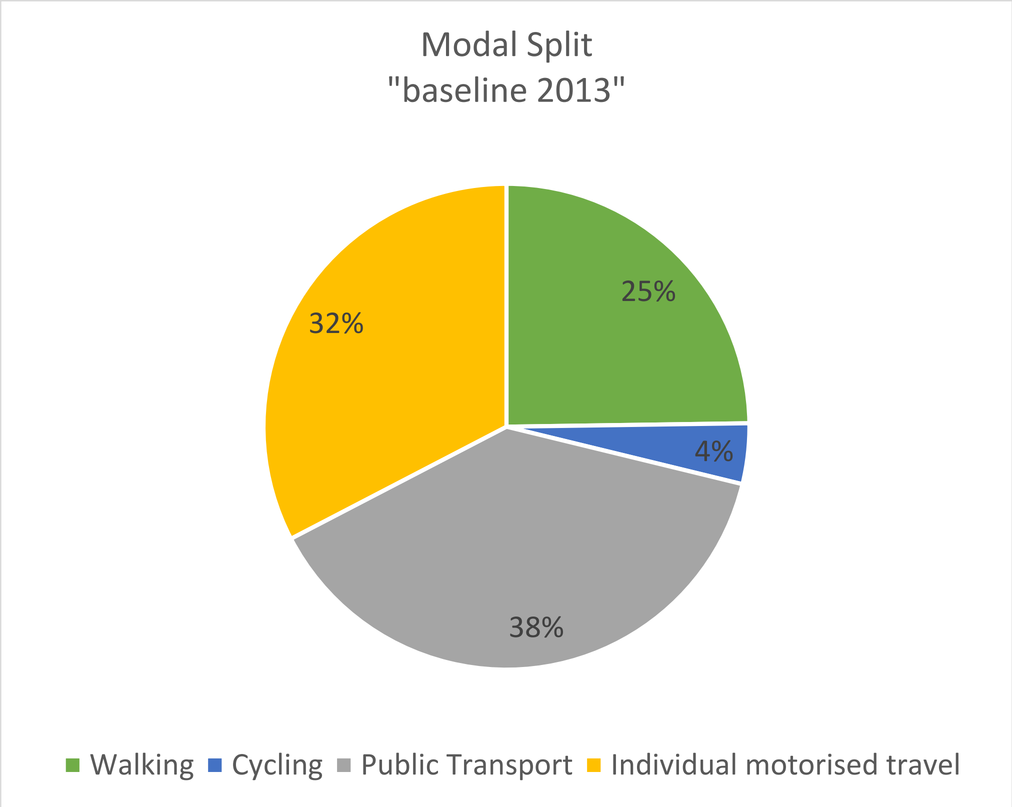

Figure 5. Modal split of Vienna in the year 2013 ("baseline 2013").

Figure 6 depicts the modal split in 2030 within the BAU-scenario modelled in MARS, without the implementation of the selected measures (“BAU 2030”).

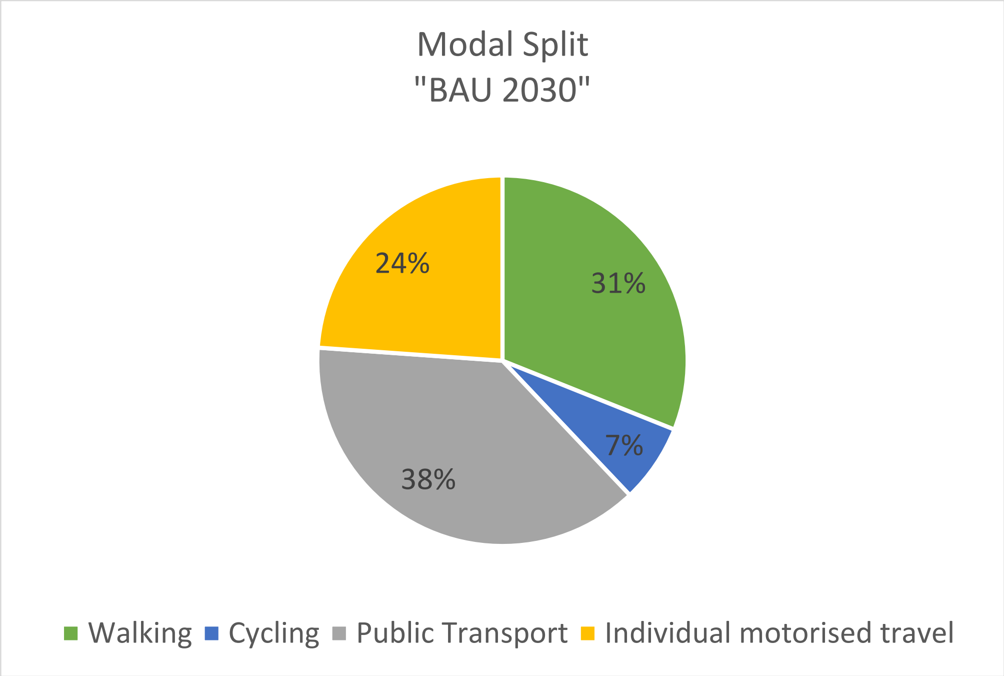

Figure 6. Modal split of the “BAU 2030” scenario for Vienna.

Compared with the modal split of the baseline year 2013 (“baseline 2013”), which is depicted in figure 5, the share of individual motorised travel is reduced by approx. 25%, even in the “BAU 2030” scenario. The share of pedestrians is increased by approx. 25%, whereas the share of cyclists nearly doubles. The changes can be attributed to the underlying assumptions of the MARS model (which were described in section 4.2).

Figure 7 shows the modal split in 2030 after the implementation of the selected measures to foster active mobility (“all measures 2030”, obtained from the MARS model).

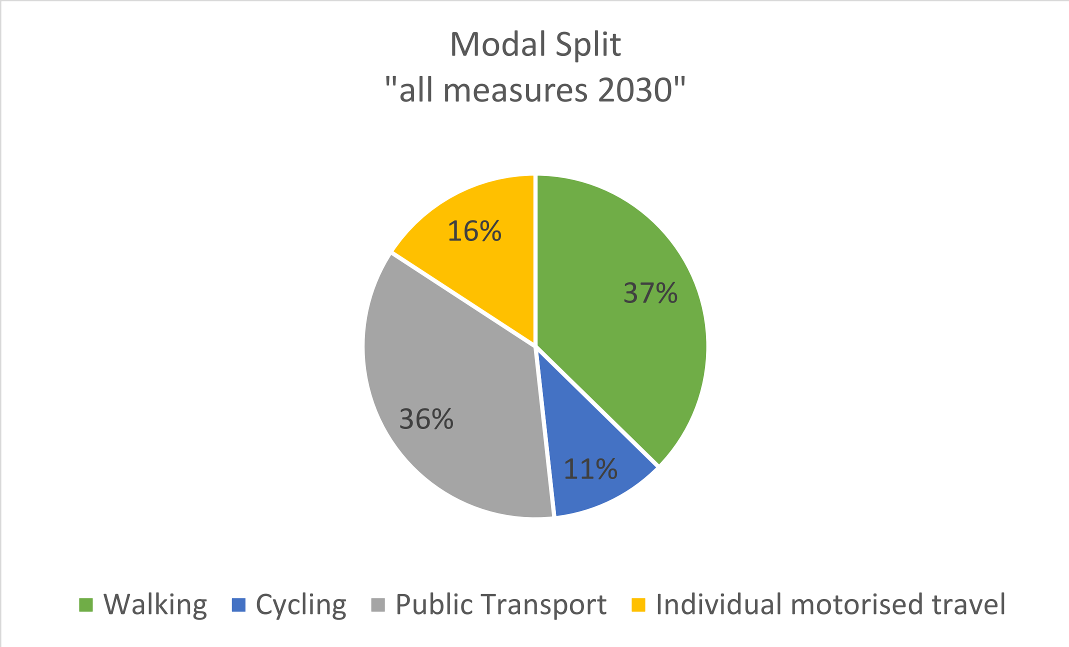

Figure 7. Modal split of the “all measures 2030” scenario.

Compared with the BAU-scenario, the share of people walking and cycling increases by almost one fifth and around two thirds respectively, while the share of IMT decreases by more than 30%. This suggests that the selected measures that are implemented in the scenario in the MARS model “pushed” people away from individual motorised travel and “pulled” them towards active travel modes.

Compared with the modal split in the baseline year 2013 (“baseline 2013”), the share of IMT is halved. The share of pedestrians almost doubles and the share of cyclists is increased substantially by 175% (from 4% to 11%).

The share of public transport (PT) decreases slightly in the “all measures 2030” scenario, compared to both the BAU-scenario and the baseline. PT and active travel modes, such as cycling and walking, are competitive modes of transport, and a shift from PT to active modes is found to be easier than from IMT to active modes (Batty et al., 2015).

Notably, the modal split in the “all measures 2030” scenario is similar to the modal split envisioned by the Urban Mobility Plan Vienna (STEP 2025, City of Vienna). It is important to note that the shares of active mobility (i.e. walking and cycling) and public transport in the STEP 2025 are presented via a fluctuation range rather than exact numbers. However, in a draft version of the detailed concept there are points of reference for the modal split shares, which are also applied by Maier in his “STEP 2025” scenario (Maier, 2015, see section 3.2.2). Those points of reference are chosen for a comparison between the modal splits of the “all measures 2030” scenario and the STEP 2025 goals as well.

Figure 8 compares the modal splits for the City of Vienna for the baseline (“baseline 2013”), the “all measures 2030” scenario and the STEP 2025 scenario.

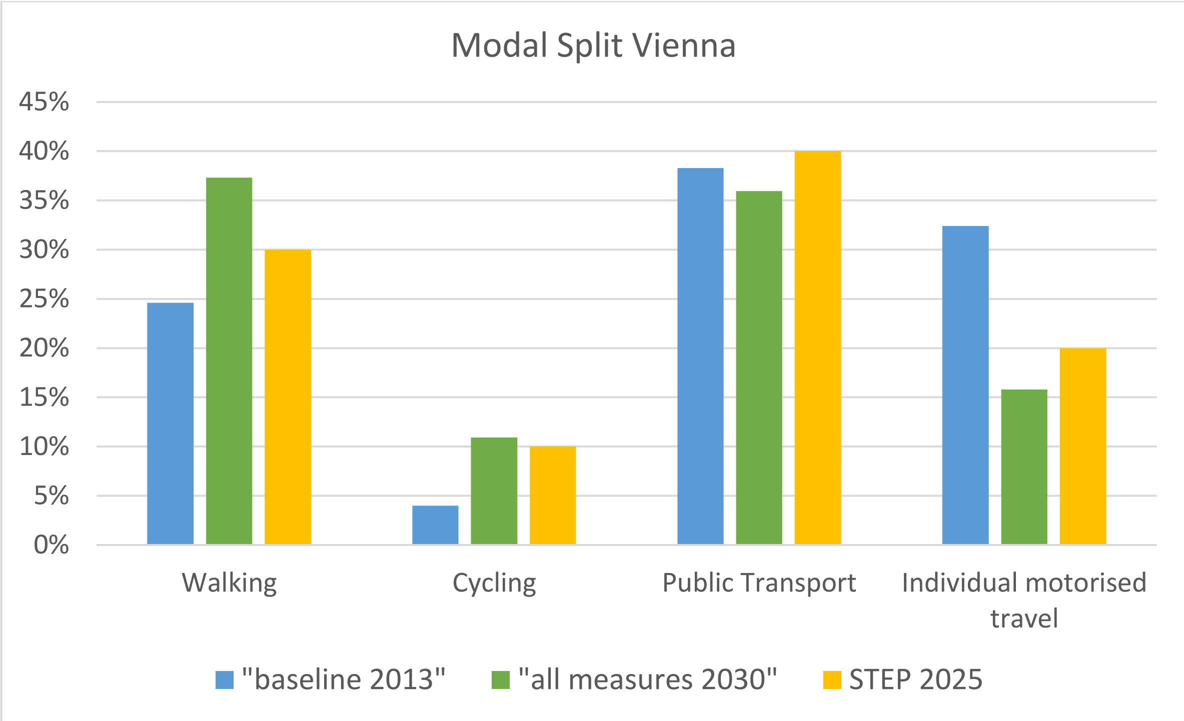

Figure 8. Modal split of Vienna for the baseline, the “all measures 2030” scenario and the STEP 2025 scenario.

In the modal split from the STEP 2025 goal, individual motorised travel is supposed to decrease to 20% by 2025 and to 15% by 2030 (Urban Mobility Plan Vienna). The share of IMT in the modal split of the “all measures 2030” scenario is around 16%.

The Urban Mobility Plan (MA18, 2015), which is part of the STEP 2025, compiles measures to achieve the envisioned modal split. The measures, some of which are included in the measure catalogue (see chapter 5), are mostly “pull” measures (measures aimed at increasing the attractiveness of active mobility, see Batty et al., 2015), such as mobility management efforts, car and bike sharing initiatives, or improvements and expansion of transport infrastructure. Public transport plays a crucial role in a lot of the proposed measures. The Urban Mobility Plan for the most part refrains from “push” measures (see page 59), which might be highly unpopular with a vocal group of voters (Batty et al., 2015; Wegener et al., 2017), whereas two of the four selected measures in this thesis are “push” measures (increase of parking fees and limitation of parking spaces). While the need to reduce above-ground parking spaces is acknowledged in the Urban Mobility Plan, parking spaces are to be moved underground mostly. Walking as an essential transport mode is recognized, but the City of Vienna lacks a specified budget for it (Wegener et al., 2016). The share of pedestrians in the modal split envisioned by STEP 2025 is around 30% (see Fig. 8), whereas the share of pedestrians in the “all measures 2030” scenario lies at 37% (see Fig. 7). These findings suggest that the importance of walking as a mode choice is undervalued.

The results show that with the implementation of the four selected measures (see section 5.2), the ambitious goals of the Urban Mobility Plan (STEP 2025) can potentially be reached. Additional accompanying measures, such as targeted and sustained information campaigns, may be viable to increase the acceptancy of the selected measures and facilitate long-lasting change.

6.2 Climate effects – Changes in emissions

6.2.1 Changes in emissions from MARS

The MARS model provides estimates of changes in carbon dioxide (CO_2)-emissions in the passenger transport sector between the “all measures 2030” scenario and the “BAU 2030” scenario for the Viennese population. The introduction of the four selected measures to foster AM and discourage IMT thus leads to emission savings. Emissions considered in the MARS model are carbon dioxide (CO_2), as well as the air pollutants nitrous gases (NO_x) and particulate matter (PM) (see Appendix 11).
Figure 9 shows the absolute amount of CO_2 in the passenger transport sector in both scenarios in kilotons per year (kt/a) for the MARS area/region. Due to a shift in transport mode choice towards active mobility (i.e. cycling and walking), individual motorised travel and associated CO_2-emission decrease. The amount saved (114,980 t/a) translates to a 6.4% reduction of CO_2-emissions in the “all measures 2030” scenario.

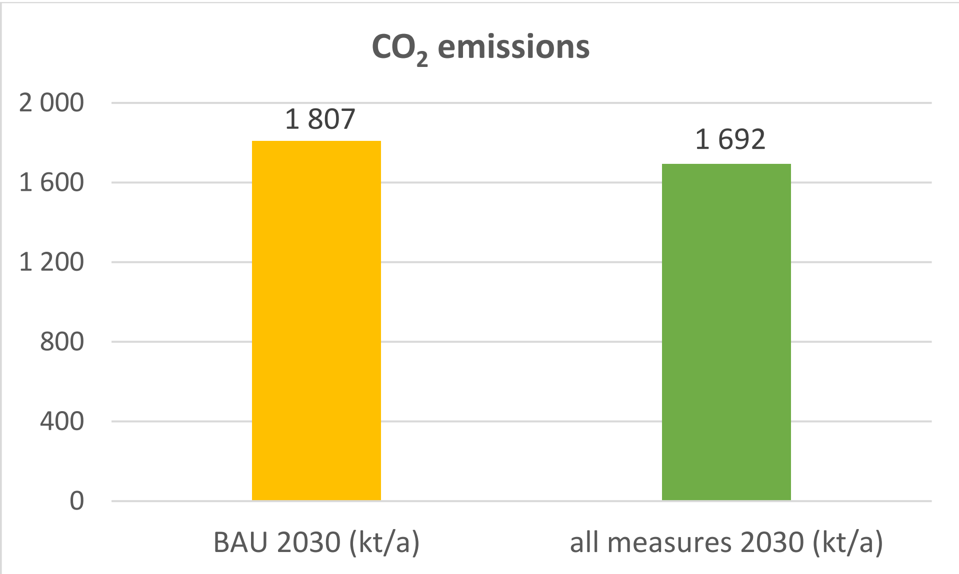

Figure 9. CO_2-emissions in the Viennese passenger transport sector in the “BAU 2030” and “all measures 2030” scenarios in kilotons per year.

Table 6 summarises the emission savings between the “BAU 2030” scenario and the “all measures 2030” scenario plotted above.

Table 6. CO_2-emissions in tonnes per year (t/a) between the scenarios “BAU 2030” and “all measures 2030”.

	“BAU 2030” [t/a]	“all measures” 2030 [t/a]	Change [absolute]	Change [%]
CO_2	1,807,410	1,692,430	114,980	-6.4

Also obtained from the MARS model are the emissions in the passenger transport sector in the year 2013 for the BAU-scenario, which act as a baseline (see Figure 10). In order to avoid confusion with the "baseline 2013" emission estimates obtained from own calculations, the baseline emissions are labelled as "baseline 2013_M". Emissions within the MARS model are calculated employing an emission/fleet composition module. Data provided by the "Bundesländer-Luftschadstoff-Inventur" (Umweltbundesamt, 2016) uses an accounting method which produces significantly different numbers for emissions in the transport sector. Thus, comparison is not possible and data on emissions was taken from the MARS model.

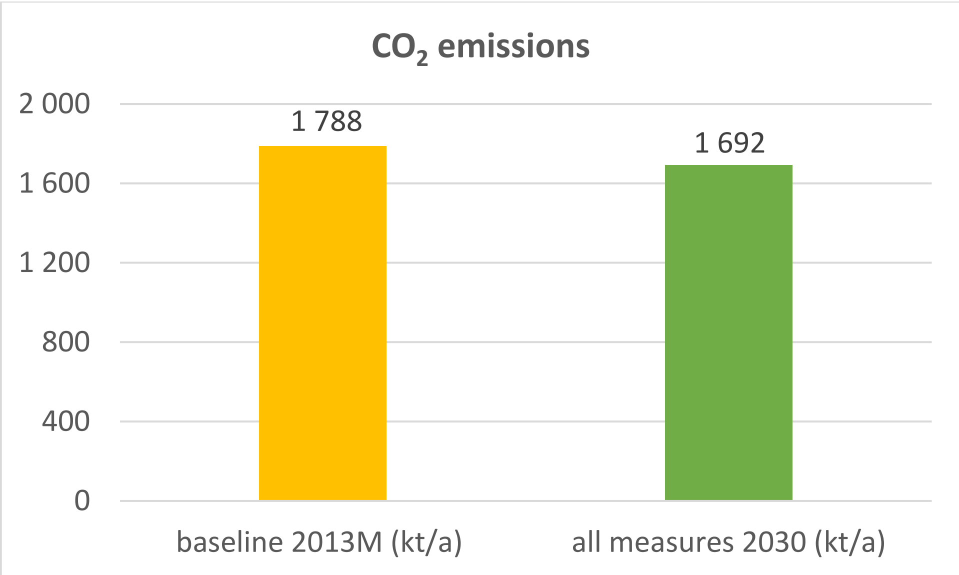

Figure *10*. CO2-emission in the MARS region passenger transport sector in the "BAU 2013" and the "all measures 2030" scenarios in kilotons per year.

Table 7 summarises the emissions and savings between the "all measures 2030" scenario and the missions from the year 2013 of the BAU-scenario ("baseline 2013_M").

Table 7. CO_2-emissions in tonnes per year (t/a) between the baseline year 2013 and the "all measures 2030" scenario.

	"baseline 2013_M" [t/a]	"all measures 2030" [t/a]	Change [absolute]	Change [%]
CO_2	1,788,290	1,692,430	95,860	-5

6.2.2 Changes in emissions – own calculation

Additionally to the output provided by the MARS model, changes in CO_2-emissions stemming from individual motorised travel (IMT) between the "baseline 2013" and the "all measures 2030" scenario are calculated after the approach used by Maier (2015, see section 4.3).
Table 8 shows the CO_2-emissions and savings between the baseline and the future scenario for the four variants calculated: Substitution, substitution and higher occupancy rate, substitution and lower emission factor, and combined effects of higher occupancy rate and lower emission factor.

Table 8. CO_2-emissions in tonnes per year (t/a) between the baseline and the "all measures 2030" scenario.

	"baseline 2013" [t/a]	"all measures 2030" [t/a]	Change [absolute]	Change [%]
Substitution	369,983	209,874	160,108	43%
Substitution + higher occupancy rate	369,983	184,689	185,293	50%
Substitution + lower emission factor	369,983	163,056	206,927	56%
Combined effects	369,983	143,389	226,494	61%

Figure 11 summarises the absolute amounts of CO_2-emissions in tonnes per year in the baseline and the four scenario variants calculated.

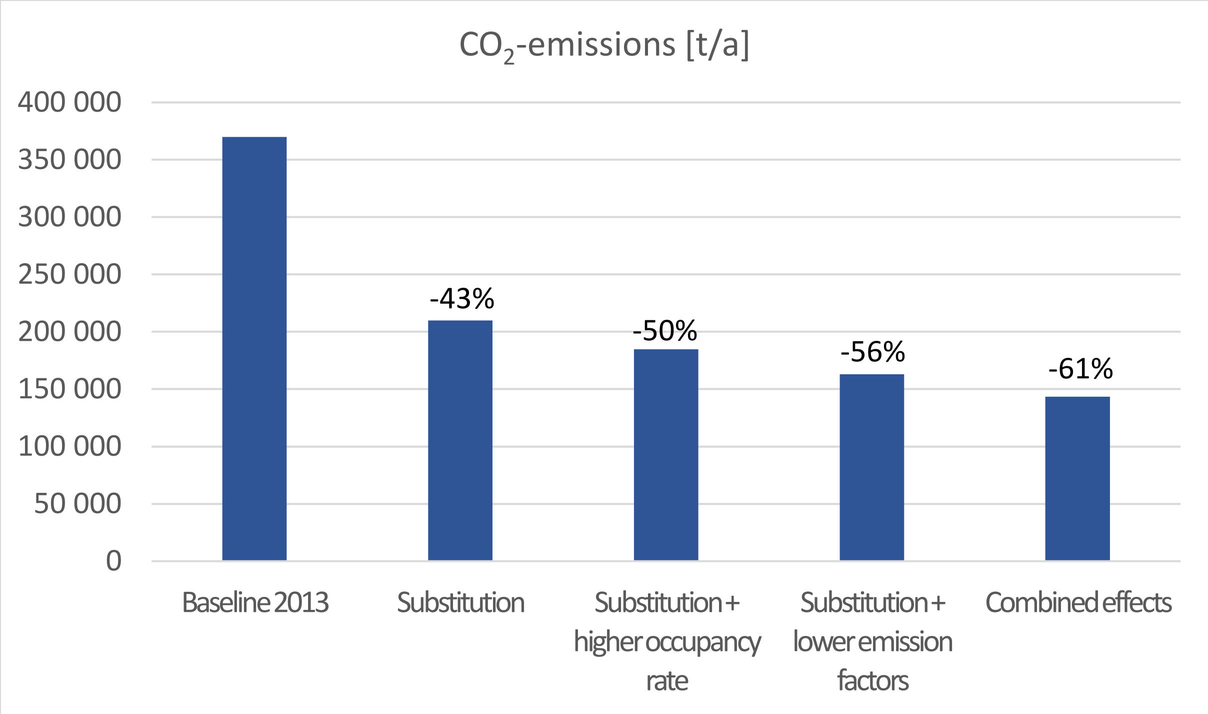

Figure 11. Comparison of absolute CO_2-emissions of the baseline and the four variants calculated.

The results summarised in table 8 and figure 11 show that with a more efficient use of IMT (higher occupancy rate) and technological progress (lower emission factors) emissions can be reduced even further, up to 61% (for the combined effects variant). Lower emission factors have a bigger impact on emissions than higher occupancy rate.

6.2.3 Discussion of results concerning CO_2-emissions

When comparing the results obtained from the MARS model (comparison of two future scenarios against the "baseline 2013_M") with the results from own calculations, percentual changes differ vastly. Since the MARS model covers not only the City of Vienna but surrounding areas as well (see footnote 8), consequently total carbon dioxide emission considered are higher. Residents outside of Vienna are not affected by the introduction of measures, therefore the relative emission reduction is a lot lower than when just considering Vienna itself. Moreover, the absolute changes (i.e. reductions) in CO_2-emissions from own calculations are higher by a factor of 1.5 up to 2 (depending on the calculated variant) compared to the results derived from MARS. Explanations refer to two assumptions, which are considered decisive for the results (pers. Communication with Paul Pfaffenbichler, October 2020). The MARS model employs higher emission factors (156 g CO_2/vkm in 2030, compared to 128.6 g CO_2/vkm in the calculation method after Maier, 2015) and a constant occupancy rate (1.3 persons per car, compared to 1.5 persons per car in scenario variants in the calculation method after Maier, 2015), thus adopting a more conservative approach. Furthermore, it is important to note that the MARS model uses the same scenario assumptions for occupancy rate and emission factors for both the "BAU 2030" and the "all measures 2030" runs, whereas the own calculations employ the different variants discussed in section 4.3. Theoretically, harmonizing the scenario assumptions would have been possible, but was out of the scope of this thesis.

The results of the own calculations are similar to those obtained by Maier (2015). This is expected, as the same assumptions for occupancy rate and emission factors, as well as the same variants for the (future) scenario are used. The emission savings estimated in this thesis are slightly higher than those from Maier (up to 61%, compared to a maximum of 56% for Maier's results, see 3.2.2). A possible explanation of these findings is the modal split share of IMT, which amounts to 16% in the "all measures 2030" scenario obtained from MARS, whereas the modal split share of car travel envisioned in STEP 2025 amounts to 20% (see fig. 8 for a comparison of modal splits). Additionally, in the year 2030 the population is projected to be higher, thus more citizens are affected by the interventions.
Overall, both estimates show that with the introduction of the four measures selected, substantial CO_2-emission reductions can be achieved. Subsequent impacts on the health sector due to a change in burden of disease and thus a declining need to treat sick patients may result in even further emission reductions (Weisz, U., et al., 2020).

6.3 Health effects – Changes in disability-adjusted life years (DALYs)

6.3.1 Relative Risks and PIFs

Table 9 summarises the associated diseases, exposure, Relative Risks (RRs) and Potential Impact Fractions (PIFs) in the “all measures 2030” scenario compared to the “baseline 2013” for additional cyclists and additional pedestrians respectively.

Table 9. Physical inactivity (PI): Diseases, RRs and PIFs of additional cyclists and pedestrians.

Disease associated with PI	Exposure	RR	PIF cyclists	PIF pedestrians
Ischemic heart disease	Insufficiently active vs. sufficiently active	1.44	4%	5%
Ischemic stroke		1.10	1%	1%
Breast cancer		1.13	1%	2%
Colon cancer		1.18	2%	3%
Diabetes mellitus type II		1.24	2%	3%

With the introduction of the four selected measures, road calming, improvement and expansion of cycling routes, increased parking fees and limitation of parking spaces, the amount of people participating in active mobility (i.e. cycling and walking) increases in the “all measures 2030” scenario compared to the baseline (“baseline 2013”), thus increasing the share of people in Vienna who are sufficiently active in the 2030 scenario. In the “all measures 2030” scenario there is an increase of around 140,300 cyclists and 198,100 pedestrians compared to the baseline, corresponding to an increase of 209% and 72% respectively. Due to the higher share of “sufficiently active” citizens in Vienna the burden of disease expressed in DALYs or healthy life years gained changes (see below).
In order to show the effect of population growth, two estimates are made, one including population growth as a parameter and one omitting it. Estimates are shown in rounded numbers.

6.3.2 Change in burden of disease (including population growth)

Due to an increase in the share of “sufficiently active” citizens in Vienna (and population growth), the burden of disease attributable to physical activity (PA) changes, which is expressed in changes in DALYs (disability-adjusted life years).
Considering incremental cycling only (and population growth as a parameter) the share of “sufficiently active” citizens in Vienna rises to 49%[10] in the “all measures 2030” scenario. Table 10 compares the DALYs in the “baseline 2013” and “all measures 2030” scenarios for additional cyclists.

[10] 38% of the Viennese population is inherently “sufficiently active”, the increment of 11% is a result of additional cyclists

Table 10. Change in disease burden due to additional cyclists in Vienna in “all measures 2030”.

Disease associated with PA	"baseline 2013" [DALYs]	"all measures 2030" [DALYs]	Change [absolute]	Change [%]
Ischemic heart disease	12,000	11,500	-500	-4%
Ischemic stroke	1,700	1,680	-20	-1%
Breast cancer	4,300	4,240	-60	-1%
Colon cancer	2,190	2,150	-40	-2%
Diabetes mellitus type II	4,240	4,140	-100	-2%
Total[11]			-720	

[11] Possible co-morbidities not considered in sum, applies to all following totals

Considering additional walking only (and population growth as a parameter) the share of “sufficiently active” citizens in Vienna rises to 54% in the “all measures 2030” scenario.
Table 11 compares the DALYs in the “baseline 2013” and “all measures 2030” scenarios for additional pedestrians. Incremental PA due to a higher share of walking affects burden of disease stronger than cycling does.

Table 11. Change in disease burden due to additional pedestrians in Vienna in “all measures 2030”.

Disease associated with PA	"baseline 2013" [DALYs]	"all measures 2030" [DALYs]	Change [absolute]	Change [%]
Ischemic heart disease	12,000	11,360	-640	-5%
Ischemic stroke	1,700	1,670	-30	-1%
Breast cancer	4,300	4,220	-80	-2%
Colon cancer	2,190	2,140	-50	-3%
Diabetes mellitus type II	4,240	4,100	-140	-3%
Total			-940	

Summing up the number of additional cyclists and additional pedestrians, the share of “sufficiently active” citizens in Vienna increases to 65% of the population in the “all measures 2030” scenario, compared to 38% in the “baseline 2013” (see Appendix 8). Table 12 compares the DALYs in the “baseline 2013” and “all measures 2030” scenarios for additional cyclists and additional pedestrians.

Table 12. Change in disease burden due to additional cyclists and pedestrians in Vienna in “all measures 2030”.

Disease associated with PA	"baseline 2013" [DALYs]	"all measures 2030" [DALYs]	Change [absolute]	Change [%]
Ischemic heart disease	12,000	10,900	-1.100	-9%
Ischemic stroke	1,700	1,650	-50	-3%
Breast cancer	4,300	4,160	-140	-3%
Colon cancer	2,190	2,100	-90	-4%
Diabetes mellitus type II	4,240	4,000	-240	-6%
Total			-1,620	

Additional walking trips account for more than half of DALYs saved (-940 DALYs), compared to 720 DALYs saved by additional cycling trips only. The biggest contributor to savings of DALYs are related to ischemic heart diseases with a reduction of approximately 1,100 DALYs in the

“all measures 2030” scenario when considering both additional cyclists and additional pedestrians (9% reduction of DALYs). Ischemic heart diseases account for the highest share of DALYs in Austria, so savings in this regard can be viewed as very positive.
Diabetes mellitus type II amounts to 4,240 DALYs in the year 2013. In the “all measures 2030” scenario around 240 DALYs can be saved, which translates to a 6% reduction. DALYs saved in relation to diabetes mellitus type II are the second highest of the diseases considered.
Summing up the DALYs stemming from the diseases of interest (24,430 DALYs when considering both cycling and walking in the baseline), the reduction amounts to 6.6% of DALYs associated with physical inactivity for the age cohort in Vienna. When comparing to total DALYs (all causes) of the selected age cohort in the Viennese population, the healthy life years gained translate to a 0.7% reduction of overall DALYs/burden of disease (see Appendix 9).

6.3.3 Change in burden of disease (excluding population growth)

The following estimates omit population growth as a parameter. As expected, the share of “sufficiently active” persons and the amount of DALYs saved is higher when considering population growth.
Considering cycling only and excluding population growth the share of “sufficiently active” citizens in Vienna rises to 45% in the “all measures 2030” scenario, compared to 38% in the “baseline 2013”. Table 13 summarises DALYs of the two scenarios for additional cyclists.

Table 13. Change in disease burden due to additional cyclists in Vienna in “all measures 2030”, excluding population growth as parameter.

Disease associated with PA	"baseline 2013" [DALYs]	"all measures 2030" [DALYs]	Change [absolute]	Change [%]
Ischemic heart disease	12,000	11,700	-300	-2%
Ischemic stroke	1,700	1,690	-10	-0.6%
Breast cancer	4,300	4,270	-30	-1%
Colon cancer	2,190	2,170	-20	-1%
Diabetes mellitus type II	4,240	4,180	-60	-1%
Total			-420	

For incremental walking only, the share of “sufficiently active” citizens in Vienna rises to 49% in the “all measures 2030” scenario when omitting population growth. Table 14 summarises DALYs of the two scenarios for additional pedestrians.

Table 14. Change in disease burden due to additional pedestrians in Vienna in “all measures 2030”, excluding population growth as parameter.

Disease associated with PA	"baseline 2013" [DALYs]	"all measures 2030" [DALYs]	Change [absolute]	Change [%]
Ischemic heart disease	12,000	11,540	-460	-4%
Ischemic stroke	1,700	1,680	-20	-1%
Breast cancer	4,300	4,240	-60	-1%
Colon cancer	2,190	2,150	-40	-2%
Diabetes mellitus type II	4,240	4,140	-100	-2%
Total			-680	

When considering both cyclists and pedestrians and omitting population growth, the share of citizens who fall under to category of “sufficiently active” rises to 60% in the “all measures 2030” scenario, compared to 38% in the “baseline 2013” year (same calculation as shown in Appendix 8). A summary of DALYs saved due to additional cyclists and pedestrians is found in table 15.

Table 15. Change in disease burden due to additional cyclists and pedestrians in Vienna in “all measures 2030”, excluding population growth as parameter.

Disease associated with PA	"baseline 2013" [DALYs]	"all measures 2030" [DALYs]	Change [absolute]	Change [%]
Ischemic heart disease	12,000	11,100	-900	-8%
Ischemic stroke	1,700	1,660	-40	-2%
Breast cancer	4,300	4,190	-110	-3%
Colon cancer	2,190	2,110	-80	-4%
Diabetes mellitus type II	4,240	4,040	-200	-5%
Total			-1,330	

6.3.4 Discussion of results of the Comparative Risk Assessment

The results obtained from the CRA show that there are positive effects on health caused by an increase in PA due to the implementation of measures in the “all measures 2030” scenario. The higher share of citizens in Vienna who are “sufficiently active” in the future scenario leads to savings in disability-adjusted life years (DALYs) for associated diseases. The effects are higher when considering population growth as a parameter, simply because the population in Vienna is expected to be larger in 2030 compared to 2013. It is likely that the share of the population who is inherently “sufficiently active” (i.e. without the implementation of the four specified measures) does not decline as the population grows, as is assumed in the estimate including population growth.

Due to the assumptions made in this thesis, it is possible that the results underestimate the effects of an increase of PA (see chapter 4.4 addressing the limitations of this thesis). Cycling speeds vary, thus some cyclists may participate in “vigorous intensity active mobility”, rather than the applied “moderate intensity active mobility”.

It is important to note that this thesis assumes that additional cyclists and pedestrians were “insufficiently active” at baseline, which may overestimate the effects, since benefits of incremental PA are highest for those who are not physically active and are lower for those who are already active at baseline.

The following section aims to compare the results obtained in this thesis to other studies. Comparison between CRAs is difficult due to the different approaches chosen, varying data availability and diverse underlying conditions in different cities (e.g. different cycling “cultures”).

This thesis focuses on physical activity and omits health determinants like traffic injuries and fatalities, and air pollution. While effects of air pollution can be both beneficial (for the general population) and detrimental (for the individual traveller), the effects of traffic injuries and fatalities are likely negative. However, as mentioned before, detrimental effects are outweighed by the benefits obtained from an increased PA. This effect can be observed in various other studies, some of which will be discussed in this section.

Table 16 provides a comparison of different studies addressing changes in burden of disease, expressed in DALYs, in relation to physical activity (and other health determinants).

Table 16. Comparison of results from this thesis with other studies addressing change in burden of disease in relation to physical activity.

Study	Study group and area	Assumptions	Health determinants considered	Total DALYs
Maier, 2015	Age cohort 20-69 years in Vienna, Austria	Reduction of 35% of daily IMT trips in 2025 with 2010 as baseline, with 2/3 of trips substituted by cycling	Physical activity Air pollution (individual traveller) Traffic incidents	-808 for PA +80 for air pollution +30 for traffic incidents
Rojas-Rueda et al., 2013	Age cohort 16-64 years in Barcelona (Greater metropolitan area), Spain	Eight scenarios of car trip replacement with public transportation and cycling trips	Physical activity Air pollution (individual traveller & general population) Traffic incidents	Depending on scenario: -103 to -259 for PA +0.4 to +2 for air pollution (individual traveller) -0,2 to -0,8 for air pollution (general population) -62 to +5 for traffic incidents
Holm, Glümer & Diderichsen, 2012	Commuters in age cohort 15-69 years in Copenhagen, Denmark	42% of trips to work or place of education by cycling, compared to 35% at baseline	Physical activity Air pollution (individual traveller) Traffic incidents	-76 for PA +5 for air pollution +51 for traffic incidents
Chiu, 2020 (this thesis)	Age cohort 20-64 years in Vienna, Austria	Increases in cycling and walking trips in a future scenario (2030), compared to a baseline (2013)	Physical activity	-720 DALYs for cycling -940 for walking -1,620 when considering both

The Vienna case study by Maier focuses on the modal split envisioned by STEP 2025 (Maier, 2015). While the modal split obtained by the MARS model in this thesis is very similar to the modal split envisioned by the STEP 2025 strategy plan, the means to reach the modal split in the "all measures 2030" scenario are specific, pre-defined instruments.
Maier estimates the DALYs saved due to cycling to be slightly higher than in this thesis (-808 DALYs compared to -720 DALYs). A possible explanation for this is the selected age cohort – Maier selects the age cohort 20-69 years, while in this thesis the age cohort 20-64 years is chosen.
Analogous to this thesis, ischemic heart diseases account for the highest share of healthy years gained (-558 DALYs, a reduction of around 3%) and type II diabetes for the second highest share of DALYs saved (-146 DALYs, a reduction of around 2%). Maier includes effects of air pollution (on the individual traveller) and traffic injuries and fatalities. He estimates an increase of DALYs in relation to air pollution (+0.5%, which amounts to around 80 DALYs lost) and an in relation to traffic injuries and fatalities (+14% and +0.02% respectively, which translates to around 30 DALYs lost in relation to traffic incidents). Compared to the DALYs saved due to an increase in PA, the effects of air pollution and traffic incidents can be considered minor. Additionally, Maier estimates effects of air pollution on the individual traveller with reduced PM-concentrations, yielding 20 DALYs saved.
Maier does not consider the "Safety-in-numbers" effect which has been described earlier in this thesis (see section 3.1.1). This effect has been proposed and observed by a number of studies (Jacobsen, 2003; Elvik, 2009; de Nazelle et al., 2011) and may decrease the dangers of road traffic incidents even more. Furthermore, reductions in the volume of motorized travel may lead to reductions in traffic incidents as well (Niewenhuijsen & Khreis, 2016).
In contrast to the case study presented by Maier, this thesis includes additional walking trips. DALY reductions obtained from an increase in walking trips are higher than those obtained from cycling trips alone, suggesting that fostering walking as a main mode of transport may yield high benefits for health as well. However, the Vienna City administration does not have a specified budget for measures encouraging walking (Wegener et al., 2016), suggesting the importance of walking might be underestimated.
Rojas-Rueda et al. estimate changes in burden of disease due to substitution of car trips by public transportation and cycling trips for eight scenarios (based on Rojas-Rueda et al., 2012) for Barcelona (Rojas-Rueda et al., 2013). They include effects from an increase in PA, effects of air pollution on the individual traveller as well as the general population and road traffic incidents. Depending on the scenario, the estimates range from 103 to 259 DALYs saved attributable to physical activity. Air pollution affects the individual traveller negatively (+0.4 to +2 DALYs per year) but results in 0.19 to 0.75 DALYs saved for the general population. Depending on the scenario Rojas-Rueda et al. estimate an increase or a reduction of traffic incidents. Compared to the effects of physical activity, benefits and risks from air pollution and traffic incidents are rather minor.
The study conducted by Holm, Glümer & Diderichsen estimates the effects of physical activity, air pollution and traffic incidents for a scenario in which 42% of trips to work or place of education are cycling trips, compared to 35% of trips at baseline in Copenhagen (Holm, Glümer & Diderichsen, 2012). They focus on a specific population affected by a policy goal formulated by the City of Copenhagen (commuters aged 15-69 years old). They estimate a reduction of 76 DALYs related to PA, and an increase of 5.4 DALYs and 51.2 DALYs in relation to air pollution and traffic incidents respectively. Compared to other studies the detrimental effects of road traffic incidents are higher, whereas the benefits obtained from PA are lower. In contrast to Maier, 2015 or this thesis, Holm, Glümer & Diderichsen do not assume that the additional

cyclists were “insufficiently active” at baseline, which may explain the difference in DALYs saved in relation to PA. Additionally, the study group selected is smaller.

Increases in physical activity consistently yield the highest benefit for health throughout the studies mentioned. While air pollution and traffic incidents may affect individual travellers negatively, the detrimental effects on health are outweighed by the benefits obtained from physical activity. Changes in ambient air pollution may affect the general population positively, further cancelling out the detrimental effects. It can be assumed that due to these findings, the results obtained in this thesis may slightly overestimate the health benefits of an introduction of the four measures. However, the net effect is likely to be overwhelmingly positive.

The amount of DALYs saved varies between the studies discussed. The results strongly depend on the approach, the selected study group and the assumptions being made, which makes comparison between studies difficult. Thus, studies can only be compared in terms of magnitude of effect. The results obtained from Maier, 2015 are similar to those of this thesis, as expected since this thesis uses the same approach. However, this thesis put emphasis on the effects from specific measures (road calming, improvement and expansion of cycling routes, increasing parking fees and limitation of parking spaces) implemented in order to achieve said results.

Overall, increases in active travel mode yield a net positive effect on human health. While this thesis did not include air pollution or traffic incidents, it depicts a clear positive effect on morbidity due to an increase in active travel modes (i.e. cycling and walking). In contrast to the other studies discussed this thesis includes pedestrian trips. Walking trips account for more than half of the DALYs saved, indicating the importance of walking as an active travel mode. Furthermore, the results obtained stem from four specific, pre-defined measures which are implemented in the MARS model, rather than policy goals. In conjunction with the substantial carbon dioxide emission reductions that can be accomplished by fostering active mobility and decreasing the attractiveness of individual motorised transport, health benefits can create tangible arguments for policy and decision makers to adopt such measures.

7. Conclusion and outlook

Active mobility, i.e. cycling and walking, hold great potential to not only aid climate change mitigation, but to offer substantial benefits for health as well due to increases in physical activity. The emerging co-benefits for health can act as additional incentives for stakeholders and decision makers to adopt climate change mitigation measures. There is a plethora of interventions to foster active mobility (AM) and decrease the attractiveness of individual motorised travel (IMT) in academic and grey literature, some with evidence of effectiveness, most however lacking evidence. Implementation of measures within bundles are agreed to be the right approach, even if it makes isolating effects of specific interventions challenging. Intersectoral cooperation and emphasising health issues in all fields of decision making (i.e. adopting a Health-In-All-Policies approach) are enabling factors, necessary to ensure subsequent measures to succeed.

With the introduction of four selected measures, road calming, improvement and expansion of cycling routes, increase of parking fees and limitation of parking spaces, the share of people in Vienna who are "sufficiently active" increases to 65% in a future scenario when considering both walking and cycling, compared to 38% in the baseline (year 2013).

A shift towards cycling and walking yields benefits for health in terms of a reduction in disability-adjusted life years (DALYs) due to an increase in physical activity. The amount of cycling trips can be increased substantially (by around 200%) in Vienna, yielding high benefits for health. Ischemic heart diseases are the biggest contributor to DALYs in Austria. The measures proposed could save approximately 1,100 DALYs in the future scenario for ischemic heart diseases alone, which translates to a 9% reduction. Considering the total burden of disease in Vienna, the measures could reduce overall DALYs (all causes) by about 0.7%.

This thesis shows that the rather ambitious goals formulated by the Viennese Urban Development Plan STEP 2025 ("Stadtentwicklungsplan 2025") can theoretically be reached with the four selected measures (road calming, improvement and expansion of cycling routes, increase of parking fees and limitation of parking spaces), offering benefits for climate and health. The measures aim to increase the attractiveness of AM ("pull" measures) while making IMT less attractive or viable, driving people away from car travel ("push" measures). Such a combination of "pull" and "push" measures, and implementing interventions in bundles, seem to be of great importance.

Walking trips account for more than half of the DALYs saved (940 DALYs saved), which indicates the importance of walking as an active travel mode. Measures encouraging walking have no specified budget in Vienna (Wegener et al., 2016), but the findings suggest that more attention should be paid to walking, in particular because cycling may not be as viable for children or the elderly due to safety concerns.

The thesis uses the system dynamics model MARS (Metropolitan Activity Relocation Simulator) to model transport mode choice and emissions for a hypothetic scenario. Transport modelling tools like MARS can benefit by including health effects – the coupling of transport models with models addressing health concerns aids addressing the interdisciplinary and complex questions raised by sustainability issues.

In addition to yielding high benefits for health, a shift towards active mobility reduces IMT, which decreases CO_2-emissions from transport considerably (up to a reduction of 61% of CO_2-emissions from IMT). Hence, the measures directly aid climate change mitigation and reduce the dependency of society on fossil fuels (for transportation purposes). The short-term and local effects of an increase in physical activity (and effects on the environment in terms of a decreased air pollution) can act as additional incentives to adopt those measures. The co-

benefits for climate and health allow to create win-win situations, advancing climate change mitigation, while producing tangible health impacts.
The evaluation of measures to foster active mobility and reduce the attractiveness of IMT, as well as their effects on climate and health, create politically compelling arguments for the implementation of climate change mitigation measures. Political engagement and commitment to such measures is often lacking, especially considering measures which may be highly unpopular for voters, such as an increase in parking fees. Overcoming such challenges is a crucial step and assessing evidence of effectiveness of measures is of high importance.
Assessing subsequent impacts on the health care sector, stemming from a change in burden of disease, may generate further arguments and incentives to adopt measures. Fostering active mobility may lead to potential economic savings and even carbon dioxide emission reductions within the health sector, due to a declining need to treat sick patients.
Further research is necessary to address air pollution effects, both on the individual traveller and the population level, changes in traffic injuries and fatalities, as well as effects of noise, social benefits, social capital and mental health. Fundamentally, a shift towards active mobility should be perceived as a crucial step towards a more sustainable, healthy and just life, particularly in cities.

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9. Appendix

The appendix provides supplementary information on calculation details, data sources, results plotted in tables and figures presented and discussed in the main text.

1. Calculation of distance travelled by individual motorised travel (IMT, car travel) between the “baseline 2013” and the “all measures 2030” scenarios, with and without changes in occupancy rate (approach adopted from Maier, 2015).

Table 17. Distance travelled by IMT with and without changes in occupancy rate.

Distance travelled by car	"baseline 2013"	"all measures 2030"	Change [absolute]	Change [%]
IMT distance travelled [km/year] without change in occupancy rate	2,235,032,300	1,267,831,400	967,200,900	43%
IMT distance travelled [km/year] with change in occupancy rate	2,235,032,300	1,115,691,600	1,119,340,700	50%

2. Translation of modal split into additional cycling and walking trips per working day

Table 18. Translation of modal split into additional cycling trips per working day.

Cycling trips / working day	"baseline 2013"	"all measures 2030"	Change [absolute]	Change [%]
Residents age cohort 20-64	1,118,384 [a]	1,268,816 [b]		
Trips / person / working day [c]	2.9	2.9		
Modal split share cycling [%]	6% [d]	16% [e]		
Cycling trips / working day	194,599	**601,609**	+407,010	+209%
[a]Statistics Austria, [b]own calculation (App. 5), [c]BMVIT, 2016, [d]Maier, 2015, [e]own calculation (App. 4)				

Table 19. Translation of modal split into additional walking trips per working day.

Walking trips / working day	"baseline 2013"	"all measures 2030"	Change [absolute]	Change [%]
Residents age cohort 20-64	1,118,384 [a]	1,268,816 [b]		
Trips / person / working day [c]	2.9	2.9		
Modal split share walking [%]	25% [c]	37% [d]		
Walking trips / working day	797,855	**1.372,479**	+574,623	+72%
[a]Statistics Austria, [b]own calculation (App. 5), [c]BMVIT, 2016, [d]MARS model				

3. Translation of number of cycling trips and pedestrian trips per working day into number of additional cyclists and pedestrians in comparison to the baseline

Table 20. Number of additional cyclists in "all measures 2030".

Number of additional cyclists	"baseline 2013"	"all measures 2030"	Change [absolute]	Change [%]
Residents age cohort 20-64	1,118,384 [a]	1,268,816 [b]		
Trips / person / working day [c]	2.9	2.9		
Cycling trips / working day	194,599	601,609	+407,010	+209%
Cyclists / working day	67,103	207,451	**+140,384**	+209%
[a]Statistics Austria, [b]own calculation (App. 5), [c]BMVIT, 2016				

Table 21. Number of additional pedestrians in "all measures 2030".

Number of additional pedestrians	"baseline 2013"	"all measures 2030"	Change [absolute]	Change [%]
Residents age cohort 20-64	1,118,384 [a]	1,268,816 [b]		
Trips / person / working day [c]	2.9	2.9		
Walking trips / working day	797,855	1,372,479	+574,623	+72%
Pedestrians / working day	275,122	473,268	**+198,146**	+72%
[a]Statistics Austria, [b]own calculation (App. 5), [c]BMVIT, 2016				

4. Calculation of time spent cycling per week (working days only) by additional cyclists and time spent walking per week (working days only) by additional pedestrians in the "all measures 2030" scenario.

Table 22. Time spent cycling by additional cyclists in "all measures 2030".

Time spent cycling (working days only)		**Sources**
Additional cyclists / working day	140,348	Own calculation
Mean distance per cycling trip [km]	3.4	BMVIT, 2016
Trips / person / working day	2.9	BMVIT, 2016
Mean cycling speed [km/hr]	14	Pfaffenbichler, 2011
Time spent cycling / trip [min]	14.57	
Time spent cycling / week [min]	**211.3**	

Table 23. Time spent walking by additional pedestrians in "all measures 2030".

Time spent walking (working days only)		**Sources**
Additional pedestrians / working day	198,146	Own calculation
Mean distance per walking trip [km]	1.2	BMVIT, 2016
Trips / person / working day	2.9	BMVIT, 2016
Mean walking speed [km/hr]	4	Own assumption
Time spent walking / trip [min]	18	
Time spent walking / week [min]	**261**	

5. Calculation of share of cyclists in the age cohort 20-64 years between the "baseline 2013" and the "all measures 2030" scenario.

Table 24. Share of cyclists in age cohort 20-64 years.

Modal Split share [%]	"baseline 2013"	"all measures 2030"	Change
Cycling (whole population)	4% [a]	11%	173%
Cycling (age cohort 20-64)	6% [b]	16%	173%
[a]BMVIT, 2016, [b]Maier, 2015			

6. Calculation of population in age cohort (20-64 years) in the "all measures 2030" scenario.

Table 25. Age cohort in "all measures 2030".

Year	Total population	Age cohort 20-64 years	Share of age cohort [%]
2030	2,031,575 [a]	1,255,575	62% [a]
2030	2,053,000 [b]	1,268,816	62%
[a]Statistics Austria, [b]MARS			

7. Calculation of number of citizens in age cohort (20-64 years) classified "sufficiently active" and "insufficiently active" in "baseline 2013" and "all measures 2030".

Table 26. Age cohort: sufficiently vs. insufficiently active

Year	Age cohort 20-64 years	Share "sufficiently active" [%] [c]	Number of "sufficiently active"
2013	1,741,246 [a]	38%	424,986
2030	1,268,816 [b]	38%	482,150
[a]Statistics Austria, [b]MARS, [c]Putz, 2009, Elmadfa et al., 2012, Maier, 2015			

The table summarises the number of citizens in the selected age cohort (20-64 years), which are classified as "sufficiently active" and "insufficiently active" in the baseline ("baseline 2013") and in 2030 (inherently, without the implementation of measures in the "all measures 2030" scenario).

8. Calculation of number and share of “sufficiently active” citizens in the selected age cohort (20-64 years) in the “all measures 2030” scenario with the implementation of measures to foster AM, considering both walking and cycling.

Table 27. Additional participants in cycling and walking in “all measures 2030”.

Additional participants	Cycling	Walking	Sum
	140,348	198,146	**338,495**

Table 28. Number of “sufficiently active” citizens in “all measures 2030”.

Number of “sufficiently active” persons in age cohort (20-64)	Inherently	Due to implementation of measures	Sum
	482,150	338,495	**820,645**

Table 29. Share of “sufficiently active” citizens in age cohort.

Share of “sufficiently active” persons in age cohort (20-64)	“baseline 2013”	Share [%]	“all measures 2030”	Share [%]
Total population	1,118,384 [a]		1,268,816 [b]	
Sufficiently active	424,986	38% [c]	820,645	65%
Insufficiently active	693,398	62%	448,172	35%
[a]Statistics Austria, [b]own calculation (App. 5), [c]Putz, 2009, Elmadfa et al., 2012, Maier, 2015				

9. DALYs for diseases associated with physical inactivity (PI) for the “baseline 2013” for Austria and Vienna for the age cohort 20-64 years.

Table 30. Number of residents in age cohort (20-64 years) in baseline.

Number of residents in age cohort [a]	Age cohort	Residents Austria	Residents Vienna
	20-64	5,242,298	1,118,384
	20-64	100%	21%
[a]Statistics Austria			

Table 31. DALYs applied to age cohort (20-64 years) in Vienna at baseline.

Disease associated with PI	Age cohort	DALYs Austria [a]	DALYs Vienna
Ischemic heart disease	20-64	56,266	12,004
Ischemic stroke	20-64	7,955	1,697
Breast cancer	20-64	20,158	4,301
Colon cancer	20-64	10,278	2,193
Diabetes mellitus type II	20-64	19,868	4,239
[a]Institute for Health Metrics and Evaluation			

Table 32. Total DALYs applied to age cohort (20-64 years) in Vienna at baseline.

	Age cohort	DALYs Austria [a]	DALYs Vienna
Total DALYs	20-64	1,067,439	227,726
[a]Institute for Health Metrics and Evaluation			

10. Calculation of distribution of colon and rectum cancer incidents in Austria in [%] for the “baseline 2013”.

Table 33. Distribution of colon and rectum cancer incidents in Austria at baseline.

	Incidents [absolute]	Incidents [%]
Colon cancer	2,940	68%
Rectum cancer	1,382	32%
Total	4,322	100%
Source: STATcube		

11. Emission savings for air pollutants nitrous gases (NO_x) and particulate matter (PM) between the "all measures 2030" and the "BAU 2030" scenarios, obtained from MARS.

Table 34. NO_x and PM-emissions for "BAU 2030" and "all measures 2030".

	"BAU 2030" (t/a)	"all measures 2030" (t/a)	Savings in t/a	Savings in %
NO_x	3.360	3.147	212	6,3
PM	317	297	20	6%

Figure 12 shows the absolute amount of NO_x in the transport sector in both scenarios in tonnes per year (t/a). In the "all measures 2030" scenario an absolute amount of 212 t/a is saved, which translates to a 6.3% reduction of NO_x-emissions.

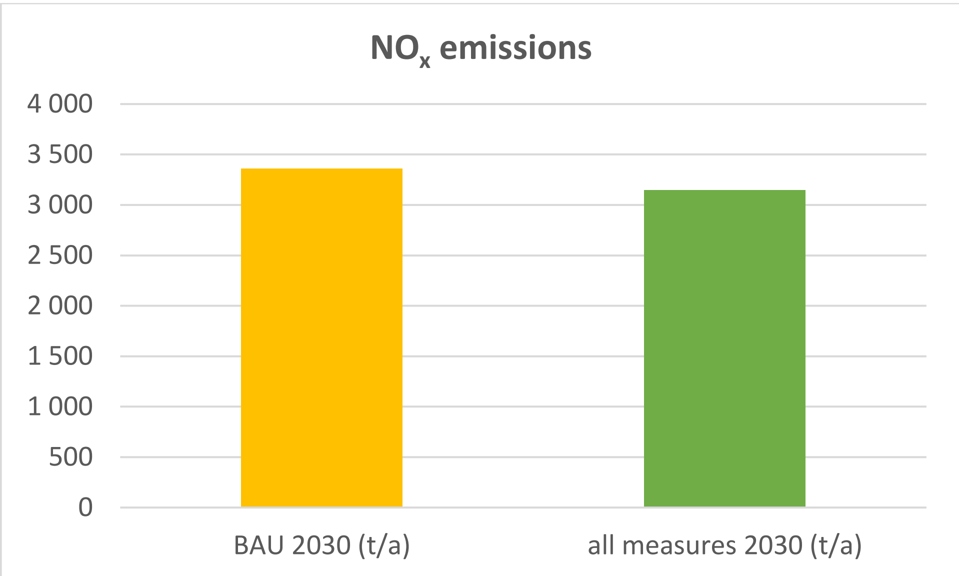

Figure 12. NO_x-emissions in the transport sector in the "BAU 2030" and "all measures 2030" scenarios.

Figure 13 shows the absolute amount of particulate matter (PM) in the transport sector in both scenarios in tonnes per year (t/a). In the “all measures 2030” scenario a total amount of 20 t/a is saved, which translates to a 6% reduction of PM-emissions.

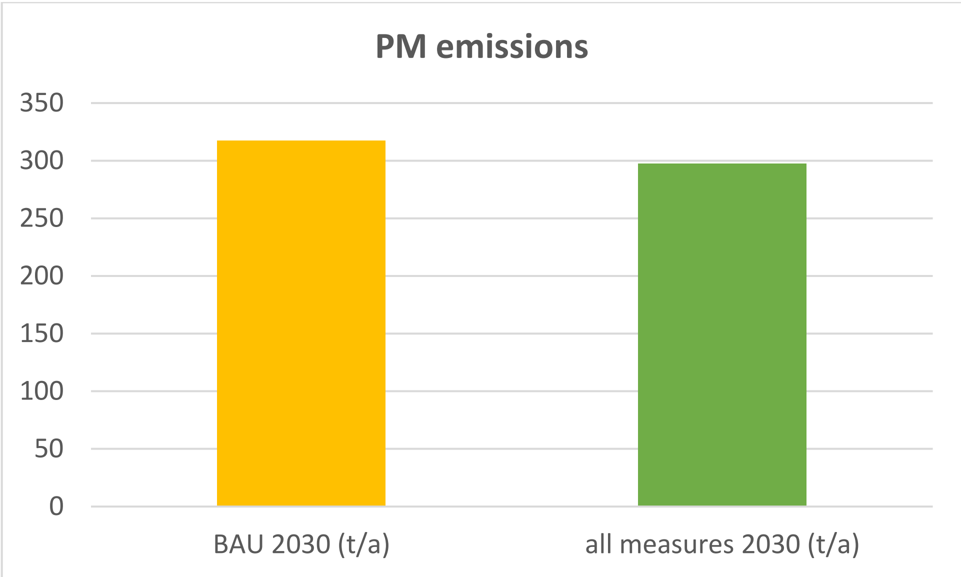

Figure 13. PM-emissions in the transport sector in the “BAU 2030” and “all measures 2030” scenarios.

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