Journal of Sustainable Development of Energy, Water and Environment Systems

http://www.sdewes.org/jsdewes

Year XXXX, Volume XX, Issue X, 1090426

Quantification of Savings for the European Transport Sector through Energy Efficient Urban Planning

Hamza Abid[1], **Mikkel Strunge Kany**[1], **Brian Vad Mathiesen**[1], **Petter Næss**[2], **Morten Elle**[1], **David William Maya-Drsydale**[1]*

[1] Department of Planning - Aalborg University, Copenhagen, Denmark
hamzaa@plan.aau.dk
[2] Department of Urban and Regional Planning - Norwegian University of Life Sciences, Oslo, Norway

Cite as: Abid, H., Strunge Kany, M., Mathiesen, B. V., Næss, P., Elle, M., William Maya Drysdale, D., Quantification of Savings for the European Transport Sector through Energy Efficient Urban Planning, J.sustain. dev. energy water environ. syst., 1100426, DOI: https://doi.org/10.13044/j.sdewes.d10.0426

ABSTRACT

The transport sector accounts for around 30 % of Europe's final energy consumption. To meet the EU's decarbonization goals by 2050, it is important to quantify the energy savings potential in technology, infrastructure, and planning. This study analyses the European transport sector in the context of traditional and energy-efficient urban development. The latter demonstrates a scenario where accessibility is provided through enhanced proximity to a destination rather than through increased mobility, where mobility is shifted from roads and aviation towards rail. This development is ensured by, among other things, investing heavily in urban and inter-urban transport systems and abstaining from building new freeways and airports. The results indicate that it is not only desirable but economically beneficial to shift towards an energy-efficient transport system. The development of the European transport sector in the proposed trajectory significantly reduces annual final energy demand, and the investment made in new infrastructure for rail, bikes, and walkable urban areas are paid back by the reduced cost from road transport.

KEYWORDS

Transport scenarios, Energy-efficiency, Urban-development, Energy-savings, Urban-planning.

INTRODUCTION

In an attempt to achieve the climate targets of the Paris Agreement, the European Union aims to be net-zero Green House Gas (GHG) emissions by 2050 [1]. Despite the prevalent policy measures, the transport sector has proved to be the most challenging to decarbonize. It accounts for around a quarter of the European GHG emissions, and while other sectors have seen a decline of around 20-50 % since 1990, the transport sector's emissions have since increased by almost around 20 % [2].

---

* Corresponding author

In the horizons of urban development, the use of energy in transport is very closely linked to the design of urban spatial development, existing and planned future infrastructure, economic policies, and the dominant modes used for freight and passenger transport. The European Commission has also outlined the role of cities and local urban planning as one of the key areas of action [3]. However, estimating the energy efficiency potentials in urban spatial and infrastructure development has proved to be a challenging task; this is even more so for the case of an inter-connected region like the European Union comprising a multitude of geopolitical, cultural, and social entities.

Much research has been focusing on how the built environment characteristics influence travel and transportation energy use. For an overview of the general state-of-the art in this field one could visit Handy et al [4]; Cao et al [5]; Saelens and Handy (2008) [6]; Ewing and Cervero (2010) [7]; and Næss (2012) [8]. The main challenge is seen as maintaining accessibility while reducing transport volumes and sustaining a shift form energy demanding travel modes to travel modes requiring less energy per person kilometer traveled or ton kilometer of freight. Based on the- state-of-the art research such as the ones mentioned above, we consider the following three spatial characteristics to be most important:

First characteristic: High population density for the city as a whole, understood as the continuous urbanized area (i.e. the morphological city). Newman and Kenworthy (1989) [9] made the connection between urban density and energy use for transport very clear. This groundbreaking study has been supported by a number of later studies, see for instance Næss (1993) [10]; Næss (1996) [11] and Kenworthy (2003) [12].

Second characteristic: Residential location close to the main center of a larger city/metropolitan area. Numerous studies shows that the number of kilometers traveled decrease, the closer the residential area is to the center, and at the same time the travel modes are shifting towards modes requiring less energy per person kilometer. For recent European studies, see for example Næss et al. [13](2017); Næss et al. (2019) [14]; Elldér (2014) [15] and Engebretsen et al. (2018) [16].

Third characteristic: Location of specialized labour-intensive or visitor-intensive jobs close to the main center of the city/metropolitan area. This has been seen in several studies, among the recent studies are Engebretsen et al. (2018) [17] and Wolday et al. (2019) [18].

A large volume of existing literature concerning the impacts of built environment (i.e. land use, buildings, and transport infrastructure) characteristics on transport volumes and modal split has been reviewed in relation to the study presented in this article (for the full review, visit P. Næss, F. Wolday, M. Elle, H. Abid, M. Strunge Kany, and B. Vad Mathiesen (2020) D2.1 Report on energy efficiency potentials in the transport sector) [19]. It is evident that the studies are very diverse and they have been carried out in different cities of different sizes and different countries, thus representing different geographical, social, political, and cultural contexts. The same applies to the few studies about the travel behavioral effects of economic instruments to regulate traffic, such as road tolls and parking fees, where most studies are from the USA. Some cities are well represented in a number of studies and indicate – on a case level – that urban development following the three above mentioned characteristics are impacting the energy use related to transport in a positive way, making it representing an energy efficient urban development (Næss et al. (2011)[20], Vold (2006) [21], Tittu et al. (2020) [22]).The existing studies on built environment impacts on transportation are of varying methodological quality and focus on different aspects.

For example, some studies focus only on commuting, others on non-work travel (e.g. shopping); some studies include only residents of the morphological city (or parts of it), some include residents from all over the metropolitan area; and some focus only on local or intra-metropolitan transport while other studies also include travel outside the metropolitan area (such as holiday trips).

Hence, the difficulty in generalizing the effects of energy-efficient urban planning on travel behavior is quite evident. It is on the other hand quite evident that it is necessary to – despite the difficulties – to try to generalize the effects. This study aims to provide a quantitative assessment for an exploratory scenario that outlines potential savings through efficient urban planning mainly in terms of spatial development, transport infrastructure, and economic instruments. The exploratory scenario is put in contrast to traditional urban development that is considered as a business as usual scenario. The results for the two scenarios are compared in terms of final energy demand and annualized systems costs to assess the potential impact of introducing best practices in urban spatial and infrastructure development.

METHOD

To analyze the extent of the impact of energy-efficient urban development practices as compared to traditional development practices, a two-stepped approach is used in this study. First, a reference model for the European transport sector comprising 28 European countries is set up using a bottom-up analysis tool. This model encapsulates the main indicative output features to compare the two scenarios such as the final transport energy demand, transport activity demand, and transport systems costs. Once a reference model for a base year is established, then the transport demand is projected into the future considering different traffic growth rates and modal shift rates. These growth and modal shifts rates are key in establishing a baseline EU28 traditional model and an alternate EU28 transport model based on energy-efficient urban spatial and infrastructure development. The second step is mainly focused on estimating, to the extent possible, the future annual growth and modal shift rates for the two scenarios. These steps are further elaborated in the following sections.

Reference Model

To create a reference model for EU28, a bottom-up approach is used where different transport data is gathered from a variety of different sources and analyzed accordingly. Figure 1 shows the major inputs and some of the outputs that result in a EU28 reference model for a base year.

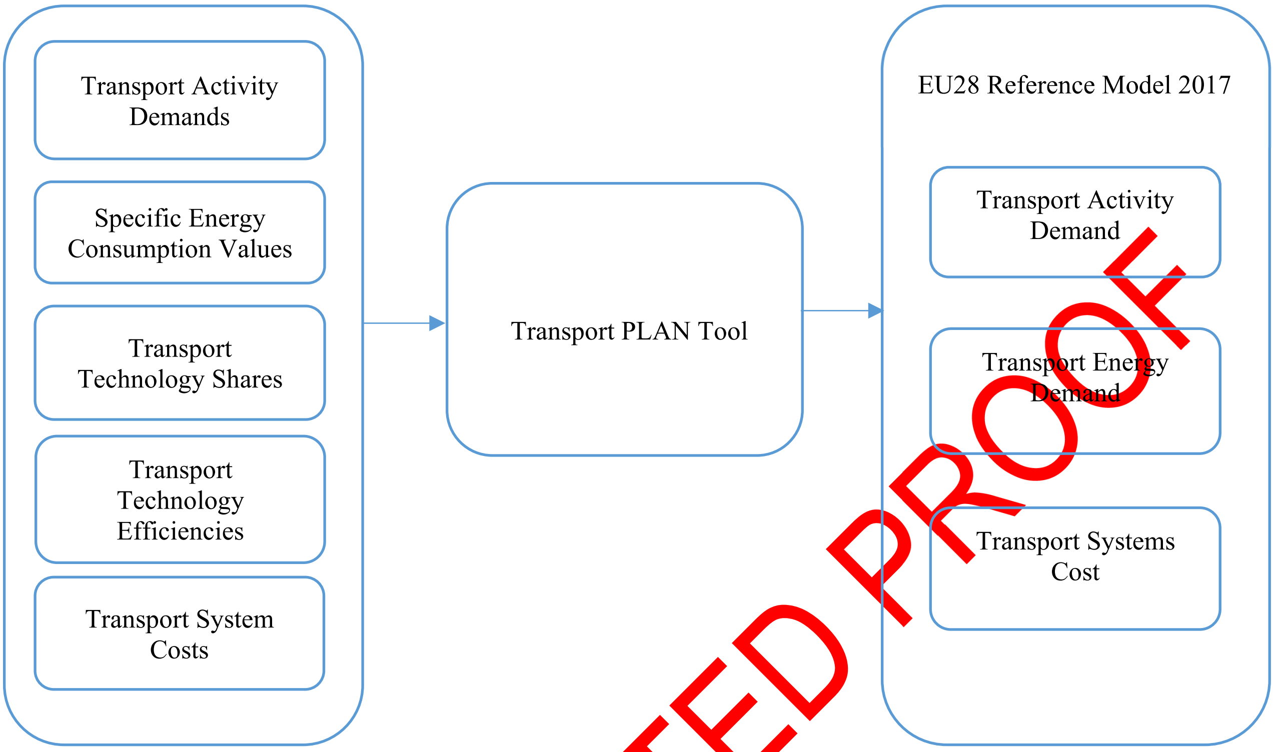

Figure 1. The methodology followed for creating a EU28 reference transport model

A transport scenario modeling tool called 'TransportPLAN' is used to create the reference model and the two scenarios (baseline and energy-efficient urban spatial development) are built on top of the reference model. The tool was originally developed as a part of the CEESA project [23]. TransportPLAN allows for the user to create detailed transport scenarios with five-year intervals from 2020 to 2050. For all modes of transport, the transport demand, share of fuels and technologies, and vehicle and infrastructure costs are found through statistics, models, and publications and make up the foundation of the scenario development. The transport sector is split into two parts; passenger and freight, each of which has different modes of transport as shown in Figure 2.

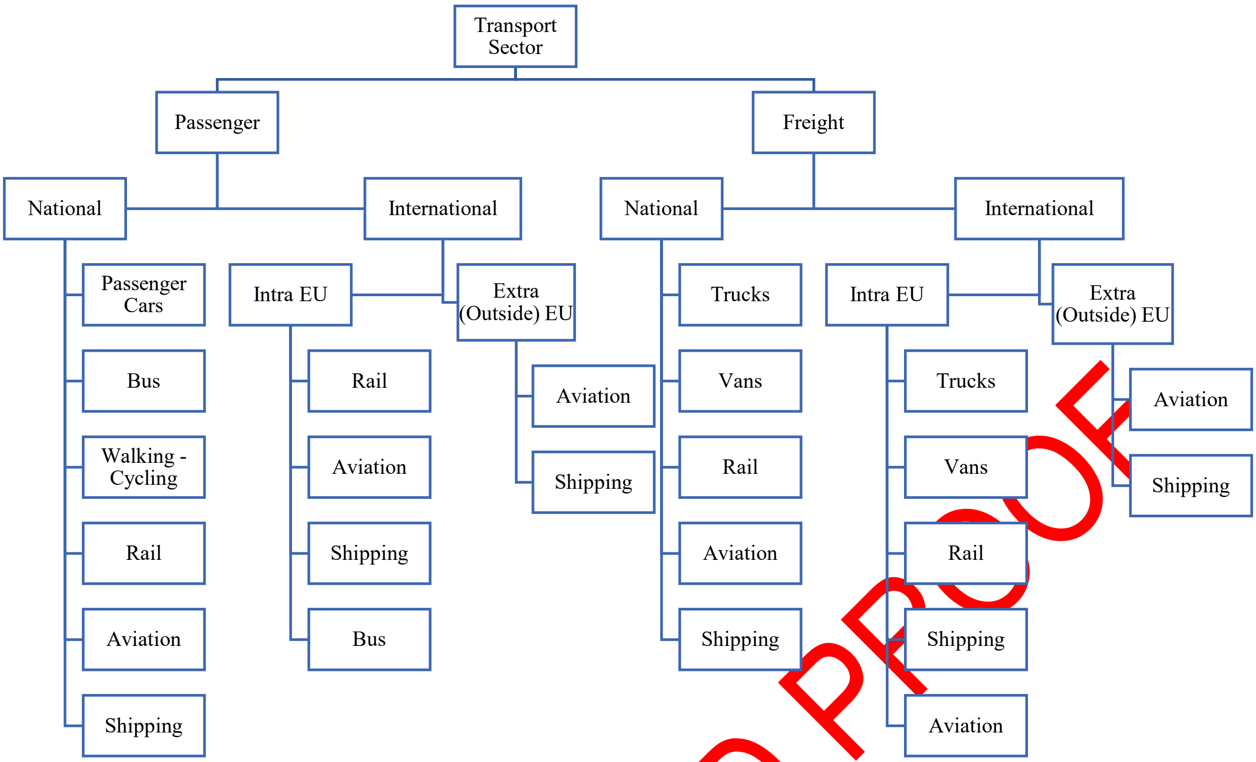

Figure 2. Modes of transport analyzed in TransportPLAN

The transport demand of passenger cars, trucks, buses, and bicycles/walking are analyzed based on different distance bands whereas a split between international and national transport is applied for air, rail, and sea transport. Determination of transport energy demand and transport activity demand is key in estimating the energy efficiency potentials for the transport sector.

The data inputs include different transport demand data, transport system cost data, and transport technology efficiencies. Different sources have been used to make reasonable estimates for the accumulation of transport demand. These sources include national travel surveys from individual countries, 'EU transport in Figures' (Eurostat statistical pocketbook) [24], and Eurostat database [25]. The specific energy consumption values for both passengers and freight transport were estimated for each country and were, along with the transport activity, used to calculate the overall energy demand of each mode. Finally, the fuel share distribution for each mode is obtained from the Eurostat database [25]. The energy efficiency of all vehicles used in the analysis follows the methodology introduced in the Danish transport system model "Alternative Drivmidler" (AD) [26]. The methodology is adapted to display the energy efficiencies in a Danish context, but it is estimated that the methodology is applicable in a European context. The transport technology efficiencies and the cost of road vehicles and charging stations are found in the Danish Energy Agency's transport model [26]. The transport system infrastructure cost for road and rail infrastructure is calculated for each country based on historic infrastructure investment and maintenance cost. [27]

Regarding system costs, only the transport systems costs related to road vehicles' annual investment and operation and maintenance costs were considered. Because of large deviations and unavailability of reliable references, the vehicle costs data for other modes such as rail, shipping, and aviation are not included in the analysis. However, the annual fuel cost for all types of vehicles, annualized investment, maintenance cost related to road and rail infrastructure, and the annual cost of expanding the electric vehicle charging infrastructure were included.

The results from the TransportPLAN scenario tool as shown in Figure 1 are the annual transport demand in all modeled years, the energy consumption by mode of transport and type of fuel, and the costs associated with vehicles, fuel, and infrastructure.
To develop transport scenarios towards 2050, TransportPLAN allows for adjustment of five main parameters:

1. Annual growth of transport demand
2. Modal Shift rates
3. Market share of transport technologies
4. Annual vehicle technology energy efficiency improvements
5. Annual capacity utilization rates

The parameters enable the user to create alternative scenarios that are made of:

- Different levels of transport demand
- Variable rates of implementation of renewable transport technologies
- Move transport demand between modes of transport,
- Improve the energy efficiency of conventional vehicles, and
- Improve the capacity utilization for both passenger and freight transport.

Since the purpose of this study is to provide an estimate of the potential in energy savings due to energy-efficient urban planning, the two parameters that were varied in this study are the annual growth rates of transport demand and modal shifts. Both of these parameters form the basis of differences in the traditional growth and the energy-efficient growth scenario.

The market share of transport technologies, vehicle technology energy efficiency improvements, and capacity utilization rates remain largely unvaried in both scenarios, except for some inherent (to a small degree) increase in capacity utilization due to inter-dependence of urban spatial development and capacity utilization. The values from these are taken from disaggregation of the data provided by the PRIMES model as described in the Clean Planet for All report [28].

The EU28 transport reference model set up in this study is constrained by several system boundaries that might affect the results, albeit not to a great extent. The model is set up on a bottom-up approach where different modes of transport have different categorizations in distance bands. This categorization is not uniformly available in the national travel surveys of the different countries up to such a fine resolution, and the available data was approximated to fit the resolution needed for the TransportPLAN tool. The results could be enhanced with the availability of better data in the future.

Scenario Development

Once the groundwork for creating a reference EU28 model for a base year is complete, the next step is to make assumptions on the development of the two future scenarios towards 2050. As mentioned before, the two scenarios considered in this study are based on traditional development vs energy-efficient urban development encompassing spatial development, economic instruments, and transport infrastructure development. Among the five major variable parameters mentioned in the previous section, the annual growth rates and the modal shift rates form the actual basis of departure for the two aforementioned scenarios in 2050.

For the baseline, traditional development scenario, the annual growth and modal shift rates are taken the same as those of the reference baseline for the PRIMES model [89].

Whereas for the energy efficiency scenario, alternate modal shift and growth rates are obtained using a comprehensive analysis. The steps are outlined below and the details of which are presented as part of the sEEnergies report D2.1 [29]. Whilst realizing the inaccuracies associated with making future growth and modal shift assumptions applied to an aggregated geographical entity such as the EU, some estimations have been made in order to explore the potential of energy-efficient urban spatial, infrastructure, and price developments.

It should be noted that these estimates are in no way an attempt to actualize or predict the future of the European transport sector but only serve as exploratory scenarios to be observed in a quantified manner. The premise undertaken is to explore an alternatie pathway of urban development to that of traditional development. To obtain the annual growth and modal shift rates for the energy efficiency scenario, the following steps were followed:

Step 1: A literature review about the impacts of urban spatial development, infrastructure development, and economic instruments such as road pricing and parking fees, on travel behavior patterns, is carried out from European studies published in peer-reviewed journals since 2000. These studies have been compiled in a manner as recommended by [30] and are used to estimate the elasticities between travel behavior and the built environment. A comprehensive list of these studies is available in Appendix B of [31].

Step 2: Based on the literature review in step 1, plausible estimates of the effects of these factors on travel behavior and current trends were carried out. This was done for urban regions with the main city of the region belonging to the following size categories:

- Large Urban Areas (greater than 1 million inhabitants)
- Medium-Sized Urban Areas (100,000 – 1 million)
- Small Urban Areas (10,000 – 100,000)

On top of these distributions, to the extent possible, the estimates of effects of the built environment, road pricing, and infrastructure development on travel behavior are also classified into four geographical regions of Europe. These are based on assumed, sociocultural, political, and urban-geographical differences of the regions and are given as:

- Northern Europe
- Western and Cent Europe
- Southern Europe
- Eastern Europe

Northern Europe	Western and Central Europe
Denmark	Austria
Finland	Belgium
Iceland	France
Norway	Germany
Sweden	Ireland
	Liechtenstein
	Luxemburg
	Netherlands
	Switzerland
	UK
Southern Europe	**Eastern Europe**
Andorra	Bulgaria
Cyprus	Check Republic
Greece	Croatia
Italy	Estonia
Macedonia	Hungary
Malta	Latvia
Portugal	Lithuania
Spain	Poland
	Romania
	Slovakia
	Slovenia

Figure 3. Distribution of EU and EFTA countries between the four defined sub-regions of Europe

Step 3: An analysis of best practices for the three energy efficiency measures:

- Urban spatial development
- Transport infrastructure
- Economic instruments such as road pricing and parking fees from (1990-2015)

identified in steps 1 and 2 is performed to estimate how much energy could have been saved if all regions of Europe had followed these best practices.

Step 4: In the next step, both the energy savings effect based on the best practices and the business as usual effects from (1990-2015) of the three measures are prolonged till 2050 to calculate the energy differentials for the two cases.

Step 5: The absolute energy saving potentials (in terms of TJ) calculated via the differential in step 4 are then converted into annual growth rates, cautiously assuming a 50/50 split in the energy savings attributable to demand reduction and modal shifts.

Peak car

As a final step, before the annual growth rates are fed into the TransportPLAN tool, the growth rates of cars are adjusted for the four regions of Europe based on the concept of 'Peak Car'. Peak car is a phrase linked to the observation of slower rates of growth, leveling off, or reduction in various measures of car use. This phenomenon has been observed in many, but not all, developed countries. The peak car discussion is contrasting the former idea that car use would grow with the growth of GDP – with the assumption that people would replace slower forms of transport with transport by a car when they could afford it. According to some studies such as [32] we have reached the fourth era of travel in which the average per-capita growth of 'daily travel' has ceased and the per capita vehicle travel grew rapidly between 1970 and 1990, but has since leveled off in most OECD countries, and is much lower in European countries than in the US [33].

One of the driving forces in the decrease in the share of car-based transport is that young people are less likely to have a driver's license and travel exclusively by car than the previous generation. The decline in the number of young people with a driver's license can be used as an indicator of a coming peak car situation [34]. This is partly due to the increasing cosmopolitan globetrotting culture popular among young adults that are increasingly replacing holiday car travel with flights to exotic international destinations. This does not consider the effects of Covid-19 on the reduction in air travel and transport demand in 2020.

There is not much data available on part of Eastern Europe. Private cars have become more common after the fall of The Berlin Wall in 1989. It can be assumed that the private car still is a symbol of freedom in Eastern Europe and the peak car situation will occur later here than in the rest of Europe. This will mirror the situation in the global South where car peak will be expected to occur later [35]. This has been implemented in 'TransportPLAN' by assuming different peak car periods for the four regions of Europe. As shown in figure 4, it is assumed that cars will peak later in Eastern Europe than in Northern, Southern, West, and Central Europe.

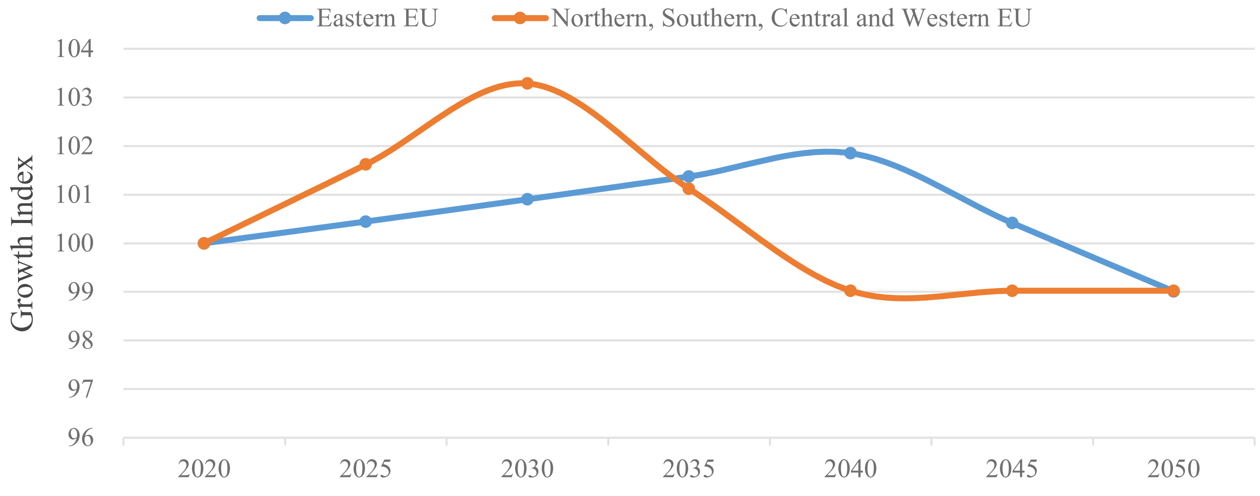

Figure 4. Passenger car evolution for four regions of Europe

Similarly, figure 5 shows the aggregated EU level traditional (reference baseline) passenger car travel demand development compared with the development when the energy-efficient practices of urban spatial, infrastructure, and road price development are introduced.

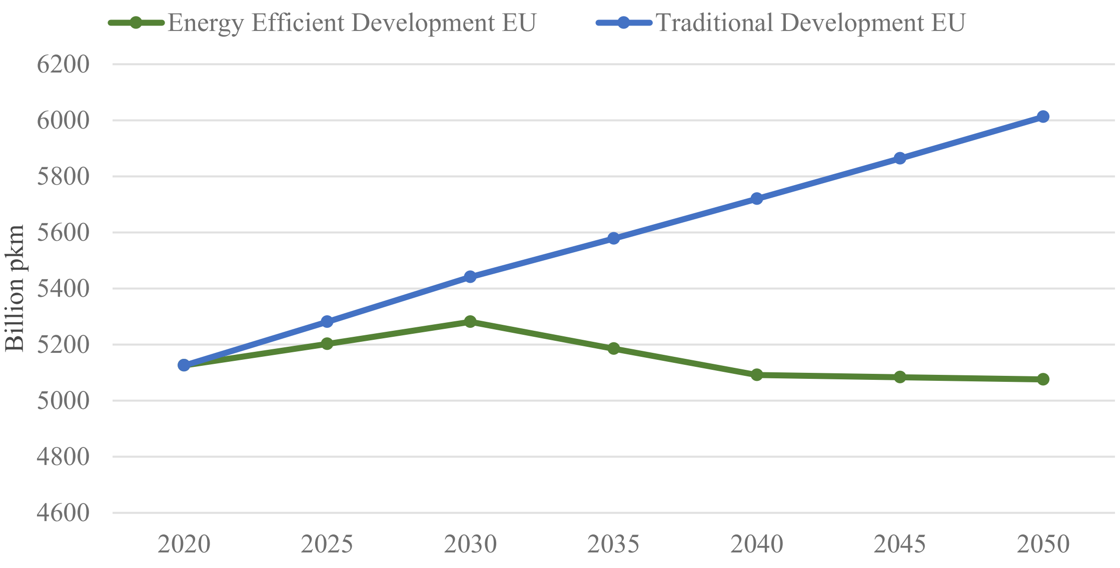

Figure 5. EU passenger car evolution with and without energy-efficient development

RESULTS AND DISCUSSIONS

This section presents the results for EU28 transport sector development from reference 2017 to future 2050. The results are shown for both the traditional and energy efficiency development scenarios. The two scenarios are compared in terms of transport demand activity and final energy demand, i.e. the end-user's energy consumption, hence without considering fuel production energy losses. Furthermore, the growth schemes will be compared based on the total transport system cost, including cost and maintenance of vehicles, fuel production cost, and cost associated with renewal and development of transport infrastructure.

Transport Activity

The composition of the current state of the transport system in the EU28 in this study is based on travel data from national travel surveys along with transnational European transport statistics. The transport activity is analyzed for passenger and freight transport separately. In the following, the current transport system is presented along with the forecasted development from 2017 to 2050 for the two different transport demand development schemes. In this work, the development of the traditional development scenario, in terms of implementation of new transport technologies and fuels, is based on the Baseline 2050 scenario from the European Commission. [28].

Passenger transport

The passenger transport demand in the 2017 reference model is split between transport in personal vehicles, public transport (buses, coaches, and railways), biking and walking, and aviation. Figure 6 shows the passenger transport activity distribution in 2017 for EU28 along with four representative countries for the four geographical regions of Europe. The majority of the passenger-kilometers are traveled in personal vehicles, which constitute 81% of the total transport demand. Public transport comprises 10% while biking and walking, and aviation makes up the remaining 2% and 10% respectively.

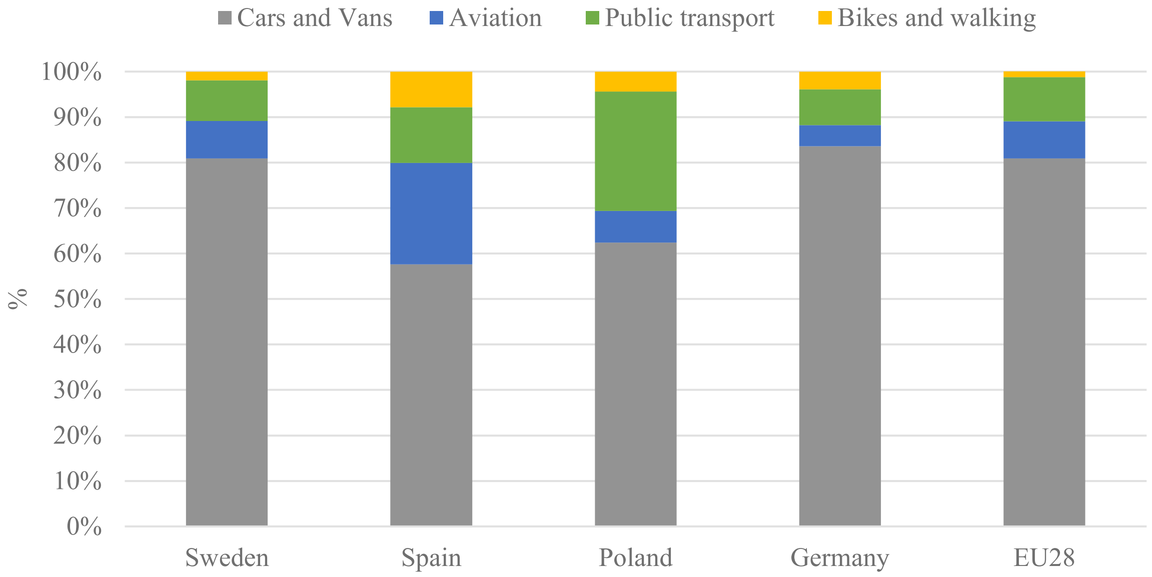

Figure 6. Passenger activity demand distribution in 2017

The share of transport demand differs from country to country. A clear pattern emerges: in Central, West and Northern Europe, the vast majority of passenger kilometers are traveled in personal vehicles and a small share in public transport, by walking or cycling or by aviation. In the Southern and Eastern regions, a much larger share of transport is covered by public transport or walking or cycling. Figure 7 shows the evolution of passenger transport demand of EU28 from 2017 till 2050 for both traditional and energy efficiency development.

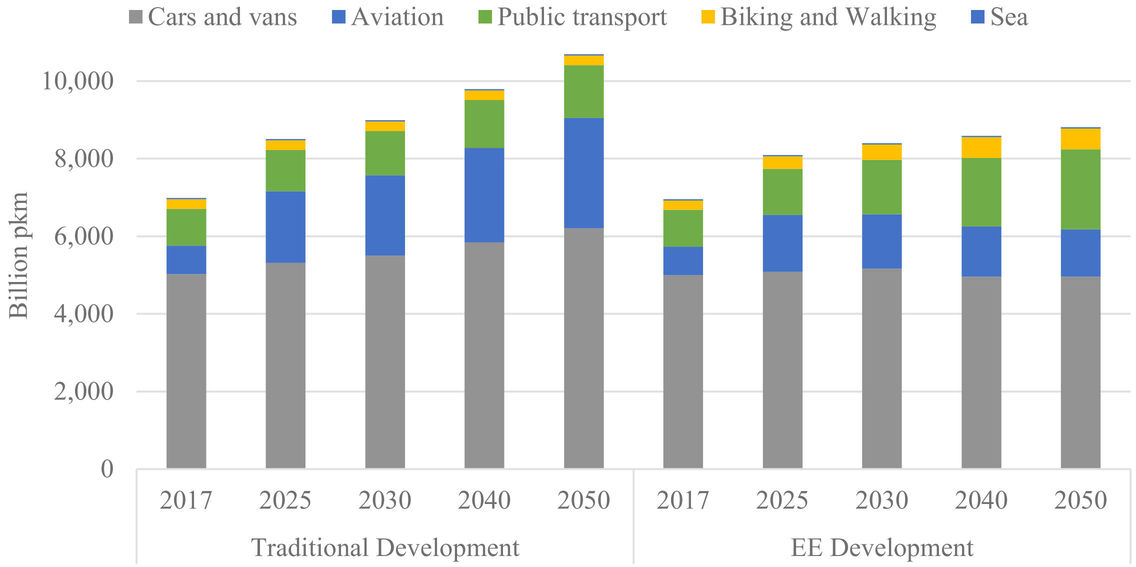

Figure 7. Passenger activity demand distribution for traditional and energy-efficient development

The development of passenger transport demand towards 2050 in the traditional urban development scheme sees an overall increase of 28% in total passenger kilometers for all modes of transport combined. This transport demand in passenger vehicles grows by 20% from 2017 - 2050, public transport by around 34%, and transport activity by air grows a whopping 84%.

In the energy efficiency scenario, the development of the passenger transport demand towards 2050 follows a different trajectory. It is interesting to note that despite implementing all the energy efficiency measures, the passenger demand for cars and vans witness no substantial reduction in 2050 compared to 2017. This is because of the huge expected increase in passenger cars and vans in EU28 in the traditional development scenario. The energy efficiency scenario displays a reduction in passenger cars and vans by 20 % as compared to traditional development by 2050. Meanwhile, measures such as road pricing incentives, energy-efficient urban spatial and infrastructure development form the basis of significant modal shifts towards public transport and bicycling, and walking. In contrast to the traditional development in 2050, the transport activity for bicycle and walking grows by 116% in the energy efficiency scenario, while the passenger-kilometers traveled by public transport (which includes buses, coaches, and railways) increase by more than 50 %. The economic instruments targeting air transport and abstaining from expanding airports amounts to a reduction of 55% in the transport demand for aviation as compared to traditional development.

Freight transport

The freight transport demand in the 2017 reference model is covered by trucks, vans, railways, aviation, and by sea. The majority of goods are transported by sea-going vessels, hence sea transport is responsible for the majority of the transport demand. Trucks and vans cover 24% of the total ton-kilometers in the EU28. 6% of the freight transport demand is covered by rail, while aviation and sea transport cover the remaining 0.5% and 69.5% respectively.

The modal split differs slightly between different countries in the EU28, depending primarily on the access to freight transport by sea. In all countries, freight transport on road covers the majority of the transport demand.The development of the freight transport demand in the EU28 is in this work only considered under the traditional urban growth scheme. The incentives briefly described above and outlined in detail in sEEnergies deliverable D2.1 [29] target passenger transport and the reduction of transport in cars and aviation mainly. The implementations will most likely have an effect on intra-metropolitan freight transport, but the effects have not been quantified in this study, hence only the development under the traditional urban growth scheme is considered.

In Figure *8*, the development of the transport demand by the mode of transport is presented. Road freight transport increases by 40% in the period from 2017 to 2050, while freight transport by rail grows by 59%. The transport demand for aviation and sea increases by 84% and 31% respectively.

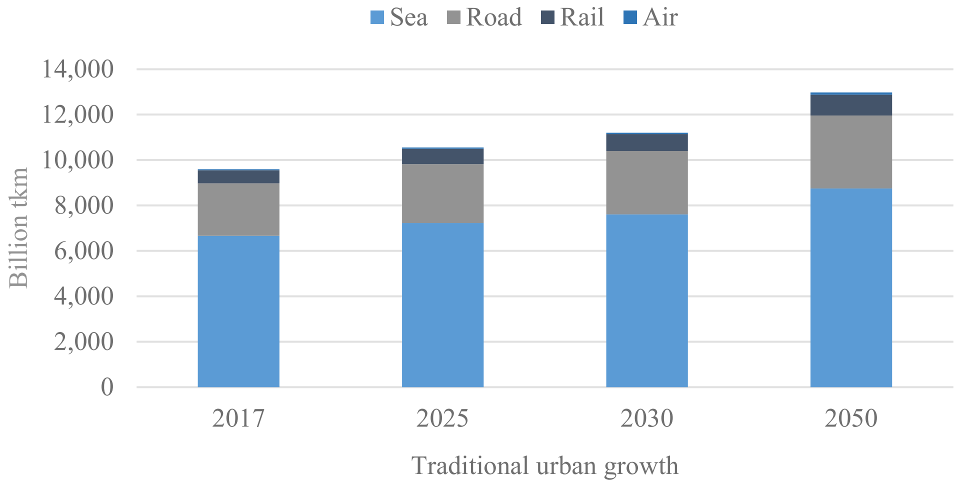

Figure 8. Freight transport activity demand for EU28

Transport Energy Demand

The final energy demand for the transport sector in the EU28 in the 2017 reference model amounts to 18 PJ. Diesel-type fuels and petrol cover 75%, while 20% is met with jet fuel. The remaining energy demand is covered with biofuels and electricity. Electricity is primarily consumed by trains and biofuels are blended with diesel and petrol for road vehicles.
In figure 9, the development of the final energy demands for the two growth scenarios is presented. The same transport demand growth observed in the EU28 under the traditional urban growth scheme is not visible in the final energy demand. Primarily due to 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 final energy demand decreases 19% from 2017 to 2050 under the traditional urban growth scheme. If the energy-efficient urban growth scheme is achieved, the final energy demand decreases 37% in the same period.

Under the energy-efficient urban growth scheme, the final energy demand for diesel and petrol for road vehicles decreases slightly. However, even more noticeable, the final energy demand for jet fuel decreases significantly when restraining from expanding airport infrastructure and implementing economic incentives to reduce air transport.

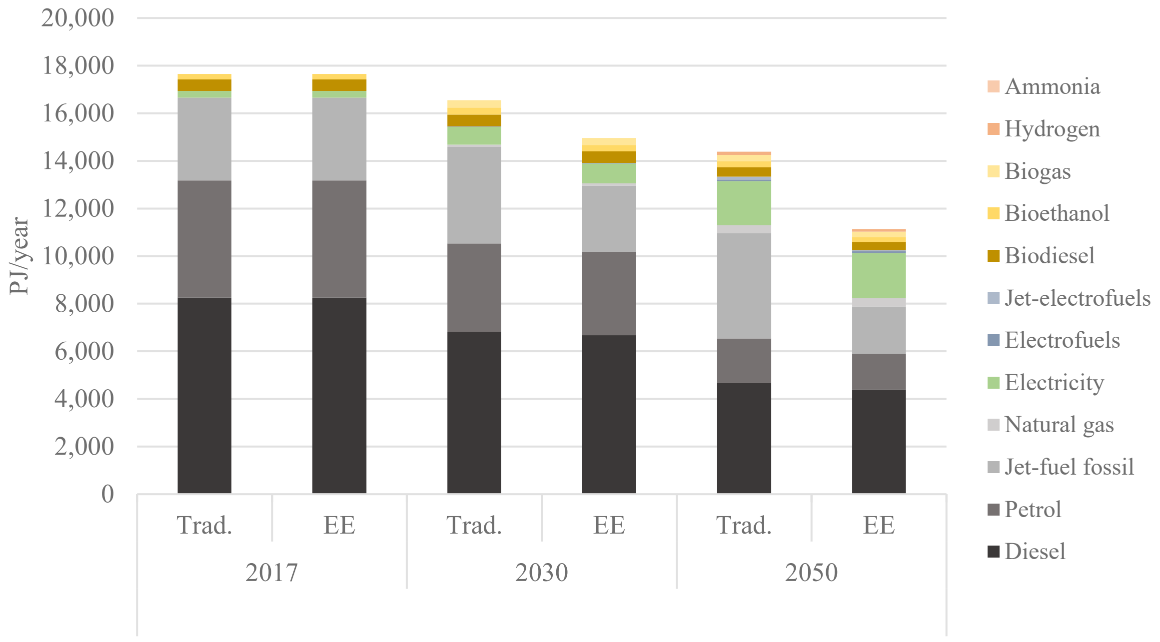

Figure 9. EU28 Annual transport energy demand distribution by fuel

Transport Systems Cost

The annual transport system costs consist of the cost of new vehicles and maintenance of existing vehicles, the cost related to road and railway infrastructure, as well as charging infrastructure and fuel cost. The fuel cost and especially the production cost of renewable transport fuels are uncertain, hence three different fuel cost scenarios are investigated. The results presented in this study consider the medium fuel scenario, all the three fuel costs scenarios are further elaborated in section 3.3 of the sEEnergies D2.3 report [36].The annual transport system cost in the EU28 in the 2017 reference model is 1.3 €bn/year. The vehicle cost comprises 68% of the total annual transport system cost, while fuel cost comprises 22%.

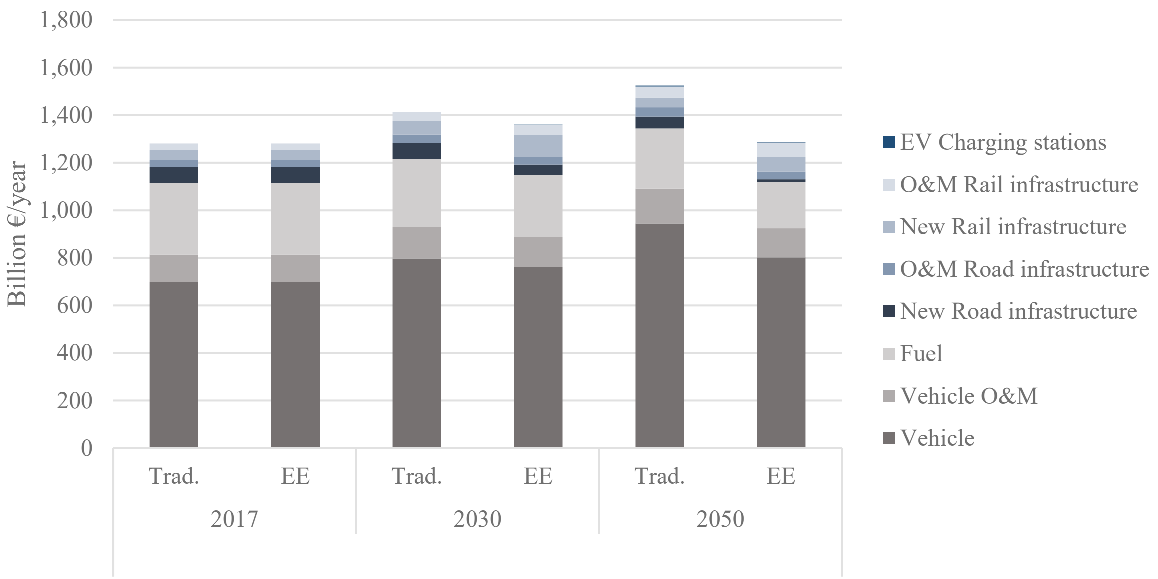

Figure 10. EU28 annual transport systems costs for traditional and energy-efficient development

In the development of the annual transport system cost is outlined for the traditional urban growth scheme and the energy-efficient urban growth scheme. Under the traditional urban growth scheme, the annual transport system cost increases by 19% from 2017 to 2050. Vehicle and fuel costs still comprise the majority of the annual cost in 2050. If the transport demand growth follows the energy-efficient urban development schemes, the annual transport system cost will remain stable from 2017 to 2050 and no increase is observed. Less transport in passenger vehicles and a modal shift towards public transport lead to a smaller increase in vehicle cost. The lower energy consumption per passenger-kilometer in public transport compared to passenger cars leads to a decreased annual cost of fuel. The increased cost of rail infrastructure is balanced by a decreased cost of new road infrastructure.

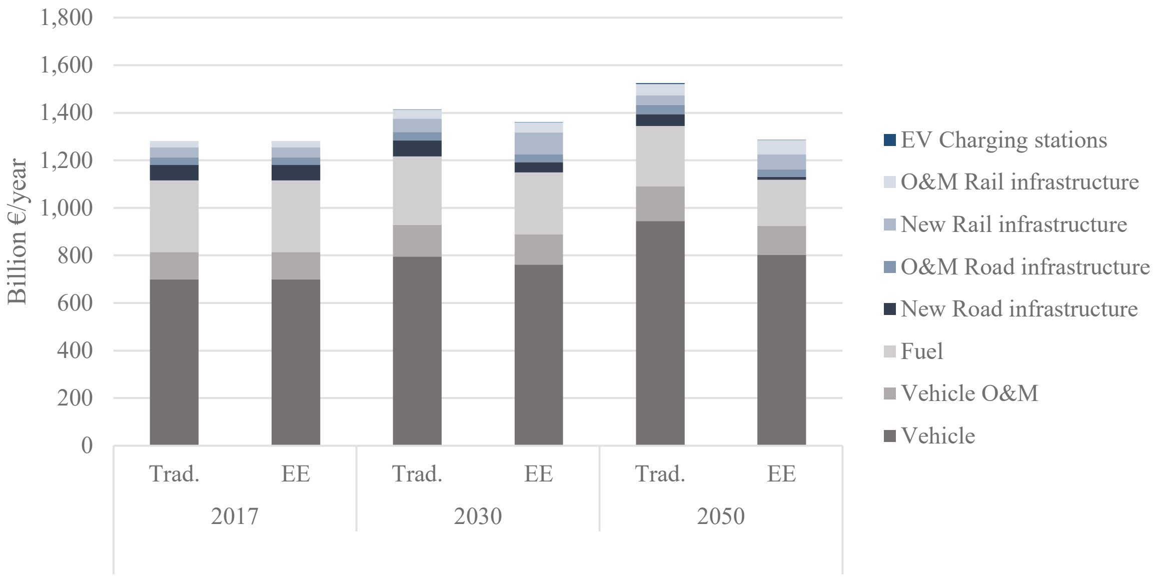

Figure 10. EU28 annual transport systems costs for traditional and energy-efficient development

CONCLUSION

In this work, the evolution of the transport system in the EU28 towards 2050 considering traditional and energy-efficient urban development is analyzed. A reference model of the current state of the transport system for the EU28 was built in the Transport PLAN tool, developed at Aalborg University, to create alternative scenarios from a well-documented, comprehensive starting point. The development of the transport demand was analyzed in a traditional urban growth scheme and an energy-efficient growth scheme.

The results strongly indicate that measures such as:

- Energy-efficient urban spatial development focused on energy-efficient transport behavior
- Economic incentives to discard travel in cars
- Abstaining from large investments in road infrastructure and airports

- will have a noticeable effect on the final energy demand the transport system.

Suppose the trajectory of the energy-efficient urban growth scheme is followed. In that case, the annual final energy demand will decrease by 20% in 2050 compared to the final energy demand in the traditional urban growth scheme. Hence, energy-efficient urban growth is recommended to pursue, as this will significantly reduce the need for implementation of renewable transport technologies and fuels and thus reduce the total cost of the transition.

REFERENCES

[1] European Commission, “United in delivering the Energy Union and Climate Action - Setting the foundations for a successful clean energy transition,” 2019.

[2] “Greenhouse gas emissions from transport in Europe — European Environment Agency.” https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases-7/assessment (accessed Apr. 16, 2021).

[3] European Commission, “Transport emissions | Climate Action,” 2017. https://ec.europa.eu/clima/policies/transport_en (accessed Apr. 15, 2021).

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

[5] Cao, Xinyu Jason, Patricia L. Mokhtarian, and Susan L. Handy: "The relationship between the built environment and nonwork travel: A case study of Northern California." *Transportation Research Part A: Policy and Practice* 43.5 (2009): 548-559.

[6] Saelens, B. E. & Handy, S. Built environment correlates of walking: A review. *Medicine & Science in Sports & Exercise*, 40, 2008, 550–566.

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

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

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

[10] Næss, P.: Transportation Energy in Swedish Towns and Regions. *Scandinavian Housing & Planning Research*, 10(4), 1993, 187-206.

[11] Næss, P.; Sandberg, S. L. & Røe, P. G. : Energy use for transportation in 22 Nordic towns. *Scandinavian Housing & Planning Research,* 13 (2), 1996, 79-97.

[12] Kenworthy, J. R. : 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.

[13] Næss, P.; Cao, X. & Strand, A. 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), 2017, 945–964.

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

[15] Elldér, E. : Residential location and daily travel distances: The influence of trip purpose. *Journal of Transport Geography*, 34, 2017, 121-130.

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

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

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

[19] P. Næss, F. Wolday, M. Elle, H. Abid, M. Strunge Kany, and B. Vad Mathiesen, "Report on energy efficiency potentials in the transport sector," Sep. 2020. DOI: 10.5281/ZENODO.4059191.

[20] Næss, P.; Næss, T. & Strand, A. : Oslo's farewell to urban sprawl. *European Planning Studies,* 19 (1), 2011, 113-139.

[21] Vold, A.: Phased implementation of transport pricing for Greater Oslo. *Transport Policy*, 13(2), 2006, 140-148, https://doi.org/10.1016/j.tranpol.2005.11.009.

[22] Tiitu, M.; Næss, P. & Ristimäki, M.: The urban density in two Nordic capitals – comparing the development of Oslo and Helsinki metropolitan regions. *European Planning Studies*, 2020, https://doi.org/10.1080/09654313.2020.1817865.

[23] H. Lund *et al.*, *Coherent Energy and Environmental System Analysis The Danish Council for Strategic Research Programme Commission on Sustainable Energy and Environment*. 2011.

[24] "EU transport in figures - Publications Office of the EU," *Statistical Pocketbook 2020*, 2020. https://op.europa.eu/en/publication-detail/-/publication/da0cd68e-1fdd-11eb-b57e-01aa75ed71a1 (accessed Dec. 02, 2020).

[25] "Database - Eurostat," 2020. https://ec.europa.eu/eurostat/web/transport/data/database (accessed Sep. 04, 2020).

[26] Danish Energy Agency and Cowi, "Alternative drivmidler," 2013.

[27] International Transport Forum, "Transport infrastructure investment and maintenance spending," 2020. https://stats.oecd.org/Index.aspx?DataSetCode=ITF_INV-MTN_DATA.

[28] European Commission, "A Clean Planet for All: A European long term strategy for a prosperous, modern, competitive and climate neutral economy," 2018. [Online]. Available: https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf.

[29] P. Næss, F. Wolday, M. Elle, H. Abid, M. Strunge Kany, and B. Vad Mathiesen, "Report on energy efficiency potentials in the transport sector," Sep. 2020. DOI: 10.5281/ZENODO.4059191.

[30] P. Næss, "Meta-Analyses of Built Environment Effects on Travel: No New Platinum Standard," *J. Plan. Educ. Res.*, p. 0739456X1985642, Jun. 2019, DOI: 10.1177/0739456X19856425.

[31] P. Næss, F. Wolday, M. Elle, H. Abid, M. Strunge Kany, and B. Vad Mathiesen, "Report on energy efficiency potentials in the transport sector," Sep. 2020, DOI: 10.5281/ZENODO.4059191.

[32] D. Metz, "Peak Car and Beyond: The Fourth Era of Travel," *Transp. Rev.*, vol. 33, no. 3, pp. 255–270, May 2013, DOI: 10.1080/01441647.2013.800615.

[33] T. Litman, "Evaluating Public Transit Benefits and Costs Best Practices Guidebook," 2020. Accessed: Dec. 02, 2020. [Online]. Available: www.vtpi.org.

[34] T. Kuhnimhof, D. Zumkeller, and B. Chlond, "Who Made Peak Car, and How? A Breakdown of Trends over Four Decades in Four Countries," *Transp. Rev.*, vol. 33, no. 3, pp. 325–342, 2013, DOI: 10.1080/01441647.2013.801928.

[35] Y. D. Bussière, J. L. Madre, and I. Tapia-Villarreal, "Will peak car observed in the North occur in the South? A demographic approach with case studies of Montreal, Lille, Juarez, and Puebla," *Econ. Anal. Policy*, vol. 61, pp. 39–54, Mar. 2019, DOI:

10.1016/j.eap.2018.06.002.

[36] H. Abid, M. Strunge Kany, B. Vad Mathiesen, S. Nielsen, M. Elle, and P. Næss, "Report on energy efficiency potentials in the transport sector and conclusions from the developed scenarios," Jan. 2021, DOI: 10.5281/ZENODO.4670789.