Report on additional impacts of energy-efficiency measures in the transport sector

Næss, Petter; Elle, Morten; Abid, Hamza

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

sEEnergies

QUANTIFICATION OF SYNERGIES BETWEEN ENERGY EFFICIENCY FIRST PRINCIPLE AND RENEWABLE ENERGY SYSTEMS

D2.4 Report on additional impacts of energy-efficiency measures in the transport sector

Project

Acronym	**sEEnergies**
Title	Quantification of Synergies between Energy Efficiency First Principle and Renewable Energy Systems
Coordinator	Prof. Brian Vad Mathiesen, Aalborg University
Reference	846463
Type	Research and Innovation Action (RIA)
Programme	HORIZON 2020
Topic	LC-SC3-EE-14-2018-2019-2020 - Socio-economic research conceptualising and modelling energy efficiency and energy demand
Start	01 September 2019
Duration	34 months
Website	https://seenergies.eu/

Consortium

Aalborg Universitet (AAU), Denmark
Hogskolan i Halmstad (HU), Sweden
TEP Energy GmbH (TEP), Switzerland
Universiteit Utrecht (UU), Netherlands
Europa-Universität Flensburg (EUF), Germany
Katholieke Universiteit Leuven (KULeuven), Belgium
Norges Miljø- og Biovitenskapelige Universitet (NMBU), Norway
SYNYO GmbH (SYNYO), Austria
Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. (Fraunhofer), Germany

Deliverable

Number	D2.4
Title	Report on additional impacts of Energy Efficiency measures in the transport sector
Lead beneficiary	Norwegian University of Life Sciences
Work package	WP2
Dissemination level	Public
Due date	30.04.2021
Submission date	26.04.2021
Authors	Petter Næss (NMBU) Morten Elle (AAU) Hamza Abid (AAU)
Reviewers	Wina Crijns-Graus (UU) Eva Wiechers (EUF)

Document history

Version	Date	Comments
1.0	31.03.2021	Draft submitted for review
2.0	26.04.2021	Submitted version

ISBN: 978-87-93541-35-1

Table of Contents

Summary

The sEEnergies project is based on the concept of Energy Efficiency First Principle and is aimed at the identification of energy efficiency potentials on which the future European energy system should be designed. In two earlier deliverables (D2.1 and D2.3), the energy savings of the Energy-efficiency scenario compared to a business-as-usual trajectory have been assessed. The present deliverable, D2.4, discusses additional environmental and social impacts of the measures included in the Energy-efficiency scenario. For each impact category, the causal mechanisms producing the impact are briefly described. For some of the impacts, quantitative assessments of the impacts compared to a business-as-usual trajectory have also been made. However, for most impact categories, only qualitative descriptions have been possible.

The measures of the Energy-efficiency scenario for the transportation sector are likely to produce a large number of environmental and social impacts in addition to their intended impacts in terms of energy saving. Most of the identified 'additional' impacts are positive, judged against relevant environmental and social criteria, but there are some less favorable impacts.

Since emissions from traffic are resulting from energy use for transportation, it is hardly any surprise that the Energy-efficiency scenario has substantial positive impacts in terms of reduced greenhouse gas emissions and reduced air pollution. Energy efficient urban spatial development and halt in motorway construction also have substantial positive impacts in terms of reduced conversion of natural areas, farmland and areas for hiking, skiing and other kinds of area-demanding outdoor life. The strategies for urban spatial development and infrastructure construction also give substantial positive effects in terms of lower material consumption. The concentrated urban spatial development and urban rail and metro construction of the Energy-efficiency scenario is likely to cause some reduction of intra-urban green areas and put some increased pressure for demolition of heritage buildings. These effects are, however, counteracted by moderately lower encroachments on intra-urban green areas and heritage buildings due to halt of motorway construction in the energy-efficiency scenario. The urban densification of the Energy-efficiency scenario may increase vulnerability to climate change to some extent, but its impacts on climate change resilience are estimated to be moderate and partly ambiguous. Finally, although energy-efficient vehicle technology improvement will cause substantial energy savings as well as reductions in greenhouse gas emissions and air pollution, the increased energy-efficiency gained through improved vehicle technology is estimated to cause a considerable rebound effect likely to reduce some of the energy gains of the Energy-efficiency scenario as well as its positive effects on air pollution and noise. A small rebound effect may also occur as a result of energy-efficient urban spatial development, although this effect is more uncertain.

By offering greater proximity between trip origins and destination and increasing the mobility opportunities for people who do not drive cars, the Energy-efficiency scenario offers substantial positive effects in terms of accessibility for residents who are unable to drive as well as reduced travel time for daily-life purposes and easier everyday schedule. Although motorway construction is often justified by predicted travel time savings, evidence has shown that the higher speeds offered by motorways tend to be counteracted by increased travel distances and region enlargement where local inhabitants are facing harder competition for local jobs from non-local job applicants. The impacts of the halt in motorway construction of the Energy-efficiency scenario on travel time and access to jobs and service facilities is therefore estimated to be ambiguous. Through its halt in motorway construction, intensified urban rail and metro construction and travel demand

management measures, the Energy-efficiency scenario is estimated to enhance the competitiveness of public transit substantially. Part of this effect is caused by the possibility of using revenues from road pricing on transit improvements.

Moreover, the urban spatial development of the is expected to have a considerable positive effect on urban vibrancy, and its provision of better infrastructure for walking and cycling is estimated to bring considerable positive health effects. The intensified shift to electric vehicles in the Energy-efficiency scenario will also give health benefits due to reduced noise and air pollution. Halt in motorway construction implies that negative social impacts pertaining to the construction period will be avoided, but on the other hand, some such impacts will occur due to the intensified urban rail and metro construction in this scenario. The remaining identified social impacts of the Energy-efficiency scenario are estimated to be rather moderate or ambiguous. We estimate that the Energy-efficiency scenario will reduce traffic accidents somewhat, and the destinations of leisure trips will become more local. Whether the latter will bring positive or negative social impacts is, however, ambiguous and contestable.

1 Introduction

The sEEnergies project is based on the concept of Energy Efficiency First Principle and is aimed at the identification of energy efficiency potentials on which the future European energy system should be designed. The transport sector is among one of the three major sectors of energy consumption, the other ones being industry and buildings, and is responsible for around 30 % of Europe's energy consumption (European Environmental Agency, 2015).

Within the scope of the sEEnergies project, WP2 deals with the assessment of energy efficiency potentials by analyzing three main strategies:

1. Making each separate mode of transport more energy efficient
2. Reducing the movement of goods and persons
3. Modal shifts from more energy-intensive to more energy-efficient modes of transport

In light of these measures, WP2 also deals with the development of different transport scenarios including efficiency measures such as energy-efficient urban spatial development, energy-efficient transportation infrastructure development, economic instruments for transportation demand management, and more energy-efficient vehicle technology. In two earlier deliverables (D2.1 and D2.3), the energy savings of the Energy-efficiency scenario compared to a business-as-usual trajectory have been assessed. The present deliverable, D2.4, discusses additional environmental and social impacts of the measures included in the Energy-efficiency scenario. For each impact category, the causal mechanisms producing the impact are briefly described. For some of the impacts, quantitative assessments of the impacts compared to a business-as-usual trajectory have also been made. However, for most impact categories, only qualitative descriptions have been possible.

In line with the overall assumptions of the sEEnergies project, this report (as well as the D2.1 and D2.3 reports in which the BEnergy-efficiency ad Business-as-usual scenarios are described) is based on the assumption that the trajectories of the Business-as-usual scenario will be not be much affected by the current Covid-19 pandemic. In other words, it is assumed that economic and social trends as well as mobility trends will quickly be re-established to the pre-Corona trajectories.

Norwegian University of Life Sciences (NMBU), which is the work package leader of Work Package 2, is the lead beneficiary of the present deliverable and has carried out this work in cooperation with Aalborg University (AAU). The whole work on this deliverable report has been carried out within a budget of less than one person-month. Partly due to the short time available and partly because of lack of quantified input data for many kinds of impact, it has not been possible to conduct an analysis of the economic additional impacts of the measures included in the Energy-efficiency scenario for the transportation sector. The title of this deliverable mentioned in the original project description of the sEEnergies project has therefore been changed from "Report on economic and social impact assessment of Energy Efficiency measures in the transport sector" to "Report on additionl impacts of energy-efficiency measures in the transport sector".

This report is structured as follows: Chapter 2 summarizes key characteristics of the Business-as usual and the Energy-efficiency scenarios for the transportation sector. Chapter 3 presents relevant environmental and social additional impacts of the measures of the Energy-efficiency scenario, including impacts of energy-efficient spatial urban development, halt in motorway construction, halt in airport expansions, improved infrastructure for walking and cycling, economic instruments for transportation demand management, other demand management measures, and energy-efficient vehicle technology. An Appendix shows in a comprehensive table the various additional environmental and social impacts, whether they are estimated to be positive, negative or ambiguous, whether the effects are substantial, considerable or moderate, and whether and at what scale the impacts are considered to be quantifiable within the frames of this study.

The results of this report will be included among the inputs to the sEEnergies project's Task 6.6, "Additional economic, social, policy and energy market impacts".

2 Summaries of the scenarios

In this chapter, only very brief summaries of the measures, strategies and assumptions pertaining to the Business-as-usual and the Energy-efficiency scenarios will be presented. For a comprehensive presentation of the scenarios, see the deliverable reports D2.1 (Næss et al., 2021) and D2.3 (Abid et al., 2021). All the scenarios are built on top of the same reference model of the current transport system in the EU28 (see the D2.3 deliverable report). The scenarios are compared by final energy demand, i.e. the energy consumption of the end-user, hence without the consideration of fuel production energy losses.

The strategies and measures for which impacts on transportation energy use in the scenarios were assessed include urban spatial development, transportation infrastructure development, economic instruments and other policy measures affecting transportation activities, and the energy-efficiency of vehicle technologies. As shown in Figure 1.1, there are important interrelationships between the various measures, where the feasibility of some of the measures may depend on the implementation of some of the other measures.

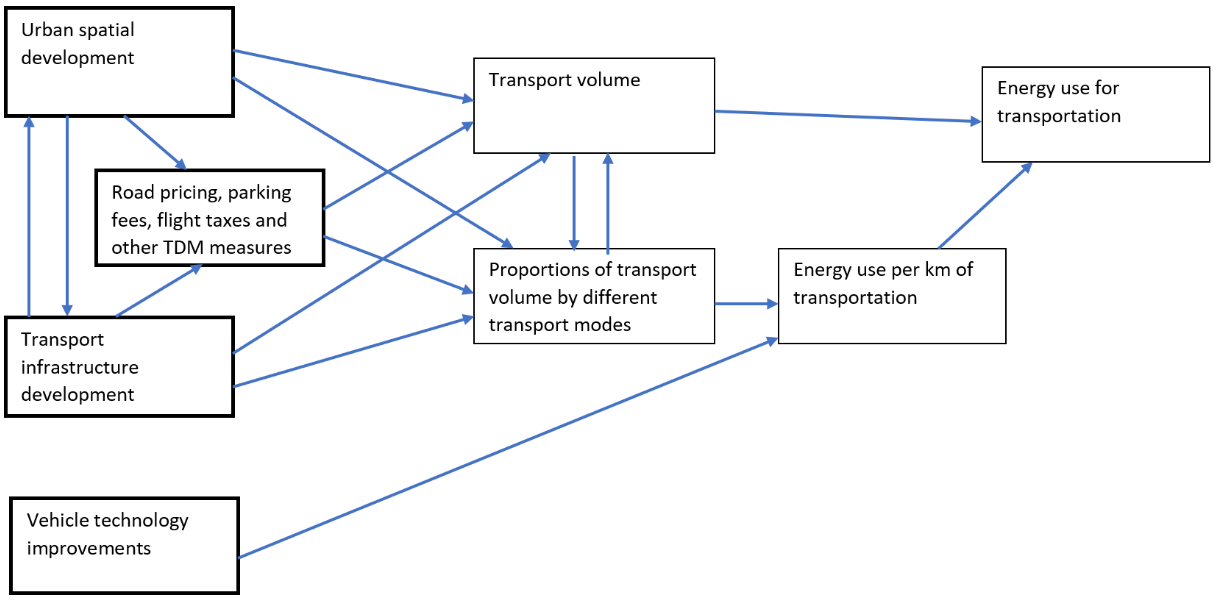

Figure 1.1: Main measures (shown with bold outlines) included in the Energy-efficiency scenario, and their direct and indirect effects on transportation energy use. The abbreviation TDM signifies transportation demand management.

Energy use for transportation is determined by the transport volume (i.e. the distance that persons and goods is transported) and the energy used to transport persons and goods a given distance. The latter depends on the modes of transportation chosen (for example, metros use less energy to transport a person a kilometer than private cars do) and the energy efficiency of each mode of transportation. Transport volumes and the proportions of transport carried out by different modes of transportation are influenced by several causes, but urban spatial development, transport infrastructure development, economic instruments and other policy measures affecting transportation activities have all been identified in the research literature as important. The energy efficiency of each mode of transportation is mainly influenced by how energy efficient the vehicles are, but it also depends on the capacity utilization of each mode of transportation, which can be influenced by some of the other measures shown in the figure.

Table 1.1 provides an overview of the key characteristics of the Business-as-usual and the Energy-efficiency scenarios. The contents of the scenarios will be described somewhat more in detail in Sections 2.2 and 2.3.

Table 1.1: Key characteristics of the Business-as-usual and Energy-efficiency scenarios.

Changes over the period 2020-2050	Business-as-usual	Energy-efficiency
Urbans spatial development	Continuation of trends 2000-2015	Strong densification Reduced residential distance to center
Highway capacity increase	According to the proposed Trans-European Road Network + other motorway construction	None
Airport construction	To accomodate growth	None
Railroad construction	According to INEA (2020)	Intensified in urban regions
Road pricing and parking fees	Very limited	Extensive urban schemes
Flight taxes	Very limited	High taxes
Vehicle energy efficiency technology	According to the European Commission’s Baseline 2050 scenario	Intensified electrification beyond the Baseline 2050 scenario, especially for road transportation.

2.1 The Business-as-usual scenario

2.1.1 Urban spatial development

In the Business-as-usual scenario, a continuation towards 2050 of the trends from the last fifteen years of the historical period for which data were available was presupposed, i.e. from the years from 2000 to 2015. The quantifications of energy impacts were based on the assumed changes in urban population density and residential distance to the main center of the urban region, calculated for regions belonging to different population size classes and corners of Europe. In some countries, especially in Northern Europe, a trend of densification had already started (primarily in the larger cities) and was supposed to continue in the Business-as-usual scenario. In several other countries, especially in Eastern Europe, urban development was dominated by outward spatial expansion, which was assumed to continue toward 2050. Intra-metropolitan transport volumes and the shares of different modes of transportation are also heavily influenced by workplace location, but due to lack of data this could not be included in the calculations (see the D2.1 report). The effect of workplace location is still assumed to be to some extent accounted for through the urban population density variable.

2.1.2 Transportation infrastructure development

The Business-as-usual scenario involves a continuation of motorway development in line with the Comprehensive program for the Trans-European Transport Network (TEN-T). In addition, this scenario assumes continued construction of motorways in settings not included in the TEN-T program, notably in urban regions but also in non-urban areas, and capacity increase of already existing motorways. The Business-as-usual scenario also includes airport development deemed necessary to accommodate (pre-Corona) projections for air traffic to and from European destinations. Railroad construction in the Business as usual scenario is assumed to take place according to INEA (2020) plans.

2.1.3 Economic and other policy instruments influencing transportation activity

In the Business-as-usual scenario, no urban road tolling or road pricing schemes (beyond those already existing in a few cities) and no substantial parking fee increases are presupposed. Also, no other policy measures to restrict energy intensive and/or favor energy-favorable forms of transportation are implemented.

2.1.4 Vehicle technology development

The Business-as-usual scenario includes, in line with the European Commission's Baseline 2050 scenario, the implementation of a large share of electric vehicles in the passenger vehicle fleet, hybrid vehicles in road freight transport, and significant electrification of the EU28 railway network. The Business-as-usual scenario includes no additional measures to increase electrification rates or use climate-wise more favorable technologies or energy carriers.

2.2 Measures in the Energy-efficiency scenario

The Energy-efficiency scenario includes a combination of the following strategies and measures: energy-efficient spatial urban development, halt in motorway construction, halt in airport expansions, improved infrastructure for walking and cycling, economic instruments for transportation demand management, other demand management measures, and energy-efficient vehicle technology.

2.2.1 Energy-efficient urban spatial development

Based on state-of-the-art research into influences of built environment characteristics on travel and transportation energy use, the D2.1 deliverable report points at dense and concentrated urban development as the transportation-wise most energy-efficient urban spatial development[1]. In the energy efficiency scenario, nearly all new buildings (apart from place-bound non-urban buildings such as farmhouses, buildings for local resource processing e.g. in quarries, mining or aquaculture, tourist facilities, etc.) are constructed within existing urban area demarcations, i.e. no spatial expansion of the morphological cities takes place except in a very few cities with very high population density in 2015 and projected future population growth, where some urban spatial expansion is allowed. Moreover, the mean residential distance to the center of the main city of each urban region is assumed to be reduced by 10%, except a slight adjustment for a very few cities with very high population density in 2015. A similar reduction in the average distance to the city center is also assumed for workplaces (yet varying across job types), but the effect of this on transportation energy use was not calculated in the scenario.

2.2.2 Energy-efficient transportation infrastructure development

Based on state-of-the-art research into influences of transportation infrastructure characteristics on travel and transportation energy use, the D2.1 deliverable report points at replacement of motorway construction and airport expansions with surface transit improvements in urban regions as the most energy-efficient way of future transportation infrastructure development[2]. The Energy-efficiency scenario includes none of the motorway construction assumed in the Business-as-usual scenario. Concerning road infrastructure development, the energy saving potential of the Energy-efficiency scenario is thus due to its absence of induced traffic resulting from the motorway construction presupposed in the Business-as-usual scenario. Moreover, in the Energy-efficiency scenario, no airport expansion to facilitate increased air traffic is presupposed to take place. Instead, intensified construction and upgrading of intra-metropolitan rail lines is included in this scenario. The Energy-eficiency scenario also includes considerably improved infrastructure for walking and cycling (effects not quantified) beyond the improvements that might take place in the Business-as-usual scenario.

2.2.3 Economic instrument for transportation demand management

According to basic economic theory, the demand for a good tends to be reduced if its price increases. Taxes and fees on different aspects of transportation therefore tend to suppress some of the demand for the affected modes of transportation in the contexts where the taxes and fees apply[3]. The energy efficiency scenario includes the use of road pricing in metropolitan areas, with taxes differentiated between the morphological city and the remaining parts of a metropolitan area, and between urban regions differing in the population size of their main morphological city. Similarly, parking fees in downtown and inner-city areas are included, differentiated between large, medium-sized and smaller cities. Moreover, taxation and other relevant regulations are applied in the Energy-efficiency scenario to an extent sufficient to keep air travel volumes at the present level. Among the transportation demand management measures included in the Energy-efficiency scenario, road pricing/tolls in urban regions and flight taxes are estimated to have the greatest effects on energy use, whereas parking fees in urban areas plays a lesser role (although important for improving local environmental qualities).

2.2.4 Other measures for transportation demand management

The Enery-efficiency scenario also includes several other policy measures to influence transportation activities, such as car-sharing, privileged lanes for energy-efficient vehicles, etc. The energy-saving effects of such measures were not quantified in the scenario.

2.2.5 Energy-efficient vehicle technology

The energy efficiency of different kinds of propulsion engines can be improved, but overall, a shift from combustion engines to electric engines offers the highest energy gains[4]. Such change also gives the greatest improvements in terms of reduced emissions (particularly locally) and noise. The Energy-efficiency scenario includes five sub-scenarios for vehicle energy-efficiency improvements: Biofuels, Hydrogen, Electrification and e-fuels, Electrification +, and 1.5 TECH. All the sub-scenarios are built on top of the zero-emissions transport technologies already implemented in the Business-as-usual scenario. Among the five sub-scenarios, we have in the present report chosen to apply the Electrification + scenario, which is the one showing the greatest benefits in terms of energy savings as well as in reduction of CO_2 emissions. In the Electrification + scenario, 95% of all passenger cars, buses, and vans in the EU28 are converted to battery-electric vehicles, whereas for road freight transport, 27% is converted to battery-electric vehicles and the remaining 73% to battery-electric vehicles with smaller onboard batteries with on-road charging support from Electric Road Systems. Moreover, it is assumed that it is possible to electrify all national air transport, while 35% of intra-EU aviation is estimated to be electrified by 2050.

3 Additional impacts of the Energy-efficiency scenario

3.1 Aditional impacts of energy-efficient spatial urban development

3.1.1 Environmental impacts

We have identified the following main environmental impacts of transportation-wise energy-efficient spatial urban development in addition to the environmental gains resulting from a lower need for production and transmission of energy.

Substantial impacts:

- Reduced conversion of natural areas and farmland into building sites
- Preserving areas for hiking, skiing and other kinds of outdoor recreation that needs large and continuous non-developed areas
- Reduced greenhouse gas emissions

Considerable impacts:

- Increased pressure against intra-urban green areas and other open space
- Reduced material consumption for infrastructure and buildings
- Reduced energy requirement for space heating and cooling

Moderate or ambiguous impacts:

- Increased pressure to demolish heritage buildings
- Reduced overall emission of other pollutants (but increased concentration of emissions)
- Reduced overall noise from traffic (but possibly more people being exposed to noise)
- Increased vulnerability to climate change
- Possible rebound effects

Reduced conversion of natural areas and farmland into building sites

The Energy-efficiency scenario has a positive impact in terms of reduced conversion of natural areas and farmland into building sites. We estimate this effect to be substantial. Nature conservation is an important part of environmental policy in most countries. This is not primarily about emissions, but reduced conversion of natural areas is also favorable from a climate change mitigation perspective (IPCC, 2019). According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, loss of biodiversity and biologically productive areas is also going on at an alarming speed threatening to create unprecedented hunger and ecological collapses (IPBES, 2019). The urgency of reducing farmland conversion is also emphasized by FAO (2019). Higher density implies more efficient utilization of building sites, which reduces the need for converting new areas into urbanized land. Building closer to the city center normally implies higher densities and is therefore an important part of a land-saving densification strategy (Alonso, 1964; Beatley, 2000; European Environmental Agency, 2006; Næss et al., 2020). We estimate that within the EU/EFTA area, about 8950 km^2 of land conversion in the Business-as-usual scenario[5] over the period 2020-2050 will be avoided in the Energy-efficiency scenario.

Case example: Since the mid-1980s, Oslo metropolitan area and its main urban settlement, the morphological city of Oslo (population in 2020: 1.04 million) has managed to combine high growth in population and building stock and low encroachments on natural and cultivated areas. While the annual consumption of land for urban expansion of the morphological city of Oslo was on average 3.8 km^2 during the period 1955–1985, it was only 0.7 km^2 annually during the period 1985–2020, despite more than twice as high population growth during the latter period (Engebretsen, 1993; Riksrevisjonen, 2007; Statistics Norway, 2020). If the increase in urban area per capita observed in the period 1955-1985 had continued over the period 1985-2020, 239 more km^2 of surrounding natural areas and farmland would have been converted into urban area. This would have implied nearly a doubling of the current area of the morphological city (270 km^2). Oslo's compact urban development has thus reduced the loss of natural areas and farmland substantially, compared to the situation if the sprawling urban development of the period up to the mid-1980s had continued.

Preserving areas for hiking, skiing and other kinds of outdoor recreation that needs large and continuous non-developed areas

The Energy-efficiency scenario has a positive impact in terms of preserving areas for hiking, skiing and other kinds of outdoor recreation that needs large and continuous non-developed areas. We estimate this effect to be substantial. The above-mentioned kinds of outdoor recreation require relatively large areas that usually exist only outside the cities. Dense and concentrated urban development, which reduces urban spatial expansion, thus reduces the pressure for conversion of such areas.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

Reduced greenhouse gas emissions

The Energy-efficiency scenario has a positive impact in terms of reduced greenhouse gas emissions. We estimate this effect to be substantial. Urban development favorable for transportation energy efficiency implies reduced motorized transportation, and particularly reduced car travel. Since motorized transportation is presently mostly based on fossil fuels, such reduction also implies reduced greenhouse gas emissions. Also after a massive change to electric vehicles will such urban development be favorable from a greenhouse gas emission reduction perspective, since electricity in many countries will continue to come, at least partly, from fossil sources, and because the production of electric vehicles and batteries involves fossil energy use. The housing types typical for dense urban development also require less energy for space heating and cooling (see below), which also implies less greenhouse gas emissions. We estimate that within the EU/EFTA area and in the absence of vehicle technology improvement, the reduced energy use for transportation due to the more concentrated urban development in the energy efficiency scenario[6] gives a reduction over the period 2020-2050 of 370 million tons of CO_2, compared to the Business-as-usual scenario (Eurostat, 2020; Næss et al., 2020a; Williams, 2012). Adjusting for vehicle technology improvement (Abid et al., 2021), we estimate the reduction to be 125 million tons. Reduced greenhouse gas emissions due to less energy-requiring housing types come in addition.

Case example: For the morphological city of Oslo (population in 2020: 1.04 million), it has been estimated that energy use for intra-metropolitan transportation would have been 20% higher if the population density had continued to decrease until 2020 like it did 1965-1985 instead of starting to increase as it actually did from the late 1980s (Næss, 2021). Accordingly, the CO_2 emissions from intra-metropolitan transportation would also have been 20% higher if Oslo had continued its sprawling urban development instead of pursuing a strong urban densification policy since the mid-1980s.

Increased pressure against intra-urban green areas and other open space

The Energy-efficiency scenario has a negative impact in terms of increased pressure against intra-urban green areas and other open space. We estimate this effect to be considerable. When new construction is to take place within existing urban area demarcations, there will be a higher demand for intra-urban construction sites and hence a greater pressure against intra-urban green areas (Engelien, Steinnes & Bloch, 2005; Haaland & van den Bosch, 2015). The increased value of land in the central parts of dense cities (Alonso, 1964; Herath & Maier, 2013; Rehák & Káčer, 2019) will increase the pressure on green spaces and other open spaces. Such pressure can still be counteracted by channeling densification to 'gray' areas and 'brownfield' sites.

Case example: Although most of Oslo's urban densification has taken place as transformation of derelict industrial and harbor areas or higher utilization of already built-up sites, it has still had its negative impacts on intra-urban vegetation and ecosystems. Over the five-year period 1999 – 2004, there was a 5% reduction of the open-access areas (defined as areas not including buildings, roads, railroads, quays, farmland, churchyards, sea or major rivers) within the morphological city of Oslo (Engelien, Steinnes & Bloch, 2005). Partly, this was a result of transport infrastructure construction, but green areas also had to yield to new kindergartens or schools in districts where densification caused population growth beyond the capacity of existing social infrastructure. Together with the rapid inner-city population growth, this has diminished the availability of open-access land per resident in these districts (Næss et al., 2020b).

Reduced material consumption for infrastructure and buildings

The Energy-efficiency scenario has a positive impact in terms of reduced material consumption for infrastructure and buildings, with associated environmental gains resulting from a lower need for provision of the relevant materials. We estimate this effect to be considerable. Concentrated building types require less outer surface area (envelopes) of the buildings. In addition, the average number of square meters per dwelling is normally smaller for apartments than single-family houses, and for the same housing type it is usually smaller in the inner city than in the suburbs. Higher density also implies shorter networks of roads pipes, cables, sewers etc. (Jones, 1997; Burchell et al., 1998).

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

Reduced energy requirement for space heating and cooling

The Energy-efficiency scenario has a positive impact in terms of reduced energy requirement for space heating and cooling, with associated environmental gains resulting from a lower need for energy supply. We estimate this effect to be considerable. Housing types associated with high-density areas have smaller outer surface area (envelopes) than detached single-family houses (Høyer & Holden, 2001; Brown & Wolfe, 2007; US Energy Administration Information, 2013). In addition, the average number of square meters per dwelling is normally smaller for apartments than single-family houses, and for the same housing type it is usually smaller in the inner city than in the suburbs. The latter reflects that the higher prices in central, high-density areas tend to make residents opt for smaller apartments.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases[7].

Increased pressure to demolish heritage buildings

The Energy-efficiency scenario has a negative impact in terms of increased pressure to demolish heritage buildings. We estimate this effect to be moderate. Many heritage buildings exist in inner and central urban districts and are relatively low-rise. Strong densification ambitions implies an increased pressure to replace such buildings with higher-density development (Skrede & Berg, 2019).

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

Reduced overall emission of other pollutants (but increased concentration of emissions)

The Energy-efficiency scenario has an impact in terms of reduced overall emission of pollutants other than greenhouse gases, but increased concentration of emissions. We estimate this effect to be ambiguous. Because of reduced traffic volume, overall emission of air pollutants will be reduced. This is also the case after electrification of vehicles, since parts of the pollution is from wear and tear of tires and asphalt. However, in dense cities more of the traffic takes place within a smaller area, and inner-city densification can increase the number of residents exposed to air pollution (unless restrictions on car use are implemented). (Cho & Choi, 2014.)

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

Reduced overall noise from traffic (but possibly more people being exposed to noise)

The Energy-efficiency scenario has an impact in terms of reduced overall noise from traffic (but possibly more people being exposed to noise). We estimate this effect to be ambiguous. Because of reduced traffic volume, overall level of noise from traffic will be reduced. This is also the case after electrification of vehicles, since parts of the noise is from the wheels, not the engine. However, in dense cities more of the traffic takes place within a smaller area, and more residents may be exposed to noise as a result of inner-city densification (Noise in EU, 2021) unless restrictions on car use are implemented.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

Increased vulnerability to climate change

The Energy-efficiency scenario has an impact in terms of increased vulnerability to climate change. We estimate this effect to be moderate and partly ambiguous. Urban densification in old harbor or industrial waterfront areas may conflict with the need to avoid flood-prone building sites. Densification can also reduce the amount of intra-urban pervious surfaces and thus reduce the resilience against heavy rainfall. Moreover, densification can increase the number of people exposed to the urban heat island effect, which can pose a health threat especially in warm countries. The urban heat island effect as such can, however, be higher with sprawl than with densification, especially if the city is surrounded by forests. (Carter, 2011; Matthews et a., 2015; Vuckovic et al., 2019; Shreevastava et al., 2019; Ogle & Seong, 2012.)

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

Possible rebound effects

The lower use of cars resulting from the more dense and concentrated urban development in the Energy-efficiency scenario may, according to some studies (Holden & Norland, 2005; Ottelin et al., 2014) lead to rebound effects (Jevons, 1866; Santarius et al., 2016) causing negative impacts on several environmental parameters. Money saved from less car-driving and possibly also reduced car ownership can instead be spent on long leisure trips, for example flights to distant parts of the world. Such effects will then counteract some of the gains in energy saving and greenhouse gas emissions reduction. It has also been stated that inter-city dwellers tend to compensate for lack of greenery in their residential environments by going on more long-distance car trips to natural areas in weekends and holidays, for example to second homes. Studies so far show little evidence for the 'compensation' hypothesis, but some rebound effect due to money-saving from lower car-dependency appears plausible (Næss, 2016; Czepkiewicz et al., 2020.) We estimate this effect of energy-efficient urban spatial development to be moderate.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

3.1.2 Social impacts

We have identified the following main social impacts of transportation-wise energy-efficient spatial urban development.

Substantial impact:

- Accessibility for residents who are unable to drive

Considerable impacts:

- Easier access to jobs and service facilities
- Reduced travel time and easier daily-life schedule
- Urban vibrancy
- Housing affordability
- Impacts on housing quality
- Reduced investment and operational costs for infrastructure

Moderate or ambiguous impacts:

- Health impacts
- Agglomeration benefits

Accessibility for residents who are unable to drive

The Energy-efficiency scenario has a positive impact in terms of better accessibility for residents who are unable to drive cars. We estimate this effect to be substantial. Because dense cities can facilitate better transit provision and more potential trip destinations will be within acceptable walking or biking distance, dense and concentrated urban development increases the accessibility to relevant facilities by travel modes other than the private car (Litman, 2020).

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

Easier access to jobs and service facilities

The Energy-efficiency scenario has a positive impact in terms of easier access to jobs and service facilities. We estimate this effect to be considerable. Because the concentration of jobs and service facilities is usually higher in the central parts of a city or metropolitan area, high overall density and a high proportion of the population living close to the city center will decrease people's average distance to these facilities. Job densification in central areas will at the same time increase the number of jobs easily accessible by transit and non-motorized modes. (Levine et al., 2012.) Given the hitherto dominating gender roles in travel behavior and caretaking responsibilities, the above accessibility gains appear particularly beneficial in terms of increasing women's range of job opportunities and available choices for services and other non-work facilities (Næss, 2008).

We do not consider it possible to quantify these impacts at either the EU/EFTA scale or for individual city cases.

Reduced travel time and easier daily-life schedule

The Energy-efficiency scenario has a positive impact in terms of reduced travel time and easier daily-life schedule. We estimate this effect to be considerable. Because distances to daily destinations are shorter, travel time tends to be somewhat shorter in dense cities, despite higher shares of slow travel modes. Especially for those who do not always have a private car at their disposal, travel times will be shorter and the possibility to cope with time-geographical constraints will be easier. (Hägerstrand, 1970; Levine et al., 2012; Næss, 2006; Næss et al., 2018.)

We do not consider it possible to quantify these impacts at either the EU/EFTA scale or for individual city cases.

Urban vibrancy

The Energy-efficiency scenario has a positive impact in terms of higher urban vibrancy. We estimate this effect to be considerable. The inner parts of cities are usually considered the most vibrant ones, both because of their concentration of cultural arenas, restaurants, bars and specialized stores, as well as for the high number of people working, visiting and living in these areas and passing through on the streets on their way to activities. Dense and concentrated urban development will enhance this vibrancy and also increase the number of inhabitants that experience it. (Jacobs, 1961; Pløger, 2002; Rypkema, 2003; Mouratidis, 2017.)

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

Housing affordability

The Energy-efficiency scenario has a negative impact in terms of lower housing affordability. We estimate this effect to be considerable. Due to the high land value at central locations, housing prices tend to be higher in these areas, and dwelling tend to become less affordable. In some way this has to do with the lower transportation costs when living or doing business in these areas, cf. bid-rent theory (Alonso, 1964). Densification in inner-city areas thus increases the proportion of dwellings located in the high-cost areas. Especially under neoliberal conditions and when inner-city living is popular, densification may lead to lower housing affordability (Cavicchia, 2021).[8]

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

Housing quality

The Energy-efficiency scenario has a negative impact on housing quality, judged from traditional functionalist architectural criteria. We estimate this effect to be considerable, although ambiguous when taking also other residential preference criteria into consideration. The taller buildings, higher plot utilization and the smaller dwelling size typical for inner-city densification tend to reduce housing quality measured by indicators traditionally emphasized by (functionalist) architects (floor area size, sunlight, greenery) (Schmidt, 2007 and 2014; Bournas et al., 2017). Densification in single-family house areas also tends to reduce the size of gardens. On the other hand, the very high prices of inner-city apartments suggest that many people consider proximity to urban facilities as at least equally important elements of housing quality as architects' traditional criteria (Sjaastad et al., 2007).

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

Reduced investment and operational costs for infrastructure

The Energy-efficiency scenario has a positive impact in terms of reduced investment and operational costs for infrastructure. We estimate this effect to be considerable. Higher density implies shorter networks of roads pipes, cables, sewers etc., which means lower material and labor costs for construction of these structures. Moreover, to the extent that densified buildings can use existing infrastructure without exceeding their capacity, densification can eliminate some need for infrastructure construction (Burchell et al., 1998). The same applies if the existing infrastructure in a densification area anyway needs to be replaced because it is substandard or worn out. On the other hand, improved urban transit infrastructure (especially metro tunnels), which is sometimes triggered by densification, may be very costly.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

Health impacts

The Energy-efficiency scenario has various health impacts. We estimate each of these effects to be considerable, but since they are partly counteracting each other, the overall health effect is ambiguous and most likely moderate. Dense and concentrated urban development implies that more people will be living in areas where many daily-life trip destinations can be reached on foot or by bike from the dwelling. By facilitating more physically active travel, this has a positive health effect. People also less often need to make long and tiresome commuting (Hansson et al., 2011; Stefansdottir et al., 2018; Ihlebæk et al., 2020). On the other hand, those who do not get exercise through daily-life travel seem to compensate this, at least partly, through more of other forms of physical activity. Access to green area for outdoor recreation is usually easier in the suburbs (Hartig, 2014) . Inner-city residents are also more exposed to concentration of air pollution and noise (Beenackers et al., 2018; Haigh et al., 2011) and probably also disease spreading (e.g. on public transit and in crowded streets). However, the exposure of inner-city residents to air pollution and noise is likely to be reduced as fossil-energy vehicles are replaced with electric vehicles. Inner-city traffic calming and zero-emission zones will also reduce such negative effects of inner-city living.

We do not consider it possible to quantify this impact at the EU/EFTA scale.

Case example: A study of residential location, travel, physical activity and health in Oslo metropolitan area found that respondents living 1 km from the city center tended to spend around 80 min more per week (corresponding to 70% more time) on non-motorized travel than persons living 21 km from the city center (Stefansdottir et al., 2018). However, when including all forms of moderate as well as vigorous physical activity, the study showed a slight tendency of more time spent on physical activity among residents of low-density than high-density areas, with no separate effect of residential distance to the city center. Non-travel-related physical activity among suburbanites seemed to slightly outweigh higher levels of non-motorized travel among inner-city residents. Oslo respondents living in an area where the population density is 20 persons per hectare thus tended to spend slightly above half an hour more per week (corresponding to 6% more time) on physical activity of moderate or vigorous intensity than those living in an area where the population density is 120 persons per hectare (Stefansdottir et al., 2018). However, living close to the city center still appeared to contribute to better self-reported general health (p=0.008), whereas high local-area density showed a slight opposite association. The results suggest that while inner-city dwellers are more exposed to air pollution and noise, they travel more by physically active modes, avoid time-consuming and dissatisfactory commutes, and might benefit from more social arenas (Ihlebæk et al., 2020).

Agglomeration benefits

The Energy-efficiency scenario probably has a positive impact in terms of economic agglomeration benefits. We estimate this effect to be moderate and possibly ambiguous. By increasing the proximity between businesses, dense and concentrated urban development creates advantages of being located close to other businesses in the same branch. Such advantages include the cost reductions of utilizing each other's competencies, as well as more qualitative relations in the form of informal contact between the companies (Christaller, 1966; Vatne, 1993; Cervero, 2001; Chorianopoulos et al., 2010). But 'edge cities' can also provide some agglomeration effects (Jarreau, 1991).

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

3.2 Aditional impacts of halt in motorway construction

3.2.1 Environmental impacts

We have identified the following main environmental impacts of halt in motorway construction in addition to the environmental gains resulting from a lower need for production and transmission of energy.

Substantial impacts:

- Reduced conversion of natural areas and farmland into road construction sites
- Reduced greenhouse gas emissions
- Reduced noise, air pollution and pollution of watercourses, soil and groundwater

Considerable impacts:

- Preserving areas for hiking, skiing and other kinds of outdoor recreation
- Reduced material consumption for infrastructure
- Increased conversion of natural areas and farmland and material consumption for railroad construction

Moderate impact:

- Reduced pressure to demolish heritage buildings

Reduced conversion of natural areas and farmland into road construction sites

The Energy-efficiency scenario has a positive impact in terms of reduced conversion of natural areas and farmland into motorway construction sites. We estimate this effect to be substantial. Motorway construction requires considerable deforestation, loss of farmland or loss of other nature types such as bogs and meadows. Motorways also entail disturbances on wildlife and ecosystems in surrounding areas. By abstaining from motorway construction, these losses are avoided. (Næss et al., 2020; Seiler, 2003; EU DG Environment, 2018; European Commission, 2018; Alexander, 1999.) We estimate that within the EU/EFTA area, about 4400 km^2 of the land conversion over the period 2020-2050 resulting from motorway construction in the Business-as-usual scenario[9] will be avoided.

Case example: According to the impact analysis of the 21 km long four-lane motorway project Knapstad – Vinterbro in southeastern Norway, the construction of the new road would require the conversion of 41 hectares of forests and 39 hectares of farmland, totaling 80 hectares (Statens vegvesen region øst, 2008). This implies a conversion per km of new four-lane road of 3.8 hectares.

Reduced greenhouse gas emissions

The Energy-efficiency scenario has a positive impact in terms of reduced greenhouse gas emissions. We estimate this effect to be substantial. By abstaining from motorway construction, the induced traffic resulting from such construction can be avoided, and thus also the greenhouse gas emissions resulting from this traffic (Næss et al. (2020), Litman, 2021a). Also after a possible full electrification of the vehicle fleet, the induced traffic would entail climate impacts, since it will probably take a long time before all electricity is produced from sources not causing any greenhouse gas emissions (Williams, 2012). The production of the vehicles and the road construction also generates greenhouse emissions that will be avoided if motorway construction is halted. Moreover, new motorways often imply encroachments on forests or bogs where the construction process reduces sequestering capacity and/or releases carbon (Honningsøy & Solvang, 2020). This too will be avoided if the proposed roads are not built.

We estimate that within the EU/EFTA area and in the absence of vehicle technology improvement, the reduced energy use for transportation due to halt in motorway construction[10] gives a reduction over the period 2020-2050 of 1400 million tons of CO_2, compared to the Business-as-usual scenario. Adjusting for vehicle technology improvement, the reduction is 480 million tons. Avoiding reduced sequestering capacity and carbon release comes in addition.

Reduced noise, air pollution and pollution of watercourses, soil and groundwater

The Energy-efficiency scenario has a positive impact in terms of reduced noise, air pollution and pollution of watercourses, soil and groundwater. We estimate this effect to be substantial. Although motorway construction can in some cases lead to an immediate reduction in traffic congestion, such reductions are most often only temporary, since motorway expansion in congested areas induces additional traffic causing congestion to build up again (Mogridge, 1997; Noland & Lem, 2002; Litman, 2021a). The additional traffic will also increase traffic nuisances on smaller roads that the vehicles must use before entering and after exiting the motorway. It is true that some bypass roads reduce people's exposure to noise and pollution. In particular, bypasses in the form of tunnels can have considerable positive such effects - but if they at the same time increase the overall road capacity and driving speeds, they will normally induce additional traffic. By inducing additional traffic, motorway construction increases traffic noise as well as air pollution from non-electric vehicles.

Motorway construction also causes pollution of watercourses, soil and groundwater during the construction process and maintenance (National Roads Authority (Ireland), 2008; Alexander, 1999). Wear and tear of tires and asphalt come in addition. Moreover, people living close to the construction sites are exposed to noise, dirt and vibrations. When abstaining from motorway construction, these negative impacts are avoided.

We do not consider it possible to quantify any of these impacts at either the EU/EFTA scale or for individual infrastructure project cases.

Preserving areas for hiking, skiing and other kinds of outdoor recreation

The Energy-efficiency scenario has a positive impact in terms of reduced encroachments on areas for hiking, skiing and other kinds of outdoor recreation. We estimate this effect to be considerable. By abstaining from motorway construction, area loss, fragmentation and noise caused by such road construction in outdoor recreation areas are avoided (Teigland, 1999; Ivehammar, 2006. National Roads Authority (Ireland), 2008).

We do not consider it possible to quantify these impacts at either the EU/EFTA scale or for individual infrastructure project cases.

Reduced material consumption for road infrastructure and vehicles

The Energy-efficiency scenario has a positive impact in terms of reduced material consumption for road infrastructure. We estimate this effect to be considerable. Motorway construction includes large consumption of materials, for example asphalt, steel (for rails, lampposts, signs etc.), concrete (for bridges and tunnels), etc. (Sullivan, 2006). This consumption of materials will be avoided if motorway construction is halted. The indirect effect of materials saved from fewer vehicles being constructed as a result of lower road traffic volumes comes in addition.

We do not consider it possible to quantify these impacts at either the EU/EFTA scale or for individual infrastructure project cases.

Reduced pressure to demolish heritage buildings

Halt in motorway construction implies a reduced risk that heritage buildings willl be affected by highway construction. However, motorway construction most often takes place outside the areas where there are many heritage buildings, and therefore it does not seem likely that a very high number of heritage buildings would be affected by the motorway construction of the Business-as-usual scenario. We therefore estimate the reduced pressure against heritage buildings due to the Energy-efficiency scenario's halt in motorway construction to be moderate.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual infrastructure project cases.

3.2.2 Social impacts

We have identified the following main social impacts of a halt in motorway construction. Apart from the reduction of investment and operational costs for transportation infrastructure, which will be substantial, we estimate all the social effects of a halt in motorway construction to be rather moderate and/or to have impacts counteracting each other, resulting in in small net effects.

- Reduced investment and operational costs for transportation infrastructure
- Impacts on traffic accidents
- Avoiding several negative social impacts pertaining to the construction period
- Avoiding reduced competitiveness for transit

- Reduced region enlargement
- Impacts on travel time

Impacts on traffic accidents

The Energy-efficiency scenario has a positive impact in terms of reduced traffic accidents, especially fatalities. We estimate this impact, which is the net effect of partially counteracting mechanisms, to be moderate. Proponents of motorway construction (and many cost-benefit analyses as well) claim accidents will be reduced because of fewer crossings, but induced traffic (which also takes place on smaller roads before and after driving on the motorways) and higher speed pull in the opposite direction (Næss, 2011 and 2020). Stop in motorway construction will avoid these effects.

We do not consider it possible to quantify these impacts at either the EU/EFTA scale or for individual infrastructure project cases.

Reduced investment and operational costs for transportation infrastructure

The Energy-efficiency scenario has a positive impact in terms of reduced investment and operational costs for road infrastructure. We estimate this effect to be substantial. Given an average cost of motorway construction in the EU of 760,000 Euro per km in 2005 (Doll & Van Essen, 2008) and an estimated increase in road construction costs per kilometer of 63% from 2005 to 2020 (Statistics Norway, 2021a), the 95,000 km of motorways constructed from 2020 to 2050 in the Business-as-usual scenario would require the spending of about 120 billion Euro for this road construction, which will be saved in the Energy-eficiency scenario. Operational and maintenance costs come in addition.

We do not consider it possible to quantify the combined impact for road and rail infrastructure at either the EU/EFTA scale or for individual infrastructure project cases.

Avoiding reduced competitiveness for transit

The Energy-efficiency scenario has a positive impact in terms of avoiding reduced competitiveness for transit. We estimate this effect to be moderate. Motorway construction strengthens the attractiveness of car travel and thus reduces the competitiveness of transit, leading to reduced transit provision and reduced accessibility for residents who are unable to drive (Mogridge, 1997).

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual infrastructure project cases.

Avoiding several negative social impacts pertaining to the construction period

The Energy-efficiency scenario has a positive impact in terms of avoiding several negative social impacts pertaining to the construction period of motorways. We estimate this effect to be moderate. Halt of motorway construction implies that the negative impacts (such as consequences for traffic on existing networks, disadvantages for local businesses, and social disruption of neighbourhoods due to the influx of a temporary population of people working on the projects) pertaining to the construction of motorways will be avoided (Næss et al., 2017b).

We do not consider it possible to quantify these impacts at either the EU/EFTA scale or for individual infrastructure project cases.

Reduced region enlargement

The Energy-efficiency scenario counteracts the region enlargement resulting from the construction of motorways. We estimate the social consequences of this effect to be ambiguous. Region enlargement implies a larger base for employers to recruit the best qualified employees and opens possibilities or workers to search for jobs within a large radius (Engebretsen & Gjerdåker, 2012). But it also reduces the possibility for local residents to get employment at local companies, since such jobs may be occupied by employees living far away (Næss et al., 2017). Stop in motorway construction counteracts these effects.

We do not consider it possible to quantify these impacts at either the EU/EFTA scale or for individual infrastructure project cases.

Impacts on travel time

The impacts on travel time from the Energy efficiency sceario's halt in motorway construction are ambiguous. In cost-benefit analyses, motorway construction is normally presupposed to generate substantial travel time savings due to higher speed caused by fewer crossings and bends, wider driving lanes, higher speed limits and congestion relief. Such savings usually make up the largest item on the benefit side of the assessment. However, such analyses usually do not take induced traffic fully into account, and sometimes not at all. Induced traffic implies longer travel distances as well as changes in modal split towards higher shares of car travel, which both increase traffic density and contribute to congestion arising anew. Both the tendency toward arising congestion and longer travel distances will counteract the initial time savings (Mogridge, 1997; Litman, 2021a; Metz, 2008; Banister, 2011; Næss et al., 2017b).

We do not consider it possible to quantify these impacts at either the EU/EFTA scale or for individual infrastructure project cases.

3.3 Additional impacts of intensified urban rail and metro construction

3.3.1 Environmental impacts

We have identified the following environmental impacts of intensified urban rail and metro construction, apart from the environmental gains resulting from a lower need for production and transmission of energy. We estimate all these effects to be rather moderate.

- Reduced air pollution
- Increased material consumption for infrastructure construction
- Increased conversion of natural areas and farmland for railroad construction
- Increased pressure to demolish heritage buildings
- Reduced greenhouse gas emissions

Reduced air pollution

Construction of improved urban rail and metro systems will enable more frequent departures and more fine-meshed networks that reduce average walking distances to stops. Door-to-door travel times by transit will thus be reduced and the travel time ratio between transit and car will become more favorable for transit. Together with other upgrading of the transit system, this will increase transit's competitiveness compared to car travel and contribute to a higher share of travelers opting for transit as their travel mode (Mogridge, 1997; Næss et al., 2001; Engebretsen et al., 2015). The ensuing reduction in car driving will contribute to reduced air pollution. However, since the level of urban car traffic in the Energy-efficiency scenario has already been suppressed through halt in motorway construction, road pricing and heightened parking fees, the main effect of the improved transit provision will be to provide mobility and accessibility opportunities for non-drivers (see below about social impacts). People living close to the construction sites will also be exposed to noise, dirt and vibrations. The separate effect of urban rail and metro construction on air pollution levels is therefore estimated to be moderate (although such transit improvement is probably a condition for the political possibility of halting motorway construction and implementing high road pricing and parking fees).

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual infrastructure project cases.

Increased material consumption for infrastructure construction

Railroads and metro lines are the most material-intensive forms of transit infrastructure, and the intensified construction of railroads and metro lines in thus requires increased consumption of construction materials. However, since the intensified railroad and metro construction in the Energy-efficiency scenario is restricted to metropolitan areas, the ensuing material consumption will be considerably smaller than the material consumption for motorway construction in the Business-as-usual scenario. We therefore estimate the increased material consumption for railroad and metro construction in the Energy-efficiency scenario to be moderate. The indirect material consumption for constructing a larger number of trains required for higher rail and metro traffic volumes comes in addition.

We do not consider it possible to quantify these impacts at either the EU/EFTA scale or for individual infrastructure project cases.

Increased conversion of natural areas and farmland for railroad and metro construction

Apart from underground sections of the lines, the construction of railroad and metro lines requires that land is converted to make space for these installations. Some of this land will be natural areas or farmland (Seiler, 2003; EU DG Environment 2018). Although such construction entails similar kinds of encroachments as motorway construction, the magnitude (in terms of length of the infrastructure as well as its width) will be substantially smaller than for the motorway construction of the Business-as-usual scenario. Since the intensified railroad and metro construction in the Energy-efficiency scenario is restricted to metropolitan areas, we thus consider the conversion of natural areas and farmland resulting from such constructionto be moderate.

We do not consider it possible to quantify these impacts at either the EU/EFTA scale or for individual infrastructure project cases.

Increased pressure to demolish heritage buildings

Especially for the parts of the non-underground railroad and metro construction taking place within existing built-up areas, there is a risk that heritage buildings may be affected. We do, however, consider the increased pressure against heritage buildings due to intensified urban railand metro construction to be very moderate.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual infrastructure project cases.

Reduced greenhouse gas emissions

By reducing intra-metropolitan car traffic and its related emissions, intensified urban rail and metro construction also contributes to reducing greenhouse gas emissions from car traffic. As discussed in Sections 3.1 and 3.2, such reductions will also apply after electrification of the car fleet, although the difference in greenhouse gas emissions resulting from a given difference in car traffic will decrease with increasing degree of car fleet electrification. On the other hand, the construction of railroads and metros is energy-intensive and leads to considerable greenhouse gas emissions per km of line construction, especially for underground sections of the lines (which tends to make up a high proportion in urban contexts). It still seems plausible that the ability of improved metro and urban rail services to attract travelers who would otherwise go by car will cause a larger reduction in CO_2 emissions than the CO_2 emissions resulting from building and operating these new rail lines. We do, however, estimate the net impact of intensified urban railroads and metro construction on greenhouse gas emissions to be only moderate.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual infrastructure project cases.

Reduced land area needed for car parking

By inducing travelers to change their travel mode from car to transit, the need for parking space will be reduced. By using less area for parking, more space will be available for intra-urban green areas or construction of new buildings. We consider this effect to be moderate. By making additional space available for densification, transit improvement also increases the densification potential somewhat.

3.3.2 Social impacts

We have identified the following main social impacts of intensified urban rail and metro construction.

Substantial impacts:

- Improved competitiveness of urban and metropolitan transit

Considerable impacts:

- Improved accessibility for residents who are unable to drive
- Reduced travel time and easier daily-life schedule
- Easier access to jobs and service facilities
- Increased investment and operational costs for infrastructure

Moderate impacts:

- Reduced traffic accidents
- Social impacts pertaining to the construction period

Improved competitiveness of urban and metropolitan transit

Construction of improved urban rail and metro systems will enable more frequent departures and more fine-meshed networks that reduce average walking distances to stops. Door-to-door travel times by transit will thus be reduced and the travel time ratio between transit and car will become more favorable for transit. Together with other upgrading of the transit system, this will increase transit's competitiveness compared to car travel (Mogridge, 1997; Næss et al., 2001; Engebretsen et al., 2015). We consider this effet to be substantial.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual infrastructure project cases.

Improved accessibility for residents who are unable to drive

The intensified urban rail and metro construction of the Energy-efficiency scenario has a positive impact in terms of better accessibility for residents who are unable to drive (Litman, 2020). We estimate this effect to be considerable.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

Reduced travel time and easier daily-life schedule

The intensified urban rail and metro construction of the Energy-efficiency scenario reduces travel time for transit passengers and makes the daily-life schedule easier especially for those population groups that depend on transit travel to reach daily or regular intra-metropolitan destinations. We estimate this effect to be considerable.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

Increased investment and operational costs for infrastructure

The intensified urban rail and metro construction of the Energy-efficiency scenario implies increased investment and operational costs for infrastructure.

Although improved railroad and metro infrastructure is usually very costly per km of new line, the magnitude of such construction will be substantially lower than the amount of mororway construction in the Business-as-usual scenario that will be avoided in the Energy-efficiency scenario. We therefore estimate the increased investment and operational costs for urban rail and metro contruction in the Energy-efficiency scenario to be "considerable" instead of"substantial".

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

Reduced traffic accidents

By contributing to reduced levels of car traffic in metropolitan areas, the intensified construction of urban rail and metro infrastructure of the energy-efficiency scenario is likely to result in some reduction in the number of traffic accidents. We consider this effect to be moderate, since the separate and direct influence of improved urban rail and metro systems on car traffic volumes is assumed to be moderate, cf. above.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

Social impacts pertaining to the construction period

The intensified construction of urban rail and metro infrastructure of the energy-efficiency scenario will entail some negative social impacts pertaining to the construction period, notably consequences for traffic on existing networks and disadvantages for local businesses. We do, however, estimate these consequences to be moderate.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual city cases.

3.4 Aditional impacts of halt in airport construction

3.4.1 Environmental impacts

We have identified the following main environmental impacts of halt in the construction of new and expanded airports in addition to the environmental gains resulting from a lower need for production and transmission of energy.

Substantial impact:

- Reduced greenhouse gas emissions

Considerable impacts:

- Reduced noise, air pollution and pollution of watercourses, soil and groundwater

Moderate impacts:

- Reduced conversion of natural areas and farmland
- Reduced material consumption for airport infrastructure and aircrafts

Reduced greenhouse gas emissions

The Energy-efficiency scenario has a positive impact in terms of reduced greenhouse gas emissions. We estimate this effect to be substantial. Stop in airport expansion implies that there will be less capacity for increase in air traffic than if airport expansion in line with present trends continues. Constrained capacity will thus suppress air traffic growth beyond a certain level, which will be lower than it would have been with trend-based airport expansion (Næss et al., 2020; Jorge & De Rus, 2004). The reduced growth in air traffic resulting from this implies that the greenhouse gas emissions from air traffic will also be lower (Aamaas et al., 2013; Carrington, 2020). We estimate that within the EU/EFTA area and in the absence of aircraft technology improvement, the reduced energy use for transportation due to halt in airport construction[11] is estimated to give a reduction over the period 2020-2050 of 1300 million tons of CO_2, compared to the Business-as-usual scenario. Adjusting for aircraft technology improvement, the estimated reduction is 780 million tons.

Reduced noise, air pollution and pollution of watercourses, soil and groundwater

The Energy-efficiency scenario has a positive impact in terms of reduced noise, air pollution and pollution of watercourses, soil and groundwater. We estimate this effect to be considerable. By inducing additional traffic, airport construction increases noise from aircrafts, air pollution, as well as pollution of watercourses, soil and groundwater during the construction process, maintenance, de-icing of aircrafts etc. (Wolfe et al., 2014; Nunes et al., 2013; Greer et al., 2020; Drabløs & Aasdalen, 2012).

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual infrastructure project cases.

Reduced conversion of natural areas and farmland

The Energy-efficiency scenario has a positive impact in terms of reduced conversion of natural areas and farmland. We estimate this effect to be moderate. Although the land requirement of airports is relatively small compared to the amount of land required for road and railway construction, the halt in airport construction will save considerable natural areas and farmland from being converted into runways and other airport infrastructure constructions (Greer et al., 2020; Drabløs & Aasdalen, 2012).

We do not consider it possible to quantify these impacts at either the EU/EFTA scale or for individual infrastructure project cases.

Reduced material consumption for airport infrastructure and aircrafts

The Energy-efficiency scenario has a positive impact in terms of reduced material consumption for airport infrastructure. We estimate this effect to be moderate. The material consumption required for construction of new or expanded airfields and terminal buildings (Greer et al., 2020) will be avoided. The indirect effect of materials saved from fewer aircrafts being constructed as a result of lower air traffic comes in addition.

We do not consider it possible to quantify these impacts at either the EU/EFTA scale or for individual infrastructure project cases.

3.4.2 Social impacts

We have identified the following main social impacts of halt in the construction of new and expanded airports.

Considerable impact:

- Avoiding reduced competitiveness for train
- Reduced investment and operational costs for airport infrastructure

Moderate and ambiguous impact:

- Change in destinations for leisure trips

Avoiding reduced competitiveness for train

The Energy-efficiency scenario has a positive impact in terms of avoiding reduced competitiveness for train. We estimate this effect to be considerable. Reduced growth in air traffic implies that there will be fewer departures and thus fewer situations where people can choose to go by airplane instead of by train. Longer intervals between departures also increases the 'hidden waiting time' and makes some difference to the travel time ratio between flights and train travel. (Jorge & De Rus, 2004; Prussi & Lonza, 2018.)

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual infrastructure project cases.

Reduced investment and operational costs for airport infrastructure

The Energy-efficiency scenario has a positive impact in terms of reduced investment and operational costs for airport infrastructure. We estimate this effect to be considerable. The costs thus avoided for each airport can be very substantial (National Academies of Sciences, Engineering, and Medicine, 2014), but since the number of new-built and expanded airports in the Business-as-usual scenario is relatively moderate compared to the amount of motorway construction in this scenario, the reduced investment and operational costs for airport infrastructure in the Energy-efficiency scenario are still judged to be ‘considerable’ but not ‘substantial’.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual infrastructure project cases.

Change in destinations for leisure trips

The Energy-efficiency scenario counteracts the growth in leisure flights to distant destinations enabled by the construction of new and expanded airports. We estimate the social consequences of this effect to be moderate and ambiguous. Fewer flights imply that fewer persons will be able to make trips to destinations at distances where surface travel would be considered by most tourists as too time-consuming. Leisure travelers are therefore likely to choose destinations closer to home more often if airport capacity is constrained (Statistics Norway, 2021 b and c[12]).

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual infrastructure project cases.

3.5 Aditional impacts of improved infrastructure for walking and cycling

3.5.1 Environmental impacts

There are additional impacts of improved infrastructure for walking and cycling, in addition to its contribution to reduced energy use. Replacing trips depending on external energy with trips depending on your own body’s energy will also have positive environmental impacts in terms of lower air pollution (notably pollution with particles) and noise.

Replacing entire trips previously made by car mostly relates to bicycle infrastructure. Planning for making cycling more attractive unfolds in many ways, but one of the more spectacular attempts is to create networks of supercycle highways, making it easier to ride longer, daily trips by bicycle[13]. Moreover, replacing car trips with combined trips – combining walking or cycling with public transit – will in most cases also have such positive environmental effects. A study in the Copenhagen Region suggests that good conditions for pedestrians make pedestrians willing to walk more than the average 500 – 600 meters to a metro- or urban rail station. In areas with good conditions for pedestrians, citizens are more likely to walk to a station and not use a car, than they are in areas with less good conditions (Hartoft-Nielsen & Reiter, 2017). The environmental impact of bicycle trips leading to stations depends on which trip it is replacing: if it only replaces a bus trip to the station, the impact is limited. But if the improved bicycle trip to the station is what makes the combined trip attractive compared with a car trip, the impact might be considerable.

Dense cities are more walkable and give the bicycle an advantage compared to the car. Reducing the car traffic has – as mentioned – a positive impact by reducing air pollution and noise. Another important impact is a reduced need for land for parked cars.

Case example: As described in D2.1 Report on energy efficiency potentials the transport sector, municipalities in the Copenhagen Region have been investing in bicycle infrastructure, including the Super Cycle Highway network. In the calculations of the future Super Cycle Highway network, with investmests of 300 billion €, it has been calculated that 6 million new bicycle trips will be created yearly. Of these it is assessed that 1 million replaces car trip. It is assessed that the CO_2-emissions are reduced by 1500 tonnes per year and the NO_x by 2.5 tonnes per year (Incentive 2018).

Apart from the mentioned case concerning the Copenhagen Region, we do not consider it possible to quatify the impacts on either EU/EFTA scala or other individual infrastructure cases.

3.5.2 Social impacts

In more than a decade there have been focus on the health impacts of replacing other trips with walking and bicycling. The World Health organization have been developing af tool for calculating the impacts of increased walking and cycling, see HEAT (2021). If the right input can be found, it is in principle possible to use the tool to calculate the impact on an EU/EFTA level. It will, however, demand a very large effort to get the right input, and hence the tool has predominantly been used on simpler cases.

Several researchers point to the health benefits of cycling as important, both in Europe and in other parts of the world (Götschi et al 2016; Litman, 2021b).

It is also most likely that combined trips will have a positive health effect – as one of the largest killers is the lack of daily exercise.

Dutch studies indicate that combinded trips consisting of bicycle trips and public transport trips can be competing with car trips concerning the time used for the trip – at least in the Randsstadt area (Kager et al., 2016).

The social impacts of fewer cars in the cities are related to health, the experienced safety and the possibility of using roads for other activities – for instance children playing.

Case examples: Much attention has been paid to the healt impacts of improved bicycle infrastructure. We have not been successful in finding comprehensive results on the European level concerning this, but a number of local results can be found. Region Stockholm would like to increase the modal share of bicycling from 7% to 20%. Using the HEAT tool to calculate the value of such an increase, the mere value of saved lives in one year was estimated to pay for the total investment in improved bicycle infrastructure (Stockholms län, 2019).

In the assessment of the above mentioned future Super Cycle Highway network in the Copenhagen region, its health benefits were estimated to make up 81 % of the total benefits. The main contributor to this is an estimated 40,000 days of sick-leave saved due to the extra exercise (Incentive, 2018). This is aligned with the Danish Ministry of Transport's considerations of benefits (Danish Ministry of Transport, 2013):

- Good conditions for cyclists can influence urban life in a positive way
- Bicycle friendly cities contribute to both diversity and equality

- Children walking or bicycling to school are better at focusing than other children

In most studies, it has been assumed that the exercise related to mobility chores are not replacing other kinds of exercise. This could, however, be questioned. One study indicates that the exercise you get from walking and/or cycling might be replacing other forms of exercise (Stefansdottir et al., 2019).

WHO estimates that up to 435 000 additional jobs might be created if 56 major cities had the same modal share of cycling as Copenhagen. These are cycling-related jobs in retail, wholesale and design. The number of jobs created in relation to general tourism, administration and other cycling-related businesses are not included in the estimate, neither are the lost jobs in other sectors, for instance the car-manufacturing industry. All in all, the estimate must be considered as quite rough (WHO, 2016).

We will conclude that an improved infrastructure for walking and cycling will have positive social impacts, but it is difficult to quantify on a EU/EFTA scale. Impacts have been assessed for specific cases, some using the HEAT tool. We do, however, not consider it possible to quantify the impacts at either the EU/EFTA scale or empirically ex-post for individual infrastructure cases.

3.6 Aditional impacts of economic instruments for transportation demand management

3.6.1 Environmental impacts

We have identified the following main environmental impacts of economic instruments for transportation demand management of the Energy-efficiency scenario (road pricing, parking fees and taxes on flights) in addition to the environmental gains resulting from a lower need for production and transmission of energy.

Substantial impacts:

- Reduced greenhouse gas emissions
- Reduced air pollution in urban areas
- Reduced noise in urban areas

Reduced greenhouse gas emissions

The Energy-efficiency scenario has a positive impact in terms of reduced greenhouse gas emissions. We estimate this effect to be substantial. In line with the general economic tendency of reduced demand when prices increase, there are elasticities between travel demand and various kinds of travel costs. Flight taxes therefore tend to reduce air travel and hence also the greenhouse emissions from such travel. Likewise, urban road and parking pricing tend to reduce urban motoring and its related greenhouse gas emissions. (Næss et al.; 2020; Aamaas et al., 2013; Eurostat, 2020; Abid et al., 2021; Williams, 2012.) We estimate that within the EU/EFTA area and in the absence of aircraft and surface vehicle technology improvement, the reduced energy use for transportation due to taxes and fees on surface and air transportation[14] gives a reduction over the period 2020-2050 of

2000 million tons of CO_2, compared to the Business-as-usual scenario. Adjusting for aircraft and vehicle technology improvement, the reduction is estimated to be 1000 million tons.

Reduced air pollution in urban areas

The Energy-efficiency scenario has a positive impact in terms of reduced air pollution in urban areas. We estimate this effect to be substantial. Urban road and parking pricing tend to reduce urban car driving and its resulting air pollution (Wangsness et al., 2018).

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual road pricing or parking pricing schemes.

Reduced noise in urban areas

The Energy-efficiency scenario has a positive impact in terms of reduced noise pollution in urban areas. We estimate this effect to be substantial. Urban road and parking pricing tend to reduce urban car driving and its resulting noise pollution (Wangsness et al., 2018).

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual road pricing or parking pricing schemes.

3.6.2 Social impacts

We have identified the following main social impacts of economic instruments for transportation demand management.

Considerable impacts:

- Better competitive power for transit, leading to improved transit provision
- Use of revenues for transit investment and operation

Moderate and/or ambiguous impacts:

- Change in destinations for leisure trips
- Distribution of benefits and burdens

Better competitive power for transit, leading to improved transit provision

The Energy-efficiency scenario has a positive impact in terms of better competitive power for urban transit and long-distance trains and buses, all of which leading to improved transit provision. We estimate this effect to be considerable. By making it more expensive to travel by car, public transit becomes relatively cheaper and thus more attractive. The population base for transit services and the revenues of the providers will then increase, enabling more frequent departures, denser network of lines and higher-standard vehicles (Mogridge, 1997). Likewise, by making flights more expensive, (high-speed) trains and long-distance bus travel becomes more attractive, which enables an improvement of these services.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual transportation demand management schemes.

Use of revenues for transit investment and operation

The Energy-efficiency scenario has a positive impact in terms of use of revenues from transportation demand management fees for transit investment and operation, leading to improved transit provision. We estimate this effect to be considerable. Revenues from road pricing/road tolls can be spent on transit improvement, like in Oslo where currently most of the toll road revenues are spent on transit (Oslopakke 3-sekretariatet, 2015).

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual transportation demand management schemes.

Change in destinations for leisure trips

The Energy-efficiency scenario counteracts the growth in leisure flights to distant destinations by making flights more expensive. We estimate the social consequences of this effect to be moderate and ambiguous. By making flights more expansive, some leisure travelers who would otherwise choose holiday destinations abroad/at distant destinations will abstain from these trips and instead choose destinations closer to home (in the domestic country or region), or spend their holiday in the home city. We consider urban road pricing schemes to have very small, if any at all, effects on the destinations of leisure trips.

We do not consider it possible to quantify this impact at either the EU/EFTA scale or for individual transportation demand management schemes.

Distribution of benefits and burdens

As 'flat' taxes, instruments such as road pricing and toll cordons tend to make driving in urban area less affordable for low-income people, whereas the fees and taxes on driving will make up a smaller proportion of the purchasing power of wealthy people. Car driving in urban areas may thus become more of a privilege of the affluent (Di Como & Lucas, 2014; Santos & Rojey, 2004). For low-income persons living in car-dependent parts of the urban region and/or having a life situation making it difficult to manage daily schedules without driving, highroad pricing or toll fees can be a considerable addition to daily expenses (Di Como & Shiftan, 2017). In some cities where tolls on urban motoring have been introduced (including Bergen and Oslo in Norway), considerable popular opposition has arisen against new or increased tolls. Although starting as a protest against increased fuel taxes and not against road pricing, the Yellow Vest movement in France is an expression of a similar discontent. On the other hand, the population groups that drive the most and accordingly have to pay the largest fees are the wealthy ones (Manville & Goldman, 2017; Santos & Rojey, 2004), whereas low-income people are overrepresented among the population groups most exposed to noise, air pollution and other nuisances from urban road traffic. The environmental and health benefits resulting from economic instruments for reducing urban motoring will thus be particularly high for low-income groups. If, as is the case in Oslo, most of the revenues from the toll roads are spent on transit improvement, this will also benefit low-income groups, among whom the share of transit riders is higher than among high-income groups. Moreover, those inhabitants who live in car-dependent parts of urban regions often benefit from considerably lower housing costs than among those living in the more central parts.

However, despite the statistical overrepresentation of affluent people among car-drivers and low-income people among transit riders, individual low-income households may become worse off with the introduction of road pricing schemes and increasing toll fees. Some sort of compensatory mechanisms (Manville & Goldman, 2017), such as reduced income tax or toll/road pricing for vulnerable population groups, might perhaps make it politically more feasible to introduce fees high enough to cause a traffic reduction as envisaged in the Energy-efficincy scenario.

In line with much of the literature on the topic (Santos & Rojey, 2004; Bureau & Glachant, 2008; Levinson, 2010; Di Ciommo & Shiftan, 2017;) we consider the impacts on the distribution of benefits and burdens from economic instruments for transportation demand management to be ambiguous. We do not consider it possible to quantify these impacts at either the EU/EFTA scale or for individual transportation demand management schemes.

3.7 Aditional impacts of other demand management measures

3.7.1 Environmental impacts

Car-sharing is a concept covering several different solutions: free floating/one-way systems, station-based car-sharing, two-way systems and peer-to-peer car- sharing. Different car-sharing systems have different properties (Giesel and Nobis 2016).

Free floating/one-ways systems are systems where the shared car can be parked anywhere in a predefined zone, typically the denser part of a city. In station-based systems you have to park the shared car at special stations. In two-way systems you have to place the car where you picked it up. Peer-to-peer car sharing will typically be a two-way system with the special feature that it is a private person’s car that is shared.

Car-sharing is generally found to lead to up to 30 % less car ownership and 15% - 20% less driven kilometers. In some countries, like the Netherlands, peer-to-peer car-sharing has been growing rapidly. Typically, the shared car replaces the household’s second or third car (Nijland and Van Meerkerk 2017). One-way – free floating systems seem to be less effective in reducing car ownership (Firnkorn and Müller 2011). Furthermore, some see car-sharing as a way of inspiring people to buy their own car.

Some planners pay special attention to the fact that car-sharing may reduce car ownership and hence reduce the need for parking – having an effect on land-use in cities. Car-sharing can make it easier to choose not to own a car.

From the literature, it is suggested that car-sharing most likely will have a positive impact on the environment due to the reduced number of kilometers driven by car as well as a lower number of cars built and sold. We do not consider it possible to quantify these impacts at either the EU/EFTA scale or for individual car-sharing schemes.

3.7.2 Social impacts

The different car-sharing systems have, as mentioned above, different properties. Car-sharing gives access to cars for people that might not have the economy to own their own car. Some peer-to-peer schemes makes it possible for some to own a car – the income from sharing makes it possible to pay for the car. Car-sharing can be part of larger systems of Mobility as a Service (MaaS), aiming at making it easier not to own your own means of transport (Jittrapirom et al 2017).

We do not consider it possible to quantify these impacts at either the EU/EFTA scale or for individual car-sharing schemes.

3.8 Aditional impacts of energy-efficient vehicle technology

The 'electrification +' scenario as mentioned before relies heavily on shifting to electrified modes of transport to the extent possible with the exception of hard to electrify sectors like shipping and international aviation. The shift from fossil-based vehicle technologies to a more electrified transport sector will have both environmental and social effects at different levels of implementation. The following are a few examples of social and environmental impacts that could possibly be attributed to the electrification of transport.

3.8.1 Environmental impacts

We have identified the following main environmental impacts of more energy-efficient vehicle technology in addition to its contribution to reduced energy use:

- Greenhouse gas emission reduction
- Air quality improvement
- Contribution to circular economy
- Rebound effects

Greenhouse gas emission reduction

Electric Vehicles at present are a factor of around three-four times more energy-efficient than their diesel-based counterparts (Danish Energy Agency, 2015) and if electricity sourced for these vehicles comes from renewable energy, there lies a huge potential for emissions reduction with the massive adoption of electric vehicles in 2050.

Air quality improvement

The level of GHG emission reduction does depend heavily on the levels of electrification in the transport sector as well as the source of electricity. However, it also stands to reason that even if, at the early adoption of electric vehicles, the electricity sourced is not 100 % renewable, there would still be benefits from local air quality improvement which would imply a betterment in the health quality indices. According to an estimate of health cost externalities, the number of annual premature deaths for the year 2000 in Europe due to Particulate Matter (PM) from international shipping traffic was around 50,000 with an external health-related cost are estimated to be of whopping 50-60 billion euros (Brandt et al., 2013). The 'electrification+' scenario envisions by 2050 to convert 50 % of shipping to electricity and the rest to electro fuels and ammonia. We expect a substantial improvement in air quality because of this shift.

Contribution to circular economy

Electric Vehicles have a much simpler design as compared to their ICE (Internal Combustion Engine) counterparts. With fewer moving parts and no need for frequent fluid changes, these vehicles are expected to cost almost 50 % less in maintenance and repairs over their lifetime as compared to ICE vehicles (Harto, 2020). In addition, the major component of electric vehicles which are the electric batteries, can be used as second-life batteries for a variety of purposes such as backup supply for frequency grid reserves before they are sent to a recycling plant (Fortum, 2021). Both these factors represent great potentials for reduction in materials and resources as compared to traditional vehicles. A strong focus on recycling should be promoted to ensure resource efficiency.

Rebound effects

Energy-efficiency could have a negative impact on several environmental parameters due to rebound effects (Jevons, 1866; Santarius et al., 2016), especially from the increased energy efficiency of vehicles. We estimate this effect to be considerable. The higher energy efficiency of vehicles will, other things being equal, reduce the cost per kilometer of driving and will thus induce an increase in driving distances[15].

This will, in its turn, counteract to some extent the gains in energy saving, reduced noise, and (to a lesser extent because of electrification) air pollution and greenhouse gas emissions reduction. We do not consider it possible to quantify the environmental impacts of more energy-efficient vehicles at either the EU/EFTA scale or for individual cities or city-regions.

3.8.2 Social Impacts

We have identified the following main social impacts of more energy-efficient vehicle technology in addition to its contribution to reduced energy use:

- Rise of autonomous vehicles
- Increased car sharing and reduced car ownership
- More electric planes and fewer airports

Rise of autonomous vehicles

With more and more electric vehicles introduced in the future and the rapid advancements in digitalization technologies, more and more autonomous (self-driving) vehicles could be expected on the roads. Electric Vehicles can be more easily adapted to greater autonomous functionalities with simple software updates as the technology develops. If the same features were instead to be implemented on Internal Combustion Engine (ICE) vehicles, they would have to be coupled with hardware modifications as well. This increase in self-driving prospects would possibly result in shorter driving times. It is still quite early to speculate whether increase in autonomous functionalities would result in decrease in traffic accidents. The reduction in traffic accidents by using more and more autonomous vehicles stems from the presumption that these technologies could eliminate or reduce the impact of human error in driving. However, general public perception and rate of technological advancements are two large uncertainty variables. Challenges of driving under snowy winter conditions also remain to be solved.

Increased car sharing and reduced car ownership

As mentioned, Electric Vehicles are much better suited to be adopted for autonomous driving than their ICE counterparts. This could also potentially lead to future business models where owning a car does not remain a necessity, with consumers moving more towards a subscription-based model to car-sharing. Different car manufacturers are already experimenting with different car-sharing strategies. For example, in 2018, Audi launched a monthly vehicle subscription service called 'Audi Select' that gives users access to certain Audi car models (CNET, 2021). It is still a developing market and the social impacts from this are expected to be moderate.

More electric planes and fewer airports

In the 'electrification+' scenario, a considerable development in electric aviation is considered, and all the national EU flights are deemed to be electric by 2050, whereas around 35 % of the intra-EU short distance flights are expected to be electric by 2050. There are numerous prototypes in development for short range e-VTOL (vertical take-off and landing) or e-STOL (short take-off and landing) planes that require either no or small take-off runway areas. This could potentially make many intra urban sites suitable for take-off and landing such as skyscraper rooftops and harbor piers. However, it remains difficult to say at present how this will play out in the long term, and at this early stage we do not consider it possible to quantify these social impacts of more energy-efficient vehicles at either the EU/EFTA scale or for individual cities or city-regions.

4 Conclusions

The measures of the Energy-efficiency scenario for the transportation sector are likely to produce a large number of environmental and social impacts in addition to their intended impacts in terms of energy saving. Most of the identified 'additional' impacts are positive, judged against relevant environmental and social criteria, but there are some less favorable impacts. Table 1 provides an overview of the various additional environmental impacts that we have identified, whereas Table 2 shows a similar overview of social impacts.

Since emissions from traffic are resulting from energy use for transportation, it is hardly any surprise that the Energy-efficiency scenario has substantial positive impacts in terms of reduced greenhouse gas emissions and reduced air pollution. Energy efficient urban spatial development and halt in motorway construction also have substantial positive impacts in terms of reduced conversion of natural areas, farmland and areas for hiking, skiing and other kinds of area-demanding outdoor life. The strategies for urban spatial development and infrastructure construction also give substantial positive effects in terms of lower material consumption. The concentrated urban spatial development and urban rail and metro construction characterizing the Energy-efficiency scenario is, however, likely to cause some reduction of intra-urban green areas and put some increased pressure for demolition of heritage buildings. However, these effects, which are estimated to be moderate, are counteracted by moderately lower encroachments on intra-urban green areas and heritage buildings due to the halt of motorway construction in the energy-efficiency scenario. The urban densification characterizing the Energy-efficiency scenario may increase vulnerability to climate change to some extent, but this effect is estimated to be moderate and partly ambiguous. Finally, although energy-efficient vehicle technology improvement will cause substantial energy savings as well as reductions in greenhouse gas emissions and air pollution, and also offers potentials for reduction in production materials and resources, the increased energy-efficiency gained through improved vehicle technology is estimated to cause a considerable rebound effect likely to reduce some of the energy gains of the Energy-efficiency scenario as well as its positive effects on air pollution and noise. A small rebound effect may also occur as a result of the energy-efficient urban spatial development, although this effect is more uncertain.

By offering greater proximity between trip origins and destination and increasing the mobility opportunities for people who do not drive cars, the Energy-efficiency scenario offers substantial positive effects in terms of accessibility for residents who are unable to drive as well as reduced travel time for daily-life purposes and easier everyday schedule. Although motorway construction is often justified by predicted travel time savings, evidence has shown that the higher speeds offered by motorways tend to be counteracted by increased travel distances and region enlargement where local inhabitants are facing harder competition for local jobs from non-local job applicants. The impacts of the halt in motorway construction of the Energy-efficiency scenario on travel time and access to jobs and service facilities is therefore estimated to be ambiguous. Through its halt in motorway construction, intensified urban rail and metro construction and travel demand management measures, the Energy-efficiency scenario is estimated to enhance the competitiveness of public transit substantially. Part of this effect is caused by the possibility of using revenues from road pricing on trasit improvements.

Table 1: Overview of estimated positive and negative environmental impacts of the measures included in the Energy-efficiency scenario. Positive effects: +++ = substantial; ++ = considerable; + = moderate. Negative effects: --- = substantial; -- = considerable; - = moderate. +/- indicates that the effect is ambiguous.

	Greenhouse gas emissions	Conversion of natural areas and farmland	Encroachments on areas for hiking, skiing and other kinds of area-demanding outdoor life	Encroachments on intra-urban green areas	Heritage buildings	Overall air pollution	Inhabitants' exposure to air pollution and noise	Soil and water pollution	Material consumption for infrastructure and/or buildings	Contribution to circular economy	Energy requirement for space heating and cooling	Vulnerability to climate change	Rebound effects
Energy-efficient urban spatial development	+++	+++	+++	--	-	++	+/-		++		++	-	-
Stop in motorway construction	+++	+++	++	+	+	+++	++	+++	+++				
Increased urban railroad and metro construction	+	-	-	-	-	+	+		-				
Stop in airport expansion	+++	+				+	++	++	++				
Economic instruments for demand management	+++					+++	+++						
Other demand management strategies	++					++	++						
Improved infrastructure for walking and cycling	+					++	++						
Improved vehicle technology	+++					+++	+++			++			--

Table 2: Overview of estimated positive and negative social impacts of the measures included in the Energy-efficiency scenario. Positive effects: +++ = substantial; ++ = considerable; + = moderate. Negative effects: --- = substantial; -- = considerable; - = moderate. +/- indicates that the effect is ambiguous.

	Accessibility for residents who are unable to drive	Travel time and daily-life schedule	Access to jobs and service facilities	Housing quality	Housing affordability	Investment and operational costs for infrastructure	Health impacts	Urban vibrancy	Agglomeration benefits	Traffic accidents	Competitiveness of urban transit and trains	Revenues used for transit investment and operation	Social impacts pertaining to the construction period
Energy-efficient urban spatial development	+++	++	++	--	--	+	+/-	++	+/-	+			
Stop in motorway construction		+/-	+/-			+++				+	++		++
Increased urban railroad and metro construction	++	++	++			--				+	+++		-
Stop in airport expansion						++					++		+
Economic instruments for demand management											++	++	
Other demand management strategies													
Improved infrastructure for walking and cycling							++						
Improved vehicle technology							++			+/-			

Table 2 (continued): Overview of estimated positive and negative social impacts of the measures included in the Energy-efficiency scenario. Positive effects: +++ = substantial; ++ = considerable; + = moderate. Negative effects: --- = substantial; -- = considerable; - = moderate. +/- indicates that the effect is ambiguous.

	Change in destinations for leisure trips	Distribution of benefits and burdens	Rise of autonomous vehicles	Increased car sharing and reduced car ownership	More electric planes and fewer airports
Energy-efficient urban spatial development					
Stop in motorway construction					
Increased urban railroad and metro construction					
Stop in airport expansion	+/-				
Economic instruments for demand management	+/-	+/-			
Other demand management strategies					
Improved infrastructure for walking and cycling					
Improved vehicle technology			+	+	+

Moreover, the urban spatial development of the Energy-efficiency scenario is expected to have a considerable positive effect on urban vibrancy, and its provision of better infrastructure for walking and cycling is estimated to bring considerable positive health effects. The intensified shift to electric vehicles will also give health benefits due to reduced noise and air pollution. Halt in motorway construction implies that negative social impacts pertaining to the construction period will be avoided, but on the other hand, some such impacts will occur due to the intensified urban rail and metro construction in this scenario. On the other hand, the dense and concentrated urban spatial development of the Energy-efficiency scenario has a considerable negative impact in terms of lower housing affordability. The remaining social impacts of the Energy-efficiency scenario that we have identified are estimated to be rather moderate or ambiguous. We estimate that the Energy-efficiency scenario will reduce traffic accidents somewhat, and the destinations of leisure trips will become more local. Whether the latter will bring positive or negative social impacts is, however, ambiguous and contestable. Combined with other measures of the Energy-efficiency scenario, its improved vehicle technology may also facilitate a rise of autonomous vehicles, increased car sharing and reduced car ownership, more electric planes and fewer airports.

References

Aamaas, B., Borken-Kleefeld, J. & Peters, G. (2013). The climate impact of travel behavior: a German case study with illustrative mitigation options. *Environmental Science Policy*, 33, 273–282.

Abid, H.; Kany, M. S.; Mathisen, B. V.; Nielsen, S.; Elle, M. & Næss, P. (2021). *Report on energy efficiency potentials in the transport sector and conclusions from the developed scenarios.* Deliverable D2.3 of the Horizon 2020 sEEnergies project. Brussels: European Commission.

Alexander D.E. (1999) Highways, environmental impact. In: *Environmental Geology. Encyclopedia of Earth Science*. Springer, Dordrecht. https://doi.org/10.1007/1-4020-4494-1_173.

Alonso, W (1964). *Location and Land Use*. Cambridge, Mass.: Harvard University Press.

Banister, D. (2011). The trilogy of distance, speed and time. *Journal of Transport Geography*, 19(4), 950-959.

Beatley, T. (2000). Preserving biodiversity—challenges for planners. *Journal of American Planning Association*, 66(1), 5–20.

Beenackers, M. A.; Groeniger,J. O.; Kamphuisb, C. M. B. & Van Lenthea, F. B. (2018). Urban population density and mortality in a compact Dutch city: 23-year follow-up of the Dutch GLOBE study. *Health and Place*, 53, 79-85.

Bournas, Iason LU ; Lundgren, Marja ; Alenius, Malin and Dubois, Marie-Claude LU (2017). Urban densification affects daylighting: existing daylight levels in Swedish multi-family housing as a base for future daylight requirement. In Proceedings of the international conference on changing cities III : Spatial, Design, Landscape & Socio-economic Dimensions, pp.987-997. Thessaly: Universiy of Thessaly.

Brandt, J. et al. (2013). Assessment of past, present and future health-cost externalities of air pollution in Europe and the contribution from international ship traffic using the EVA model system. *Atmos. Chem. Phys.*, 13(15), 7747–7764, doi: 10.5194/acp-13-7747-2013.

Brown, M., & Wolfe, M. (2007). *Energy efficiency in multi-family housing: A profile and analysis*. Washington, DC: Energy Program Consortium.

Burchell, R. W., Shad, N. A., Listokin, D., Phillips, H., Downs, A., Seskin, S.,…Gall, M. (1998). *The costs of sprawl – revisited*. Washington: National Academy Press.

Cao, J.; Mokhtarian, P. L. & Handy, S. (2009). Examining the impacts of residential self-selection on travel behavior: A focus on empirical findings. *Transport Reviews*, 29, 359-395.

Carrington, D. (2020). Heathrow third runway ruled illegal over climate change. *The Guardian*, February 27, 2020, accessed March 2021 from https://www.theguardian.com/environment/2020/feb/27/heathrow-third-runway-ruled-illegal-over-climate-change.

Carter, J. (2011). Climate change adaptation in European cities. *Current Opinion in Environmental Sustainability*, 3, 193–198.

Cavicchia, R. (2021). Are green, dense cities more inclusive? Densification and socio-spatial inequalities in Oslo. Paper under review.

Cervero, R. (2001). Efficient urbanisation: Economic performance and the shape of the metropolis. *Urban Studies*, 38(10), 1651-1671. https://doi.org/10.1080/00420980120084804.

Cho, H.-S. & Choi, M. J. (2014). Effects of Compact Urban Development on Air Pollution: Empirical Evidence from Korea. *Sustainability*, 6, 5968-5982.

Chorianopoulos, I.; Pagonis, T.; Koukoulas, S. & Drymoniti, S. (2010). Planning, competitiveness and sprawl in the Mediterranean city: The case of Athens. *Cities*, 27(4):249-259. DOI: 10.1016/j.cities.2009.12.011.

Christaller, W. (1966) Central Places in Southern Germany. Englewood Cliffs, NJ: Prentice Hall, 1966. (Translation of 'Die Zentralen Orte in Süddeutschland', published in 1933).

CNET (2021). Audi testing $1,395 subscription program in Texas - Roadshow. Accessed April 2021 from https://www.cnet.com/roadshow/news/audi-select-subscription-pilot-texas/.

Czepkiewicz, M.; Heinonen, J.; Næss, P. & Stefansdóttir, H. (2020). Who travels more, and why? A mixed-method study of urban dwellers' leisure travel. *Travel Behaviour and Society*, 19, 67-81.

Danish Energy Agency (2015). *AD models*. Copenhagen: Danish Energy Agency. Accessed August 2020 from https://ens.dk/service/fremskrivninger-analyser-modeller/modeller.

Danish Ministry of Transport (2013). *Cyklingens effekter og samfundsøkonomi*. Arbejdspapir 3 - den nationale cykelstrategi 2013.

Danish Ministry of Transport (2014). *Danmark – op på cyklen! - Den nationale cykelstrategi*. Accessed March 2021 from https://www.trm.dk/publikationer/2014/den-nationale-cykelstrategi-danmark-op-paa-cyklen/

De Jong, G. & Gunn, H. (2001). recent evidence on car cost and time elasticities of travel demand in Europe. *Journal of Transport Economics and Policy*, 35, Part 2, 137-160.

Di Como, F. & Lucas, K. (2014). Evaluating the equity effects of road-pricing in the European urban context – The Madrid Metropolitan Area. *Applied Geography*, 54, 74-82.

Di Como, F. & Shiftan, Y. (2017). Transport equity analysis. *Transport Reviews*, 37(2), 139-151.

Doll, C. & Van Essen, H. (2008). Road infrastructure cost and revenue in Europe. Delft: CE Delft. Accessed March 2021 from https://ec.europa.eu/transport/sites/transport/files/themes/sustainable/studies/doc/2008_road_infrastructure_costs_and_revenues.pdf.

Dovre & TØI (2012). *Kvalitetssikring av konseptvalg (KS2): Intercitystrekningene*. https://www.regjeringen.no/nb/dokumenter/kvalitetssikring-ks1-avkonseptvalgutr-2/id712738/?regj_oss=90.

Drabløs & Aasdalen (2012). 20.000 blir berørt av flystøy. NRK, November 26, 2012. Accessed March 2021 from https://www.nrk.no/osloogviken/_-20.000-blir-berort-av-flystoy-1.8671776

Elldér, E. (2014). Residential location and daily travel distances: The influence of trip purpose. *Journal of Transport Geography*, 34, 121-130.

Engebretsen, Ø. & Gjerdåker, A. (2012). *Potensial for regionforstørring*. TØI report 1208/2012. Oslo: Institute of Transport Economics.

Engebretsen, Ø. (1993). *Arealbruk i tettsteder 1955–1992*. TØI Report 177/1993. Oslo: Institute of Transport Economics.

Engebretsen, Ø.; Christiansen, P. & Strand, A. (2015). Bybanen i Bergen:Positiv faktor for transport- og arealutviklingen. *Samferdsel*, December 18, 2015. Oslo: Institute of Transport Economics.

Engebretsen, Ø.; Næss, P. & Strand, A. (2018). Residential location, workplace location and car driving in four Norwegian cities. *European Planning Studies*, 26(10), 2036-2057.

Engelien, E., Steinnes, M., & Bloch, V. V. H. (2005). *Tilgang til friluftsområder. Metode og resultater*. Notater 2005/15. Oslo: Statistics Norway.

EU DG Environment 2018 (Soil sealing) Accessed March 2021 from https://ec.europa.eu/environment/soil/sealing_guidelines.htm.

European Automobile Manufacturers Association (2019). *Vehicles in use Europe 2019*. Brussels: European Automobile Manufacturers Association. Available at https://www.acea.be/uploads/statistic_documents/ACEA_Report_Vehicles_in_use-Europe_2017.pdf.

European Commission (2018). *Motorways*. European Commission, Directorate General for Transport. Accessed March 2021 from https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/pdf/ersosynthesis2018-motorways.pdf.

European Commission (2020). *State of the art on alternative fuels transport systems in the European Union*. Brussels: European Commission.

European Environmental Agency (2006). *Urban sprawl in Europe: The ignored challenge.* EEA report no. 10/ 2006. Copenhagen: European Environmental Agency.

European Environmental Agency (2015). Final energy consumption by sector and fuel. Accessed January 2021 from https://www.eea.europa.eu/data-and-maps/indicators/final-energy-consumption-by-sector-8/assessment-2.

Eurostat (2021). What is the source of the electricity we consume? Accessed March 2021 from https://ec.europa.eu/eurostat/cache/infographs/energy/bloc-3b.html.

Ewing, R. & Cervero, R. (2010). Travel and the built environment. *Journal of the American Planning Association* 76(3), 265–94.

FAO (2019). *The state of the world's biodiversity for food and agriculture*. Rome: FAO Commission on Genetic Resources for Food and Agriculture Assessments.

Firnkorn, J. & Müller, M. (2011). What will be the environmental effects of new free-floating car-sharing systems? The case of car2go in Ulm. *Ecological Economics*, 70(8), 1519-1528, https://doi.org/10.1016/j.ecolecon.2011.03.014

Fortum (2020). Fortum installs innovative battery solution at Landafors hydropower plant in Sweden. Accessed April 2021 from https://www.fortum.com/media/2021/04/fortum-installs-innovative-battery-solution-landafors-hydropower-plant-sweden.

Garreau, J. (1992). *Edge city: Life on the new frontier*. New York: Anchor Books.

Giesel, F. & Nobis, C. (2016). The impact of carsharing on car ownership in German cities, *Transportation Research Procedia*, 19, 215-224, https://doi.org/10.1016/j.trpro.2016.12.082.

Götschi, T.; Garrard, J. & Billie Giles-Corti, J. (2016) Cycling as a Part of Daily Life: A Review of Health Perspectives, *Transport Reviews*, 36:1, 45-71, DOI: 10.1080/01441647.2015.1057877

Greer, F.; Rakas, J. & Horvath, A. (2020). Airports and environmental sustainability: a comprehensive review. *Environmental Research Letters*, 15, 103007.

Haaland, C. & Van den Bosch, C. K. (2015). Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban Forestry & Urban Greening* 14(4) DOI: 10.1016/j.ufug.2015.07.009.

Hägerstrand, T. (1970). What about people in regional science? *Papers in Regional Science*, 24, 7–24.

Haigh, F.; Chok, H. N. C. & Harris, P. J. (2011). Housing density and health: A review of the literature and Health Impact Assessments. Sydney: University of New South Wales. Accessed March 2021 from https://www.researchgate.net/publication/235918507_Housing_density_and_health_A_review_of_the_literature_and_Health_Impact_Assessments.

Handy, S. L.; Boarnet, M. G.; Ewing, R. & Killingsworth, R. E. (2002). How the built environment affects physical activity: views from urban planning. *American Journal of Preventive Medicine*, 23(2), 64-73.

Hansson, E.; Mattisson, K.; Björk, J.; Östergren, P. & Jakobsson, K. (2011). Relationship between commuting and health outcomes in a cross-sectional population survey in southern Sweden. *BMC Public Health,* 11: 834, doi:10.1186/1471-2458-11-834.

Hartig, T.; Mitchell, R.; De Vries, S. & Frumkin, H. (2014). Nature and health. *Annual Review of Public Health,* 35: 207–228, doi:10.1146/annurev-publhealth-032013-182443.

Harto, C. (2020). Maintenance. Chapter 2 in Harto, C. *Electric Vehicle Ownership Costs*. Yonkers, NY: Consumer Reports. Accessed April 2021 from https://advocacy.consumerreports.org/wp-content/uploads/2020/10/EV-Ownership-Cost-Final-Report-1.pdf.

Hartoft-Nielsen, P., & Reiter, I. (2017). *Trafikale effekter af stationsnær lokalisering i hovedstadsområdet 2017 – første rapport med hovedresultater og analyser*. Copenhagen: Aalborg University.

HEAT (2021). Welcome to the Health Economic Assessment Tool (HEAT) for walking and cycling by WHO/Europe. Accessed March 2021 from https://www.heatwalkingcycling.org/

Herath, S. & Maier, G. (2013). Local particularities or distance gradient: What matters most in the case of the Viennese apartment market?. *Journal of European Real Estate Research*, 6(2), 163-185.

Hills, P.J. (1996). What is induced traffic? *Transportation*, 23(1), 5-16.

Holden, E. & Norland, I.T. (2005). Three challenges for the compact city as a sustainable urban form: household consumption of energy and transport in eight residential areas in the Greater Oslo Region. *Urban Studies*, 42(12), 2145–2166.

Honningsøy, K. H. & Solvang, T. M. (2020). Klimabombene ingen tenkte på. NRK, October 31, 2020. Accessed March 2021 from https://www.nrk.no/norge/xl/klimabombene-ingen-tenkte-pa-1.15217036.

Høyer, K. G. & Holden, E. (2001). Housing as basis for sustainable consumption. *International Journal of Sustainable Development*, 4(1), 48–58.

Ihlebæk, C.; Næss, P. & Stefansdottir, H. (2020). Are compact cities a threat to public health? *European Planning Studies*. Published online June 2020 at https://doi.org/10.1080/09654313.2020.1775790.

Incentive (2018): *Samfundsøkonomisk analyse af supercykelstierne*. Holte: Incentive. Accessed March 2021 from www.incentive.dk/wp-content/uploads/2018/06/Incentive_Samfundsøkonomisk-analyse-af-supercykelstier.pdf

INEA (2020). *TEN-T projects*. Brussels: European Commission. Accessed July 2020 from https://ec.europa.eu/inea/en/ten-t/ten-t-projects.

IPBES (2019). *Global assessment report on biodiversity and ecosystem services*. Bonn: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

IPCC (2019). *Climate Change and Land*. Geneva: Intergovernmental Panel on Climate Change.

Ivehammar, P. (2006). How to deal with the encroachment costs in road investment CBA. Doctoral dissertation. Linköping Studies in Arts and Science, No. 373. Linköping: Linköping University.

Jacobs, J. (1961). *The death and life of great American cities*. London: Pimlico.

Jevons, W. S. (1866). *The coal question* (2nd ed.) London: Macmillan and company.

Jittrapirom, P.; Caiati, V; Feneri, A.-M.; Ebrahimigharehbaghi, S.; Alonso-González, M. J. & Narayan, J. (2017). Mobility as a Servie: A critical review of definitions, assessments of schemes, and key challenges, *Urban Planning*, 2(2), 13-25, https://doi.org/10.17645/up.v2i2.931.

Jonathan Levine, J.; Grengs, J.; Shen, Q. & Shen, Q. (2012). Does Accessibility Require Density or Speed? *Journal of the American Planning Association*, 78(2), 157-172.

Jones, K. (1997). *Drift og vedlikehold av teknisk infrastruktur. Variasjon i ressursbruk med bebyggelsestype i boligområder*. Project report 1997:15. Oslo: Norwegian Institute for Urban and Regional research.

Jorge, J.-D- & De Rus, G. (2004). Cost–benefit analysis of investments in airport infrastructure:a practical approach. *Journal of Air Transport Management*, 10(5), 311-326.

Jurich, K. (2016). CO_2Emission Factors for Fossil Fuels. Climate change 28/2016. German Environment Agency. Accessed March 2021 from https://www.umweltbundesamt.de/sites/default/files/medien/1968/publikationen/co2_emission_factors_for_fossil_fuels_correction.pdf#page=46&zoom=auto,-22,639.

Kager, R.; Bertolini, L. & Te Brömmelstroet, M. (2016). Characterisation of and reflections on the synergy of bicycles and public transport, *Transportation Research Part A: Policy and Practice*, 85, 208-219, https://doi.org/10.1016/j.tra.2016.01.015.

Kenworthy, J. R. (2003). Transport energy use and greenhouse gases in urban passenger transport systems: A study of 84 global cities. Presented to the international Third Conference of the Regional Government Network for Sustainable Development, Notre Dame University, Fremantle, Western Australia, September 17–19, 2003.

Levinson, D. (2010). Equity effects of road pricing: A review. *Transport Reviews*, 30, 33-57.

Litman, T. (2019). Understanding transport demands and elasticities: how prices and other factors affect travel behavior. Accessed July 2020 from https://www.vtpi.org/elasticities.pdf.

Litman, T. (2020). Evaluating accessibility for transport planning. Victoria: Victoria Transport Policy Institute. Accessed March 2021 from https://www.vtpi.org/access.pdf.

Litman, T. (2021a). Generated traffic and induced travel: Implications for transport planning. Victoria: Victoria Transport Policy Institute. Accessed March 2021 from https://www.vtpi.org/gentraf.pdf.

Litman, T. (2021b). Evaluating active transport benefits and costs - Guide to valuing walking and cycling improvements and encouragement programs. Victoria: Victoria Transport Policy Institute. Accessed March 2021 from https://www.vtpi.org/nmt-tdm.pdf

Manville, M. & Goldman, E. (2017). Would congestion pricing harm the poor? Do free roads help the poor? *Journal of Planning Education and Research*, 1-16, DOI: 10.1177/0739456X17696944.

Matthews, T.; Lo, A. Y. & Byrne, J. A. (2015). Reconceptualizing green infrastructure for climate change adaptation: Barriers and drivers for uptake by spatial planners. *Landscape and Urban Planning*, 138, 155-163.

Metz, D. (2008). The myth of travel time saving. *Transport Reviews*, 28(3), 321-336.

Mogridge, M. H. J. (1997). The self-defeating nature of urban road capacity policy: A review of theories, disputes and available evidence. *Transport Policy*, 4(1), 5–23.

Mouratidis, K. (2017). Is compact city livable? The impact of compact versus sprawled neighbourhoods on neighbourhood satisfaction. *Urban Studies*, 11, 2408-2430, https://doi.org/10.1177/0042098017729109.

Næss, P. (1993). Transportation energy in swedish towns and regions. *Scandinavian Housing & Planning Research*, 10(4), 187-206.

Næss, P. (2006). *Urban structure matters: Residential location, car dependence and travel behaviour*. New York/London: Routledge.

Næss, P. (2008). Gender differences in the influences of urban structure on daily-life travel. In Priya, T. & Cresswell, T. (eds.): *Gendered Mobilities*, 173-192. Aldershot: Ashgate.

Næss, P. (2011). The Third Limfjord Crossing– a case of pessimism bias and knowledge filtering. *Transport Reviews*, 31(2), 231-249.

Næss, P. (2012). Urban form and travel behavior: experience from a Nordic context. *Journal of Transport and Land Use*, 5(2), 21-45.

Næss, P. (2016). Urban planning: residential location and compensatory behaviour in three scandinavian cities. In Santarius, T.; Walnum, H. J. & Aall, C. (eds.). *Rethinking climate and energy policies: New perspectives on the rebound phenomenon*, pp. 181-207. Switzerland: Springer.

Næss, P. (2020). Project appraisal methods: tools for optimizing or for informed political debate? In Mouter. N. (ed.) *Appraisal methods*, pp. 287-314. Series: Advances in transport policy and planning, Vol. 6. Amsterdam: Elsevier.

Næss, P. (2021). Compact urban development in Norway: spatial changes, underlying policies and travel impacts. Forthcoming in Cao, X.; Ding, C. & Yang, J. (eds). *Urban transport and land use planning: a synthesis of global knowledge*. Amsterdam: Elsevier.

Næss, P.; Cao, X. & Strand, A. (2017a). Which D's are the important ones? The effects of built environment characteristics on driving distance in Oslo and Stavanger. *Journal of Transport and Land Use*, 10(1), 945–964.

Næss, P.; Mogridge, M. J. H. & Sandberg, S. L. (2001). Wider Roads, More Cars. *Natural Resources Forum*, 25(2), 147-155.

Næss, P.; Peters, S.; Stefansdottir, H. & Strand, A. (2018). Causality, not just correlation: Residential location, transport rationales and travel behavior across metropolitan contexts. *Journal of Transport Geography*, 69, 181–195.

Næss, P.; Saglie, I.-L. & Richardson, T. (2020b). Urban sustainability: is densification sufficient? European Planning Studies, 28(1), pp. 146-165, DOI 10.1080/09654313.2019.1604633.

Næss, P.; Strand, A.; Wolday, F. & Stefansdottir, H. (2019). Residential location, commuting and non-work travel in two urban areas of different size and with different center structures. *Progress in Planning*, 128, 1-36.

Næss, P.; Volden, G. H.; Odeck, J. & Richardson, T. (2017b). *Neglected and underestimated negative impacts of transport investments*. Concept Report no. 54. Trondheim: Trondheim: Ex Ante Academic Publisher.

Næss, P.; Wolday, F.; Elle, M.; Abid, H.; Kany, M. S. & Mathisen, B. V. (2020a). *Report on energy efficiency potentials in the transport sector*. Deliverable D2.1 of the Horizon 2020 sEEnergies project. Brussels: European Commission.

National Academies of Sciences, Engineering, and Medicine (2014). Airport capital improvements: A business planning and decision-making approach. Washington, DC: The National Academies Press. https://doi.org/10.17226/22259.

National Roads Authority (Ireland) (2008). Environmental impact assessment of national road schemes – a practical guide. Accessed March 2021 from https://www.tii.ie/technical-services/environment/planning/Environmental-Impact-Assessment-of-National-Road-Schemes-Practical-Guide.pdf.

Newman, P. W. G. & Kenworthy, J. R. (1989). Gasoline consumption and cities: A comparison of US cities with a global survey. *Journal of the American Planning Association*, 55, 24–37.

Nijland, H.& Van Meerkerk, J. (2017). Mobility and environmental impacts of car sharing in the Netherlands. *Environmental Innovation and Societal Transitions*, 23, 84-91, https://doi.org/10.1016/j.eist.2017.02.001.

Noise in EU (2021). Noise and sustainable development. Accessed March 2021 from http://www.noiseineu.eu/en/14-noise_and_sustainable_development/subpage/view/page/59.

Noland, R. B. & Lem, L. L. (2002). A review of the evidence for induced travel and changes in transportation and environmental policy in the US and the UK. *Transportation Research Part D*, 7(1), 1-26.

Nunes, L. M.; Zhu, Y. G.; Stigter, T. Y.; Monteiro, J. P. & Teixeira, M. R. (2011). Environmental impacts on soil and groundwater at airports: origin, contaminants of concern and environmental risks. *Journal of Environmental Monitoring*, 13, 3026-3039.

Ogle, J. & Seong, J. (2012). Urban heat islands, deforestation, and sprawl. Presentation at the American Association of Geographers – 2012 in Los Angeles, CA. Accessed March 2021 from https://www.researchgate.net/publication/321244230_Urban_Heat_Islands_Deforestation_and_Sprawl.

Ottelin, J.; Heinonen, J. & Junnila, S. (2014). Greenhouse gas emissions from flying can offset the gain from reduced driving in dense urban areas. *Journal of Transport Geography*, 41, 1–9.

Pløger, J. (2002). *Det senmoderne nærmiljø – livsformer og bykultur. En sammenligning af teori og praksis i Danmark og Norge*. NIBR-rapport 2002:16. Oslo: Norsk institutt for by- og regionforskning.

Prussi, M. & Lonza, L. (2018). Passenger aviation and high speed rail: A comparison of emissions profiles on selected European routes. Journal of Advanced Transportation, Article ID 6205714, https://doi.org/10.1155/2018/6205714.

Region Skåne (2018). *Cykelvägsplan för Skåne 2018–2029*. Kristianstad: Region Skåne. Accessed March 2021 from https://utveckling.skane.se/siteassets/publikationer_dokument/cykelvagsplan_for_skane_2018-2029.pdf

Rehák, S. & Káčer, M. (2019). Estimating price gradient in Bratislava with different distance measurements. *Journal of European Real Estate Research*, 12(2), 190-206.

Riksrevisjonen (2007). *Riksrevisjonens undersøkelse av bærekraftig arealplanlegging og arealdisponering i Norge* (Dokument nr. 3:11 (2006–2007)). Oslo: Norwegian National Auditing Office.

Røe, P. G. & Jones, K. (1997). *Bystruktur og trafikkulykker. Hvilke byplanforhold har betydning for ulykkessituasjonen i norske byer?* Project report 1997:12. Oslo: Norwegian Institute for Urban and Regional Research.

Rypkema, D. D. (2003). The importance of downtown in the 21st Century. *Journal of the American Planning Association*, 69(1), 9–15.

SACTRA (1994). *Trunk roads and the generation of traffic*. London: Standing Advisory Committee on Trunk Road Assessment.

Saelens, B. E. & Handy, S. (2008). Built environment correlates of walking: A review. *Medicine & Science in Sports & Exercise*, 40, S550–S566.

Santarius, T.; Walnum, H. J. & Aall, C. (eds.). *Rethinking climate and energy policies: New perspectives on the rebound phenomenon*. Switzerland: Springer.

Santos, G. & Rojey, L. (2004). Distributional impacts of road pricing: The truth behind the myth. *Transportation*, 31, 21–42. https://doi.org/10.1023/B:PORT.0000007234.98158.6b

Schmidt, L. (2007). *For tett? Fortetting, planprosess og bokvalitet i nye byboligprosjekter*. NIBR-rapport 2007:12. Oslo: Norwegian Institute for Urban and Regional Research.

Schmidt, L. (2014). *Kompakt by, bokvalitet og sosial bærekraft*. NIBR-rapport 2014:12. Oslo: Norwegian Institute for Urban and Regional Research.

Seiler, A. (2003). Effects of infrastructure on nature. In COST Action 341, *Habitat fragmentation due to transportation infrastructure: The European review*, pp. 31-50 and 201-211. Luxembourg: European Commission Directorate-General for Research.

Shreevastava, A.; Bhalachandran, S; McGrath, G. S.; Huber, M. & Rao, P. S. C. (2019). *Paradoxical impact of sprawling intra-Urban Heat Islets: Reducing mean surface temperatures while enhancing local extremes*. Scientific Reports (2019) 9:19681. Switzerland: Springer Nature. https://doi.org/10.1038/s41598-019-56091-w

Sjaastad, M., Hansen, T. & Medby, P. (2007). *Bokvalitet i by og etterspurte bebyggelsestyper*. Oslo: SINTEF Byggforsk.

Skrede, J. & Berg, S. K. (2019). Cultural heritage and sustainable development: The case of urban densification. *The Historic Environment: Policy & Practice*, 10:1, 83-102, DOI: 10.1080/17567505.2019.1558027.

Statens vegvesen region øst (2008). E18 Knapstad - E6 i Folio: Konseptvalgutredning. Oslo: National Public Roads Administration. Accessed March 2021 from https://www.regjeringen.no/globalassets/upload/sd/vedlegg/kvu-rapporter/177048_1_p_konseptvalgutredning_e18-e6.pdf?id=2274733.

Statistics Norway (2020). Areal og befolkning i tettsteder, etter tettsted, tid og statistikkvariabel. Oslo/Kongsvinger: Statistics Norway. Accessed November 15, 2020. https://www.ssb.no/statistikkbanken.

Statistics Norway (2021a). Construction cost index, by type of road constructions, contents and quarter. Table 05717. Oslo: Statistics Norway. Accessed March 2021 from

Statistics Norway (2021b). Reiser til utlandet (1 000), etter land, formål, statistikkvariabel og kvartal. Table 08662. Oslo: Statistics Norway. Accessed March 2021 from https://www.ssb.no/statbank/table/05717.

Statistics Norway (2021c). Reiser, etter reisetype, statistikkvariabel og kvartal. Table 10140. Oslo: Statistics Norway. Accessed March 2021 from https://www.ssb.no/statbank/table/10140/.

Stefansdottir, H.; Næss, P. & Ihlebæk, C. (2019). Built environment, non-motorized travel and overall physical activity. *Travel Behaviour and Society*, 16, 201-213.

Stockholms län (2019). *Cyklingens hälsoeffekter i Stockholms län 2030 - Folkhälsoeffekterna av dagens cyklande i Stockholms län jämfört med målet om 20 procent cykelandel 2030*. Stockholm: Stockholms län. Accessed March 2021 from https://cykelframjandet.se/wp-content/uploads/2019/05/cyklingens-halsoeffekter-i-stockholms-lan-2030-heat-pm-2019-05-10.pdf

Styringsgruppen for Oslopakke 3 (2019). Oslopakke 3: Handlingsprogram 2020 – 2023. Accessed March 2021 from https://www.vegvesen.no/_attachment/2711895/binary/1329720?fast_title=Handlingsprogram+Oslopakke+3+perioden+2020-2023.pdf.

Sullivan, D. E. (2006). Materials in use in U.S. Interstate Highways. Denver: U. S. Geological Survey. Accessed March 2021 from https://pubs.usgs.gov/fs/2006/3127/2006-3127.pdf.

Teigland, J. (1999). Predictions and realities: impacts on tourism and recreation from hydropower and major road developments. *Impact Assessment and Project Appraisal*, 17(1), 67-76, DOI: 10.3152/147154699781767972

US Energy Administration Information (2013). Apartments in buildings with 5 or more units use less energy than other home types. Today in energy, June 18, 2013. Accessed March 2013 from https://www.eia.gov/todayinenergy/detail.php?id=11731.

Vatne, E. (1993). *Agglomerasjonsøkonomi og eksternaliteter. Virkninger for økonomisk vekst og territorriell utvikling*. SND-report 49/93. Oslo: SND.

Vuckovic, M.; Loibl, W.; Tötzer, T.& Stollnberger, R. (2019). Potential of urban densification to mitigate the effects of heat island in Vienna, Austria. *Environments* 2019, 6, 82; doi:10.3390/environments6070082.

Wangsness, P. B.; Amundsen, A. & Franklin, J. (2018). Vegprising. In: Institute of Transport Economics (TØI), eds., *Tiltakskatalog for transport og miljø*, https://www.tiltak.no/b-endre-transportmiddelfordeling/b-1-styring-bilbruk/b-1-1/

WHO (2016). *Riding towards the green economy - cycling and green jobs*. Accessed March 2021 from https://www.euro.who.int/en/health-topics/environment-and-health/Transport-and-health/publications/2016/riding-towards-the-green-economy-cycling-and-green-jobs.-executive-summary-2016.

Williams, J. H. (2012). The technology path to deep greenhouse gas emissions cuts by 2050: The pivotal role of electricity. Berkeley: Lawrence Berkeley National Laboratory, accessed March 2021 from https://escholarship.org/uc/item/2mz2472z.

Wolday, F.; Næss, P. & Tønnesen, A. (2019). Workplace location, polycentricism and car commuting. *Journal of Transport and Land Use*, 12(1), 785-810.

Wolfe, P. J.; Yim, S. H. L.; Lee, G.; Ashok, A.; Barrett, S. R. H. & Waitz, I. A. (2014). Near-airport distribution of the environmental costs of aviation. *Transport Policy*, 34, 102–108.

Appendix: Relevant additional impacts of energy-efficiency measures in the transport sector, and their quantifiability

In the 'positive or negative' column, the importance of the effect has been suggested by the following symbols. Positive effects: +++ = substantial; ++ = considerable; + = moderate. Negative effects: --- = substantial; -- = considerable; - = moderate. +/- indicates that the effect is ambiguous..

Impacts	Positive or negative	Quantifiable at EU/EU region scale?	Quantifiable in specific city cases	Non-quantifiable
From energy-efficient urban spatial development:				
Environmental impacts				
Reduced conversion of natural areas and farmland into building sites	+++	x	x	
Preserving areas for hiking, skiing and other kinds of outdoor recreation that needs large and continuous non-developed areas	+++			x
Increased pressure against intra-urban green areas and other open space	--		x	
Increased pressure to demolish heritage buildings	-			x
Reduced greenhouse gas emissions	+++	x	x	
Reduced overall emission of other pollutants (but increased concentration of emissions)	+/-			x
Reduced overall noise from traffic (but possibly more people being exposed to noise)	+/-			x
Increased vulnerability to climate change				x
Reduced material consumption for infrastructure and buildings	++			x
Reduced energy requirement for space heating and cooling	++			x[16]
Rebound effects	-			-
Social impacts				
Accessibility for residents who are unable to drive	+++			x
Reduced travel time and easier daily-life schedule	++			x
Easier access to jobs and service facilities	++			x
Impacts on housing quality	--			x
Housing affordability	--			x
Reduced investment and operational costs for infrastructure	+			x
Health impacts	+/-		x	
Urban vibrancy	++			x
Agglomeration benefits	+/-			x
From stop in motorway construction:				
Environmental impacts				
Reduced conversion of natural areas and farmland into road construction sites	+++	x	x	
Increased conversion of natural areas and farmland into railway construction sites	--			x
Preserving areas for hiking, skiing and other kinds of outdoor recreation	++			x
Reduced greenhouse gas emissions	+++	x		

Reduced material consumption for infrastructure	+++			x
Reduced noise, air pollution and pollution of watercourses, soil and groundwater	+++			x
Social impacts	+			x
Impacts on traffic accidents	+			x
Reduced investment and operational costs for transportation infrastructure	+			x
Avoiding reduced competitiveness for transit	+			x
Avoiding social impacts pertaining to the construction period.	++			x
Impacts on travel time	+/-			x
Region enlargement	+/-			x
From stop in airport expansion:				
Environmental impacts				
Reduced greenhouse gas emissions	+++	x		
Reduced material consumption for infrastructure	++			x
Reduced noise, air pollution and pollution of watercourses, soil and groundwater	++			x
Reduced conversion of natural areas and farmland	+			x
Social impacts				
Avoiding reduced competitiveness for train	++			x
Reduced investment and operational costs for airport infrastructure	++			x
Change in destinations for leisure trips	+			x
From economic instruments for transportation demand management:				
Environmental impacts				
Reduced greenhouse gas emissions	+++	x		
Reduced air pollution in urban areas	+++			x
Reduced noise in urban areas	+++			x
Social impacts				
Better competitive power for transit, leading to improved transit provision	++			x
Possibly using revenues for transit investment and operation	++			x
Change in destinations for leisure trips	+/-			x
From other demand management strategies such as car-sharing, privileged lanes for energy-efficient vehicles, etc.				
Environmental impacts				
Reduced greenhouse gas emissions	++			x
Reduced air pollution in urban areas	++			
Reduced noise in urban areas	++			
Reduced land-use for parking in urban areas	+			x
From improved infrastructure for walking and cycling				
Environmental impacts				
Improved health	++	X	X	
Social impacts				
Increased employment	+		X	
From improved vehicle technology:				

Environmental impacts				
Reduced greenhouse gas emissions	+++			x
Reduced air and noise pollution	+++			x
Rebound effects	--			x
Social impacts				
Rise of autonomous vehicles	+			X
Increased car sharing, reduced car ownership	+			X
More electric planes and fewer airports	+			X
Health effects	++		X	X
Reduced traffic accidents	+/-			X

Notes

[1] For reviews, see Handy et al. (2002); Cao et al. (2009); Saelens & Handy (2008); Ewing & Cervero (2010); Næss (2012). Base don stte-of-the-art research literature, the D2.1 deliverable report identified the following spatial characteristics ase the most important ones for maintaining accessibility while reducing transport volumes and promoting a shift from energy-demanding travel modes to modes requiring less energy per person kilometer traveled or ton kilometer of freight:

- High population density for the city as a whole (the continuous urbanized area, i.e. the morphological city) (See, for example, Newman & Kenworthy (1989); Næss (1993); Næss et al. (1996); Kenworthy (2003).
- Residential location close to the main center of the city/the metropolitan area. For recent European studies, see, for example, Næss et al. (2017a), Næss et al. (2019); Elldér (2014) Engebretsen et al. (2018).
- Location of specialized, labor-intensive or visitor-intensive jobs close to the main center of the city/the metropolitan area. For recent European studies, see, for example, Wolday al. (2019), Engebretsen et al. (2018).

Due to lack of European-scale spatial dataset on jobs distribution, the impacts of workplace location were not quantified in the D2.1 report.

[2] Road construction that increases the standard or capacity of the road network normally results in induced additional traffic, especially in cities and urban regions where the congestion level is high. The induced traffic includes changes in travel modes (away from transit travel and freight by rail) as well as longer travel and freight distances. Improved transit provision also tends to induce additional travel distances but on the other hand it tends to induce some people that would otherwise have traveled by car to opt for public transit instead. (SACTRA, 1994; Hills, 1996; Mogridge, 1997; Litman, 2021a; Noland & Lem, 2002; Dovre & TØI, 2012.)

[3] See Litman, 2019; Norconsult, 2020; Odeck & Bråthen, 2008; Dunkerley et al., 2014; Washbrook et al., 2006.

[4] See, for example, European Commission, 2020; European Automobilie Manufacturers Association, 2019; Danish Energy Agency, 2015.

[5] Based on the differentials in population densities in 2050 assumed in the D2.1 report between the Energy-efficiency scenario and the Business as usual scenario for large, medium-size and small cities in Northern, Western/Central, Southern and Eastern Europe (Næss et al., 2020) and the proportions of the population of the EU/EEA area belonging to each of these city sizes and regions of Europe, the land conversion due to urban spatial conversion over the period 2020-2050 has been calculated to be 1055 km^2 in Northern Europe, 3830 km^2 in Western and Central Europe, 1210 km^2 in Southern Europe and 2850 km^2 in Ester Europe, mounting to 8950 km^2 in total.

[6] Assuming that 25% of the energy produced for the electricity used for intra-metropolitan transportation by electrical vehicles in 2050 will stem from fossil sources, and that the electricity proportion of the energy used for intra-metropolitan transportation was 5% in 2020 (cf. the D2.3 report, Abid et al., 2021), of which 40% from fossil fuels (Eurostat, 2021), the average fossil energy proportion of the energy used for intra-metropolitan transportation over the period 2020 – 2050 will be 61%. Given a differential in energy use 2020-2050 between the energy-efficiency scenario and the business as usual scenario for urban spatial development of 8200 PJ (Næss et al., 2020) and average CO_2 emissions of 73.1 tons per TJ (Jurich, 2016), this gives an additional emission of 366 million tons of CO_2, rounded off to 370 million tons. The above figures are before taking vehicle energy efficiency improvements into consideration. According to Abid et al. (2021), Figure 16, and assuming that air transportation makes up approx. 40% of the category "Electricity Train / bus /trucks / ships / aircrafts", energy use for surface transportation in 2050 will be only 43% of the level in 2020 despite an increase in transportation volume of 28%. This implies that the energy use per person km in 2050 will be only 34% of the level in 2020. We assume the same vehicle energy efficiency rate for freight as for passenger transportation. Adjusting for vehicle energy efficiency improvement, the reduction in CO_2 emissions due to energy-efficient urban spatial development will then be 124 million tons, rounded off to 125 million tons.

[7] Several older studies have quantified energy-saving benefits from constructing a higher proportion of apartment buildings and a lower proportion of detached single-familyhouses and other low-density housing types. However, since building insulation standards have improved substantially over recent decades, we do not consider these studies suitable for making quantitative estimations of the energy-efficiency gains from constructing a higher proportion of apartment buildings and a lower share of lower-density residential buildings.

[8] This could, however be counteracted by taxation on profits from rising land values, where revenues from these taxes could be spent on subsidies for affordable housing.
[9] According to the D2.1 report (Næss et al., 2020), the Business as usual scenario includes the construction of 95,000 km new motorways (urban as well as non-urban) and a capacity increase of existing urban motorways equivalent to the construction of 12,500 km of new motorways. Together, this makes up 107,500 km. We cautiously assume that the average number of lanes of the motorways constructed will be 2.5 in each direction. Based on the European Commission (2018), we further assume an average lane with of 3.75 m, an obstacle-free shoulder of on average 7 meters on each side of the motorway and an average width of the central median lane separator of 1.5 m. The total width of the band converted when constructing motorways will then be on average (3.75*5 + 1.5 + 2*7) meters = 34,25 m. Moreover, the construction of crossings with other roads (interchanges) represent additional land conversion. We roughly assume each such crossing to represent a land conversion equivalent to 1 km of road construction, and that the mean distance between interchanges is 5 km. This implies a 20% additional land conversion compared to motorways without any interchanges. Parts of some motorways are tunnels, but we here assume that the land saved when constructing the road underground is balanced by the need for landfill areas to dispose stone and gravel excavated when constructing the tunnels. The number of square kilometers of land conversion in the Business as usual alternative due to motorway construction will thus be 107,500*0,03425*1,2 km^2, amounting to 4418 km^2, which has been rounded this off to 4400 km^2.
[10] Assuming that 25% of the energy produced for the electricity used for surface transportation by electrical vehicles in 2050 will stem from fossil sources, and that the electricity proportion of the energy used for intra-metropolitan transportation was 5% in 2020 (cf. the D2.3 report, Abid et al., 2021), of which 40% from fossil fuels (Eurostat, 2021), the average fossil energy proportion of the energy used for surface transportation over the period 2020 – 2050 will be 61%. Given a differential in energy use for transportation 2020-2050 between the scenarios with and without motorway construction of 31,000 PJ, and 625 additional PJ pertaining to the construction period (Næss et al., 2020) and average CO_2 emissions of 73.1 tons per TJ (Jurich, 2016), this gives an additional emission of 1410 million tons of CO_2, rounded off to 1400 million tons. The above figures are before taking vehicle energy efficiency improvements into consideration. Adjusting for vehicle technology improvement, the reduction in CO_2 emissions due to halt in motorway construction will, based on similar assumptions as for urban spatial development, be 477 million tons of CO_2, rounded off to 480 million.
[11] In the D2.1 report, energy saving over the period 2020-2050 due to flight taxation and avoidance of airport expansions is estimated to be 40,000 PJ (Næss et al., 2020). Here, we assume that half of these savings are due to flight taxes and the other half due to halt in airport expansions. Moreover, assuming that 25% of the energy produced for the electricity used for air transportation by electrical airplanes in 2050 will stem from fossil sources, and that the electricity proportion of the energy used for air transportation was zero in 2020 and will increase to approx. 40% in 2050 (cf. the D2.3 report, Abid et al., 2021, fig. 16), of which 40% from fossil fuels (Eurostat, 2021), the average fossil energy proportion of the energy used for air transportation over the period 2020 – 2050 will be 88%. Given a differential in energy use for air transportation 2020-2050 between the scenarios with and without airport construction of 20,000 PJ and average CO_2 emissions of 73.1 tons per TJ (Jurich, 2016), this gives an additional emission of 1290 million tons of CO_2, rounded off to 1300 million tons. The above figures are before taking vehicle energy efficiency improvements into consideration. According to Abid et al. (2021), Figure 16, and assuming that air transportation makes up approx. 40% of the category "Electricity Train / bus /trucks / ships / aircrafts", energy use for surface transportation in 2050 will be only 4% higher than the level in 2020 despite an increase in air travel of 72% (Capros et al, 2016). This implies that the energy use per person km for air transportation in 2050 will be only 60% of the level in 2020. Adjusting for aircraft energy efficiency improvement, the reduction in CO_2 emissions due to halt in airport expansions will then be 777 million tons, rounded off to 780 million tons.
[12] The change of destinations identified in these statistics was not caused by lack of airport capacity but by Covid 19 restrictions on international journeys.
[13] In several regions in Europe it is intended to make cycling more attractive. Even countries are developing national plans for promoting cycling, for instance Denmark (Danish Ministry of Transport, 2014). In the Netherlands, you can ride from Arnhem to Nijmegen without a single stop. There are heavy investments in bicycle infrastructure in Sweden, especially in Region Skåne (Region Skåne, 2018).
[14] In the D2.1 report, energy saving over the period 2020-2050 due to flight taxation and avoidance of airport expansions is estimated to be 40,000 PJ (Næss et al., 2020). Here, we assume that half of these savings are due to flight taxes and the other half due to halt in airport expansions. Moreover, the D2.1 report estimated the energy savings due to taxes and fees on surface transportation to be 16,100 PJ (Næss et al., 2021, ibid.) Based on the same assumptions about energy sources as for surface and air transportation as assumed regarding

urban spatial development, surface transportation infrastructure development and airport expansions, fees and taxes on surface and air transportation in the energy efficiency scenario will give a reduction in CO_2 emissions over the period 2020-2050 of 2004 million tons, rounded off to 2000 million tons. The above figures are before taking vehicle and aircraft energy efficiency improvements into consideration. Based on the assumptions about vehicle and aircraft energy efficiency improvements applied for urban spatial development, surface transportation infrastructure development and airport expansions, the reduction in CO_2 emissions due to fees and taxes on surface and air transportation in the energy efficiency scenario will then be 10196 million tons, rounded off to 1000 million tons.

[15] Although fuel costs make up a small proportion of the costs of being a car owner and user, studies show that there is a price elasticity between fuel price and km driven. In a European context, De Jong & Gunn (2001), quoted from Litman (2019), found an overall elasticity between fuel price and km driven of 0.26, which means that 10% additional expenditure on fuel would on average lead to 2.6% fewer km driven. If we assume that more energy-efficient vehicles will lead to less expenditure per km for driving, this suggests that about one fourth of the energy and emissions savings due to less energy use per km could be compensated by more driving. Admittedly, this is a very uncertain estimate, and we therefore do not consider it possible to give a quantitative estimate of the rebound effect.

[16] Several older studies have quantified energy-saving benefits from constructing a higher proportion of apartment buildings and a lower proportion of detached single-family houses and other low-density housing types. However, since building insulation standards have improved substantially over recent decades, we do not consider these studies suitable for making quantitative estimations of the energy-efficiency gains from constructing a higher proportion of apartment buildings and a lower share of low-density residential buildings.