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ACCESSIBILITY MAPPING THROUGH LINKING LAND USE DEVELOPMENT POTENTIALS AND PLANNING FOR CYCLING

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Abstract

The transport sector aims to address climate change goals through reducing emissions, and an important move towards this goals is to increase uptake of sustainable modes like walking, cycling and public transport. It is thus important to discuss different ways to achieve this goal and build a portfolio of plausible reduction strategies. This study is situated in Norway where the national government has laid out a clear policy objective to reduce growth in urban car traffic and absorb future mobility on sustainable modes. Cycling has therefore gained a lot of importance in both policy discussions and program implementations through providing dedicated infrastructure to increase its modal share. The pathways to increase cycling shares can be plotted at both macro and micro levels. At micro levels, road designs, measures to improve the conditions for cyclists and make cycling paths safer can lead to potential increase in cycling. At the macro level, land use planning can be one of the tools to promote cycling usage. We analyse the issue at a macro level based on an Integrated Methodology for Land Use prognosis within Transportation Models (INMAP) which estimates the mutual effects of land use plans and increased accessibility by E-bikes. We further assess the extent to which future growth areas as earmarked by the strategic master plans of the Norwegian cities of Oslo and Trondheim coincide with the areas that have a high job accessibility with bicycles and E-bikes. Analyses reveal that on introduction of E-bikes in Oslo, accessibility to jobs in the city centre increases from 20-24 000 to over 28 000 jobs. For Trondheim, in terms of spatial expansion of accessibility for jobs, there is an extension of the catchment area from 6 km2 (600 ha) to 18 km2 (1 800 ha). Based on the findings, this study strongly recommends integrating the impact of E-bikes with land-use planning processes and decisions. Through active land-use management, municipalities and regional development authorities can take informed decisions to steer urban mobility in a more sustainable direction.

1.0 Introduction

Most European cities follow a master plan approach to earmark areas for future development which stipulate both the landuse, and the volume of development allowed in these earmarked areas. This system is shared by many countries in Europe and further on, due to climate change, there is an increased emphasis on accomplishing reductions in CO_2 emissions through planning and landuse regulations. Additionally, new modes of transport like E-bikes, E-scooters, car sharing, bike sharing etc. have made home in many European cities, but remain understudied in terms of their potential for reducing CO_2 emissions in personal transport. In light of the following two global agendas – (i) climate change and the revised targets for emissions from the transport sector, and (ii) making plans to regulate and incorporate new modes of transport like E-bikes, car sharing, bike sharing etc. there is a necessity to link the master planning approach with these two aspects. The Norwegian case provides a good example for further discussion on the topic, as it works on a master planning approach through established systems for landuse regulations which earmark and define the location and volume of landuse and built up mass that the municipalities have to work with for a stipulated time period of roughly 10 years. The master plan is revisited tentatively every 5 years to assess the land use regulations, rate of adoption of sustainable modes and reductions in CO_2 emission. Accomplishing this task is made difficult by arrival of new modes like E-bikes, car sharing etc. as there is limited data regarding the usage and potential of these modes. Additionally, the Covid-19 pandemic has impacted available data quality of travel surveys since it has been difficult to isolate the effects of the pandemic from general shifts in normal travel behaviour. There is therefore a need for a methodology to identify which areas are impacted by the new modes and how can this knowledge be further used within the master planning exercises. Due to data limitations and complexity in the current methodologies, it is difficult to ascertain the extent to which current accessibility measurements can provide insights on which areas can benefit from these new modes and how can these areas be earmarked in the landuse plans. More work is therefore required on the following topics:

i. To test if it is possible to create a methodology for assessing the current landuse plans with regards to accessibility offered by new modes.
ii. To identify which areas should be focused on and which areas should be excluded or set on low priority levels in the master plans in light of climate change goal of reducing CO_2 emissions.
iii. A simple methodology to decide which areas should be built first.
iv. To build this methodology based on available empirical data and publicly available travel cost estimates.

This paper attempts to address these four topics and provides the initial results from an "experiment" on how can one regulate land use given the inherent potential of E-bikes for increasing bicycle-usage.

2.0 Background

The Norwegian National Transport Plan for 2014-23 states that future growth in urban passenger transport should be accommodated exclusively through a corresponding growth on sustainable modes - walking, cycling and public transport. Additionally, the major cities have set their own, rather ambitious, targets. For example, Oslo City Council has a target of 50 percent reduction in greenhouse gases by 2030 compared to 1991. In order to realize these ambitious goals, the national government has launched measures to stimulate 'green' person transport, and one of the popular measures towards this end is extending financial support for designing policy packages[1] in the city-networks. One of the focal points of these policy packages is reducing car trips, as almost half of the trips registered in the National Travel Survey (NTS 2013/14)[2] of Norway are less than 5 km, and close to 50 percent of these short to medium length trips were taken on cars.

Further on, commuting statistics show that the Norwegian urban areas have had limited success in promoting sustainable commuting. Though the public transport share has increased in all cities from 2009 to 2013/14 (NTS data analyses), use of public transport for work trips remains highest in Oslo (42 percent) and drops in other cities. For example, Trondheim's (the third largest Norwegian city) share of commuting on public transport is only 19 percent. And overall, less than 20 percent walk or bike (Hjorthol et al., 2014). There is also a center-periphery dialectic as commuting patterns in the suburbs of the major cities are primarily car-based. Approximately 60-70 percent of the suburban commuting trips are made by car, compared to 30 percent in the central parts (ibid).

This indicates a potential to reduce car use and increase cycling in Norway, but a corresponding knowledge on how the advent of new modes like E-bikes and E-scooters can be tapped to address this gap is largely absent. Further, mobility solutions like the E-bikes , E-scooters etc. and a number of new modes of mobility fall in a category whose efficiency or effects are difficult to assess using the existing tools, as the current landuse and transport interaction models are based on standard modes of transport like car and public transport. Adding new modes like E-bikes and E-scooters in these tools is a difficult and time consuming exercise as there are no historical data available on these modes. On the contrary, for traditional modes like car and PT, we have decades of data to calibrate and validate the model.

Since current plans are based on accessibility afforded by cars, public transport and normal cycles, the potential accessibility offered by E-bikes has not been discussed. Currently, there are no methods available for assessing the accessibility offered by E-bikes. For such a method to be adopted in the current transport modelling and planning exercises conducted by the municipalities, not only should this method be functional and robust, but it has to simple, and based on easily available data. Municipal working protocols, costs and practical issues necessitate that the municipalities have access to a simple research-based approach to asses which areas will benefit first from increased accessibility by new modes and how to use this knowledge in decision-making exercises regarding which areas to develop first.

In light of these challenges, there is a need for a tool which can provide insight into the capabilities of the new modes and ways of utilising this insight in the planning processes. This paper puts forth an approach in which effects of a new transport mode, E-bikes, are measured through their impact on spatial accessibility, and it further ascertains if this spatial

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[1] Locally known known as *byvekstavataler,* the policy packages contain a set of measures directed towards reducing the modal share of cars and increasing the modal share of sustainable modes in the 10 largest urban regions of Norway. The White Paper on the National Transport Plan (2022-2033) stipulates a continued strong focus on urban areas, and approximately NOK 80.1 billion is earmarked for these policy packages for the urban areas during the planning period.

[2] NTS 2018/19 is still not publicly available for research purposes. This has posed challenges for research work using the NTS data, but using the 2013/14 data ensures that we can lay foundation for the methodology proposed in this study. The presented analyses can be further updated once the latest NTS data is made available.

information can be used in current planning processes. The trade-offs and bundling effects between assessing if this information can assist landuse planning processes and to what extent can the planning processes strengthen the efficient deployment of this new transport mode needs further attention. The results presented in this paper will add to the pool of knowledge existing on commuting, landuse potentials and designing cities which will not only sustain cycling but promote it as well.

This paper builds on the current knowledge on 'accessibility' and its usage in land use planning, by asking 'Can we use accessibility measures to assess the "likely" outcomes from a large-scale adoption of E-bikes?'. The study assesses the existing land use plans of two municipalities, Oslo and Trondheim, with respect to the earmarked development or growth potentials and checks if these earmarked growth potentials are in line with accessibility offered by E-bikes. A working hypothesis for this study is as following: *An accessibility-based methodology can be used to assess the impacts that E-bikes may have on job accessibility and this measurement can be further used to assess the current land use plans.*

The paper provides knowledge on how current and proposed land use and transport policies can be effectively interlinked to create cities which cater to commuting based on E-bikes. To this end, examples of Oslo and Trondheim are illustrated. The results can assist in designing both specific measures and provide inputs for decision-making on policy packaging exercises undertaken in the cities.

The article is structured as following: Section 3 provides an overview of the main findings emerging from studies focussing on cycling. This is followed by giving a brief description of the INMAP-methodology in section 4. The approach used to estimate accessibility with bicycles / E-bikes and results are presented in sub-sections 4.1 – 4.3. Following that, section 5 describes the methodology used for quantifying the municipal land use plans. In section 6, we analyse the relationships between landuse growth potential and accessibility for each case city, and assess the extent to which the landuse plans facilitate cycle and E-bike usage. Section 7 concludes the study.

3.0 Literature review

3.1 Cycling, E-bikes and master planning

The topic of cycling has been widely studied from a variety of disciplinary angles. Research studies have looked at the macro-, meso- and micro-level details and unearthed a wide range of individual, environmental and policy factors which hold potential to increase cycling rates. It has been found that individual factors like gender (Singleton and Goddard, 2016; Zhao, 2014), age (Zhao, 2014; Cervero et al., 2009; Moudon et al., 2005), education (Cervero and Duncan, 2003; Trang et al., 2012; Zhao, 2014), income (Dill and Voros, 2007; Heesch et al., 2014), car ownership (Moudon et al., 2005; Zhao, 2014), personal preferences (Small and Verhoef, 2007), physical safety and perceptions of crime (Arellana et al., 2020; Guti´errez et al., 2020) have played central roles in determining the cycling levels. Additionally, studies have conclusively established that environmental factors have quite significantly influenced both the level and rate of adoption of cycling. Poor weather (Ahmed et al., 2013; Miranda-Moreno and Nosal, 2011), hilly terrain (Cole-Hunter et al., 2015; Ma and Dill, 2015; Mateo-Babiano et al., 2016), urban form (Pucher and Buehler 2006), built environment (Nielsen et al., 2013; Christiansen et al. (2016) and presence of cycling infrastructure (Broach et al., 2012; Guti´errez et al., 2020; Heinen and Buehler, 2019; Parker et al., 2011) have both individually and collectively affected the uptake of cycling.

Despite a plethora of studies available on the topic, Handy et al. (2014) conclude that it is almost impossible to draw a list of factors which will lead to increased cycling. For all the factors mentioned above, studies are available to both prove and disprove their influence on the rate of cycling. Additionally, substantial contextual variations have led to different outcomes in varying contexts (Guerra et al., 2020). Understanding the topic of cycling therefore needs unpacking of the coupling between cycling rates and the local, contextual factors, as the degree of interlocking between the context, individual, environmental and policy factors needs to be understood in a given context.

But evidently, a mix of macro-, meso- and micro-level factors ranging from infrastructure provision of dedicated cycling lanes at the city level (macro-), land use (macro-), lane design (micro-) and targeted marketing to the different demographic groups (meso-) etc. is necessary to push the cycling agenda (Forsyth and Krizek, 2010; Pucher et al., 2011; Pucher and Buehler, 2008).

Further, the thematic area of bicycle commuting has been studied across the world. Topics like urban structure and mode usage for commuting (Cervero 2002, Srinivasan and Ferreira 2002), travel-time and trip-length (Vale 2013), access to parking (Hamre and Buehler 2014, Christiansen et al., 2016), public transport provisions (Redman et al., 2013, Blainey et al., 2012) and provision of cycling infrastructure (Wardman et al., 2007, Pucher et al., 2010, Bachand-Marleau et al., 2011) have been studied in great detail but even these topics remain unexamined in light of both upcoming transport modes like E-bikes and future landuse growth potentials. By land use growth potentials, we refer to the master planning exercises undertaken in a majority of European cities which specify the different land uses allowed in different areas within the municipal limit in a master planning period, ranging from 5-10 years.

It is thus necessary to further build on the topic of cycling as E-bikes effectively uproot some well-known reservations with cycling, like the issue of hilly terrains, time constraints, physical effort etc. There have been studies looking at this topic which have established E-bike's central position in promoting cycling (Wolf and Seebauer 2014; Sundfør and Fyhri 2017; Kroesen 2017; Winslott Hiselius and Svensson, 2017; Bjørnarå et al., 2019). However, to our knowledge, the intersection between accessibility offered by E-bikes and landuse growth potentials remains largely unexplored. Studying this relationship is of paramount importance as it holds the key to make evidence-based decisions, on climate goals in the master planning exercise, through earmarking growth areas which have an embedded potential to increase cycling.

3.2 Cycling speed and E-bikes

One of the consistent findings from studies looking at cycling behaviours of different groups is that cycling speed varies with different factors (Flügel et al., 2019). For example, men cycle faster than women (El-Geneidy et al., 2007; Parkin & Rotheram, 2010) but Flügel et al. (2019) found that the gender gap in speed (on average) is clearly reduced for E-bike (around 5% compared to 13% for regular bicycle) in Oslo. Further, literature on the effects of cycle infrastructure is mixed. Whereas cycling in a separate infrastructure resulted in higher speeds (El.Geneidy et al., 2007), no mention of this effect was found in other studies (Bernardi & Rupi, 2015; Schleinitz et al., 2017) which could be ascribed to mixed use lanes for both pedestrians and bicyclists. Flügel et al. (2019) show that cycling speeds are highest on roads where cyclists are kept separate from cars and pedestrians. They estimated values for marked cycling paths (on car streets) in Oslo to be 19.8 km/h for E-bikes and 18.7 km/h for bicycles. They conclude that it is important to separate cyclists from pedestrians from a speed evaluation point of view.

Further, they (ibid) highlight that it is difficult to draw meaningful comparisons between the cycling speeds as the concepts "average speed", "cruising speed", "speed on flat roads" and "speed identified by the constant term in regression models" are not clearly discernible. They advise that a recalibration of the general speed level is desirable before adopting a methodology for speed modelling and assessments. For the case of Oslo, their large-scale collection of GPS data on cycling shows that cycling speed varies greatly over network links, user segments and type of bicycle (regular bicycle and E-bike), and parameters like the type of infrastructure, type of crossing and link gradient etc. affected cycling speeds. In light of these findings, the constant link cycling speed as used in a majority of transport models is restrictive, and the authors (ibid) suggest that an implementation of cycling speed models is expected to increase the precision of transport model forecasts.

3.3 Accessibility measurements

Accessibility is defined as the "*potential of opportunities for interaction*" (Hansen, 1959) or "[…] *the ease with which activities may be reached from a given location using a particular transport system*" (Morris et al., 1979, p. 91). Geurs and Van Wee (2004) breaks down accessibility into four components:

1. A transport component describing the disutility associated with travelling.
2. A land-use component reflecting the demand for traveling to destinations at points of origin and the attractiveness and spatial distribution of destinations.
3. A temporal component describing time-specific constrains, such as opening hours.
4. An individual component describing variations in the ability to be mobile, depending on factors such as income, age, gender and health (Geurs & Van Wee, 2004).

Based on the number of permutations and combinations possible within this set of four major components, several different types of accessibility measures have been used across the world like the location-based cumulative and gravitational measures, person-based measures and the utility-based measures (Geurs & Van Wee, 2004; Handy & Niemeier, 1997). A majority of studies on job-accessibility employ location-based accessibility measures, and the most common location-based measures are the cumulative and gravitational measures. Cumulative measures count the number of jobs reachable from a location within a predefined cut-off value (threshold) that can be time, travel costs etc. (Smith et al., 2020), whereas the Gravitational measures count the number of jobs from a location, but discount them based on time etc. (discounted by a negative exponential function in most studies).

The most used accessibility measure is the cumulative accessibility measure that counts the number of opportunities within a defined threshold value. This measure follows the Hansen (1959) equation with a binary impedance function:

$$A_i = \sum_j E_j \, \mathrm{f}(c_{ij}) \qquad (1)$$

Where A_i is the accessibility for people living in zone i, E_j is the number of jobs in zone j and $f(c_{ij})$ is the impedance function which is:

$$f(c_{ij}) = \begin{cases} 1\, if\ c_{ij} \leq t_{ij} \\ 0\, if\ c_{ij} > t_{ij} \end{cases} \quad (2)$$

Where tij in equation 2 is the threshold value, known as the cut-off value. The most common unit to define the threshold value is time (Boisjoly et al., 2020; Deboosere & El-Geneidy, 2018; Desjardins & Drevelle, 2014; Smith et al., 2020; Sun & Fan, 2018), but different variants have also been used, like monetary cost in measuring cumulative accessibility (El-Geneidy et al., 2016).

The most commonly used threshold value for time-based cumulative measure is a value between 30 and 60 minutes. Many studies that employ travel time as the cut-off-value argue that the choice of the value should be based on average commuting travel time, namely average one way-trip to work. This value is generally derived from the national travel surveys. This approach allows for varying accessibility measures with the main group and comment on different accessibility afforded to different groups by the current land use and transport system. For example, Deboosere and El-Geneidy (2018) studied public transport accessibility to jobs across 11 Canadian metropolitan areas and measured accessibility for two distinct groups with two empirically derived thresholds. For the first group, the cut-off was the average commuting time by public transport in the respective metropolitan areas for the low-income population and for the second group, the cut-off was the average travel time for all residents in the different regions. These two distinct accessibility measurements allowed for comparing job accessibility of low-income population with the metropolitan average accessibility. The authors further argue that using empirically derived thresholds allows to partly incorporate the individual component of accessibility, thus incorporating behavior realism of person-based metrics.

Our introductory discussion on how urban transportation is being configured in light of climate change is evident in how discussions on accessibility and its singular focus on maintaining free flow of traffic (primarily car traffic) is now being widened to discuss accessibility by different sustainable modes. Some advances in quantifying public transport accessibility has already been made (Bertolini et al., 2005; Levine, 2020; Levine et al., 2019). To this end, extending the portfolio on bicycling accessibility, especially E-bike accessibility is important both as a tool to feed decision making in master planning exercises and as an independent module to be taken forward in research on accessibility.

In summary, we address the research gap that accessibility by cycling has not been linked to land use growth potentials. To this end, we draw inputs from available studies and combine existing landuse plans for Oslo and Trondheim, three major components of accessibility (transport, land-use, and temporal components) and, inputs on cycling speed to present a simplified model for plotting the interaction between these units to discuss accessibility afforded by E-bikes.

4.0 Data and INMAP Methodology

We begin with plotting the relationships between accessibility to jobs acquired by travelling with normal bicycles and E-bikes, and the existing land-use plans in the Norwegian municipalities of Oslo and Trondheim. The purpose of the analysis has been to evaluate if the current land use plans facilitate usage of bicycles and E-bikes. To do this, we have assessed the extent to which the future growth areas, earmarked in the strategic general plan of the city-regions, coincide with the areas that have a high jobs-accessibility with bicycles and E-bikes. The approach takes forward the core module of accessibility research and is rooted in an understanding that there will be a correlation between the potential for bicycle and E-bike usage in an area (for work trips), and the number of jobs that can be reached by bicycle within the same area.

The analyses presented in this paper have been performed using the Integrated Methodology for Land Use prognosis within Transportation Models (INMAP). The methodology has been developed on behalf of the Norwegian Ministry of Local Government and Modernisation since 2015 for generating land use forecasts for the Norwegian transportation models (Uteng and Kittilsen 2015).

In the INMAP methodology, supply of land is determined by the local municipalities through land use plans, while the demand for the land is estimated as a function of the accessibility to jobs, trade, general services and health services within the areas. This approach ensures that the provision and possible usage of land becomes exogenously determined variables, which greatly simplifies the task of making prognosis on the geographical distribution of population and employment. If the supply of land is fixed, we only need to model the demand for the land offered to the population. To determine this demand, the INMAP methodology uses accessibility to jobs, trade and services within each area. The assumption is that, for everything else being equal, the population will choose to settle in the areas with the highest accessibility. Analysing the urban growth patterns of Norwegian cities and a consistent focus on redensification of urban areas confirms this trend. Essentially, INMAP processes the traditional input data used by the transportation model to include the expected land-use changes derived from planned infrastructure investments and/or land use changes. The model accomplishes this through combining accessibility measurements that reflect the transportation infrastructure and current land use, with the strategic land use plan to include the expected land use of the future. This approach enables the model to capture the effects of both changes in the transportation infrastructure (as these impact the travel times between the zones), and changes in the land use plans (as these impact the growth restrictions of the zones).

INMAP uses a simplified approach in which both the supply and allowed usage (commercial and residential) of land is determined by the local municipalities. Keeping the provision and usage of the land as exogenously determined variables greatly simplifies the task of predicting the future usage of the individual plots of land, and thereby also the task of distributing the expected population growth over the available land in a region. This approach further eases the complexities involved with predicting the future commercial usage of land, as it limits the problem to the scale of the allowed activity, rather than the nature of the activity.

By letting the supply of land being exogenously determined by the authorities, future land use becomes a function of the demand of the residential and commercial land offered to the population. To determine demand, INMAP methodology uses an estimated generalized travel costs[3] between the zones in combination with official employment statistics to estimate the accessibility to jobs, trade and services within each zone with each available transport mode. INMAP then assumes that, for everything else being equal, the population wishes to settle in the areas that have both available space (as determined by the land use

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[3] See Appendix 1 for more details on the generalized travel costs.

plan) and the highest accessibility (as determined by the current land use and transportation infrastructure). The approach implies a mutual relationship between the residential and commercial land uses, as it is the commercial land use (represented by jobs) which is used to estimate the accessibility within the zones. Any significant change in the commercial land use will therefore also impact the accessibility to the areas. In INMAP, changes in the commercial land use is modelled as a function of the restrictions of the land use plans (which regulates the possible activities in the area) and the expected population growth surrounding the area (which reflects the expected customer base/demand). In nutshell, the approach consists of rescaling the number of jobs within the commercial zones to reflect the future population and travel costs, where the relationship between the variables is determined using the current system as a baseline. However, within a short to medium time horizon, it is often enough to use the current employment data in estimating accessibility. This is especially true for urban areas in which there are few new commercial areas, and where the potential densification of the existing areas is limited.

The simplicity of INMAP does, in many situations, provide a benefit in itself – its simplicity enables the user to determine the driving factors behind the given results. Thus, while INMAP ignores there are other factors that may exert influence relative to accessibility (changes in family structure, income, distance to schools etc.), it enables the users to test the effects of changes to infrastructure and land use plans for a given set of assumptions.

In this study, our focus has not been on generating forecasts but on using the methodology for land-use quantification and accessibility measurement to analyse the relationship between the land-use plans of two Norwegian cities, and accessibility with cycle and E-bike. In the analysis presented here, we only consider the current situation, and do not consider the effects of future changes in population and commercial land use. Additionally, the analysis does not consider the effects of seasonal variations.

Accomplishing this in a scientific manner required a rigorous approach for estimating the population's willingness to pay for a given travel cost, and an approach for estimating the travel times with E-bikes (as the Norwegian transportation model generates travel times with traditional bicycle only). In the following sections, we describe our approach for dealing with these issues.

4.1 Measuring accessibility with bicycle and E-bike

The methodology for estimating accessibility used in INMAP is based on an approach applied in the metropolitan areas of Santander (Coppola et al., 2013). In this method, accessibility is estimated as a function of the generalized travelling costs within the regions, willingness to pay for the given generalized travel cost acquired from statistical databases, and official employment data for the different regions.

Accessibility is modelled as a function that combines the willingness to pay (for a given time cost to a zone) with the number of jobs that can be acquired (from travelling to the zones). As in the case of Santander, we represent the willingness to travel for a given cost (with bicycle) as an exponential function where the willingness reduces as the cost increases. Simply stated, the accessibility measurements are derived from a stepwise process where we first estimate the travel times between the zones for a given transportation infrastructure (network), estimate the willingness to pay (represented by probability) for the generalized costs associated with the travel times, and finally combine the probabilities for a trip taking place with the official employment statistics of the zones (the mathematical formulation used to estimate accessibility is given in appendix 1).

The calculations have been performed using the following data-sources:

1. Number of jobs within each zone of the model has been represented by official statistics provided by the National Statistical Institute of Norway – Statistics Norway.
2. Willingness to pay the generalized travel-cost for bicycle has been derived using the Norwegian Travel Survey (2013/14).
3. Travel costs between the wards within the each city region has been estimated using the official Regional Transport Model (RTM) developed by the Norwegian Public Roads Administration (NPRA).

In generating the accessibility measurements, we faced two unique challenges. The first being that the transport model generates travel-time estimates for normal bicycle only. Generating corresponding travel times for E-bikes required a recalculation of the travel time matrices for bicycle into yielding E-bike estimates. The second challenge consisted of creating an approach for estimating the willingness to pay for the travel costs by bicycle and E-bike. As the estimation of the willingness to pay (WTP) requires a sample of observations to be calibrated against, this is doable only for normal bicycles. Thus, for estimating the WTP for E-bikes, we had to use distributions and parameters for bicycle. However, this limitation cannot be remedied until there exists a suitable sample of observations of E-bike trips. In the following sections, the approaches used for overcoming these challenges are described.

4.2 Estimated travel time by E-bike

We relied on the estimates generated by the official Norwegian Regional Transport Model (RTM) for the travel times between the municipal wards in Norway. RTM is developed and maintained by NPRA and is the official and mandatory model used in all governmental transportation analyses in Norway. The benefits of using RTM is derived from the fact that this is an official model which undergoes extensive calibration and quality control regarding the overall performance of the model, coding of the transportation network, and acquisition of data undertaken by the Norwegian government. However, while RTM was highly suited for generating travel cost estimates between the zones, it has the shortcoming of generating estimates for the traditional modes only - car, walking, cycle and public transport (bus, rail, metro etc.). Due to lack of travel time estimates for E-bike, we had to develop an approach for generating these estimates ourselves.

Due to the complexity of RTM, the task of re-programming the model to generate E-bike estimates was a job far beyond the scope of this project. We therefore sought a different approach for estimating the traveling times with E-bike between the wards in the transportation model. To do this, we exploited the fact that RTM generates travel-times for bicycle through a simplistic approach in which it first calculates the travel distance (using normal roads and cycling paths), and then derives the travel time through using an average cycle-speed of 15 km/h.

To generate comparable travel time estimates for E-bike, we used the fact that RTM stores all the travel costs components in its generalized cost matrix. Regarding the bicycle estimates, the generalized cost matrix contained information on both the minimum distance and the estimated travel time between zones. Using the estimated distances, we further generated comparable generalized cost metrics for E-bike through combining the estimates of travel distance for bicycle with the average speed with E-bike.

For estimating the average speed with E-bike, we relied on the results from a study undertaken by K. Schfeinitz et al (2017). The measured mean (M) speeds and standard deviation (SD) for the different bikes and infrastructure types are listed in Figure 1.

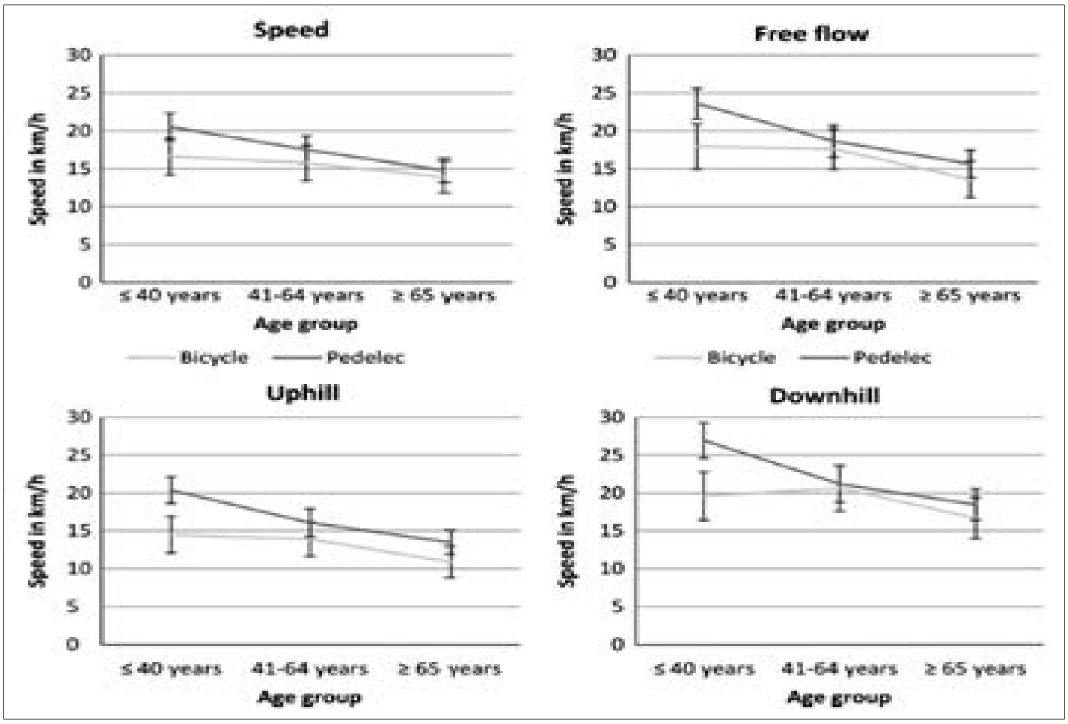

Figure 1: Measured speeds for bicycle and pedelec[4]
Source: Schfeinitz et al (2017)

Table 1: Average cycle-speed used in travel time estimation

Mode	Average speed (km/h)
Normal Cycle	15
E-bike	22[5]

Source: Schfeinitz et al (2017)

Figure 1 depicts the average speeds in free-flow, uphill and downhill for different age groups while Table 1 specifies the average speed for the normal bicycles and E-bikes considered in

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[4] Pedelecs (pedal electric cycles) are cycles that assist the rider's pedaling effort with an electric motor delivering up to 250 watts (CH: 500 watts) at a speed of up to 25 km/h; in the S-Pedelec category the motor's maximum output is 500 watts and pedal assistance is provided up to a speed of 45 km/h. Push assistance without pedaling is normally 6 km/h. Both categories are subject to differing regulations, which are applied differently in many countries.
https://www.stromerbike.com/

[5] The paper uses a speed of 22km/h for E-bikes which does not mean that the cyclists will necessarily be travelling at this speed in the current circumstances. But this speed is possible for the cyclists, with normal pedalacs, to achieve if dedicated cycle paths are constructed covering the entire city and favorable conditions are in place. Currently, dedicated cycle lanes are provided in parts of the case cities which is why the average speed recorded for E-bikers in Oslo is less than 22km/h (Flügel et. al. 2019). In this paper, we are presenting a scenario where the cities are ready and designed to allow for cycling at a speed of 22km/h. Further, since E-bikes provide a speed benefit in both uphill and downhill conditions, topography becomes relatively less important for the results.

this study. The data depicted in Figure 1 is of high relevance for several of the potential weaknesses of relying solely on RTM data.

One of the strongest objections for using the RTM estimates would be the fact that the transportation model only uses distance and average speed in estimating the expected travel time by bicycle, which means that it fails to consider the effects of elevation. As the E-bikes are capped 25 km/h, one might assume that the highest benefit of using an E-bike (regarding speed) occurs in the up-hill stretches. However, Figure 1 depicts that there is a close to a 5 km/h difference between bicycle and pedelec in both free flow, uphill and downhill (for the young travellers). Furthermore, it shows that the difference in travel-time occurs primarily in the age group of under 60, and the gap diminishes as the age of the traveller increases. Regarding the re-estimation of the generalized cost-matrices, the symmetrical difference in travel speed between normal bicycle and E-bike for both uphill and downhill implied that the effects of elevation on travel speeds (and therefore accessibility) would be small enough to be ignored.

In re-estimating the generalized cost-matrices, we therefore ignored the elevation effects, and re-estimated the travel times using the average speeds listed in Table 1.

4.3 Willingness to pay

Having generated the travel time estimates for E-bikes, the next task consisted of generating measurements for the willingness to pay for a trip with a given travel-cost. The jobs-accessibility acquired from having access to a ward is represented by the probability of a person being willing to pay the travel cost of traveling to the ward, multiplied with the number of jobs at the destination (where we can distinguish between the total number, trade jobs, services jobs, school-jobs etc). In other words, the probability of the event (the trip) multiplied with the outcome of the event (the number of jobs in the destination). The total accessibility of each ward is then found through summing the accessibility acquired from all the available wards. Within this framework, wards which are close by and contain many jobs will add significantly to total accessibility, while wards with an equal number of jobs but which are further away will contribute less.

In this regard, the willingness to pay is thus a representation of the probability for a person being willing to perform a trip (in this case a work-trip) with a given travel cost. To find such a measurement, we have used the trips data from the NTS 2013/14. To estimate the willingness to pay, we restricted the scope of analysis to cover only work trips with lengths equal to or less than 70 km. This restriction was put in place as the transport model generates cost estimates for trips up to 70 km only. Then, using the NTS, we extracted the starting and end zones for each work trip within the city regions that fulfilled the mode and distance criteria (there are very few cycling trips longer than this distance in the sample). In total, this equalled to 549 bicycle trips with a mean distance of 4,34 km and a mean travel time of 16 minutes. The properties of the bicycle trips are listed in Table 2.

Table 2: Sample properties for bicycle trips in Oslo and Trondheim, NTS 2013/14.

	Total Trips	Mean Distance (KM)	Mean Travel time (Min)	Mean Cost (Kroner)
Mode: Bicycle	549	4,34	16,10	21,83

Having identified the bicycle trips to be used in the analysis, we used the starting and end zones for each trip and used the transportation model (RTM) to acquire the corresponding travel time estimates with bicycle. Then, using the national standards for the monetary value of time, we transformed the estimated travel times into travel costs.

Using these trips and trip cost estimates for the bicycle trips, we generated the trip cost distribution for each work trip by bicycle within the city regions. This distribution contains information on how the bicycle-trips are distributed across the different cost values. Finally, through transforming the cost distribution into ratios using the total number of trips, we acquired the cumulative cost distribution and the reverse cumulative cost distribution which was further used to estimate the "willingness to pay" for a given trip. The transformation from cost-distribution to the reverse cumulative cost distribution (RCCD) is illustrated in Figure 2.

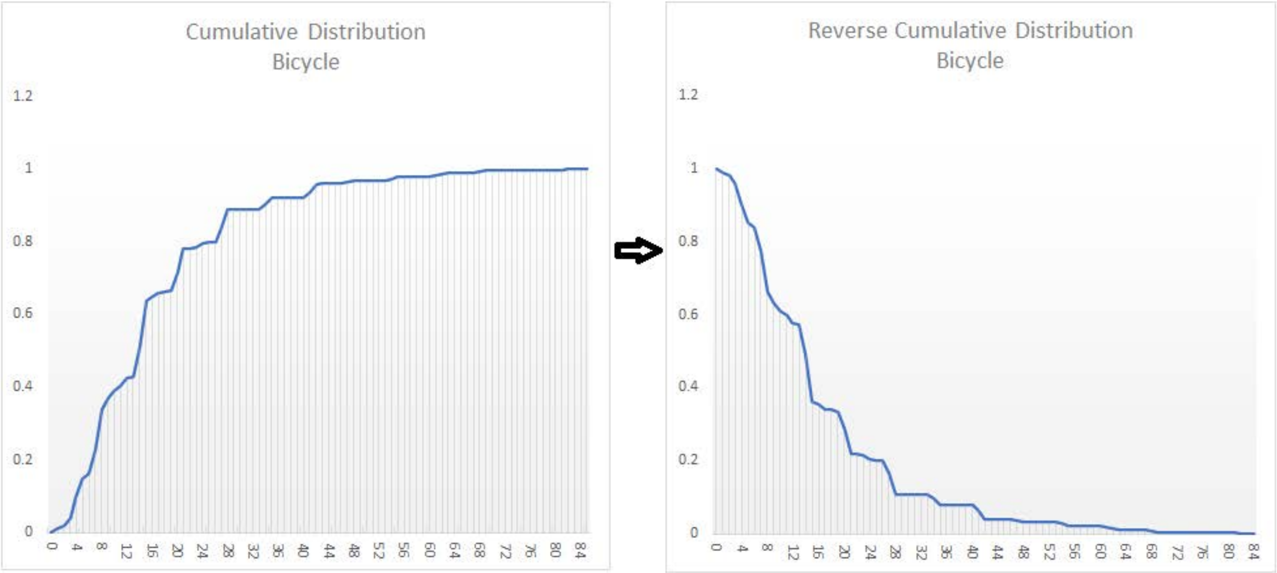

Figure 2: the cumulative cost distribution for bicycle (left side) and the corresponding reverse cumulative distribution (right side). (Y-axis shows reverse cumulative ratio, Y-axis costs in Norwegian Kroner).

The basis for using the RCCD is explained by the case that each value in the cumulative distribution reflects the sum ratio of the trips with equal to or less travel cost than the specific value. Thus, the corresponding value in the reverse cumulative cost distribution becomes an expression of the sum ratio of the trips with either equal or higher cost.

Therefore, for any new trip with a given travel cost, the ratio of the population that would be willing to perform the trip(for everything else equal) would be the ratio of the population that is currently paying either more or equal for the same trip (as this reduces their travelling costs). The willingness-to-pay for any trip with cost x can thus be represented using the reverse cumulative cost distribution for the corresponding cost. For using the RCCD, we scripted a search-algorithm in which each travel cost between the zones was rounded off to the closest 0.5 kroner, and then the corresponding value from the RCCD was used as an estimate for the probability of the population's willingness to undertake the trip.

Within this framework, the probability of a trip of 20 kroner being undertaken thus becomes the integral of the RCCD over the values 20 to infinity. An illustration of the probability depicted in Figure 3.

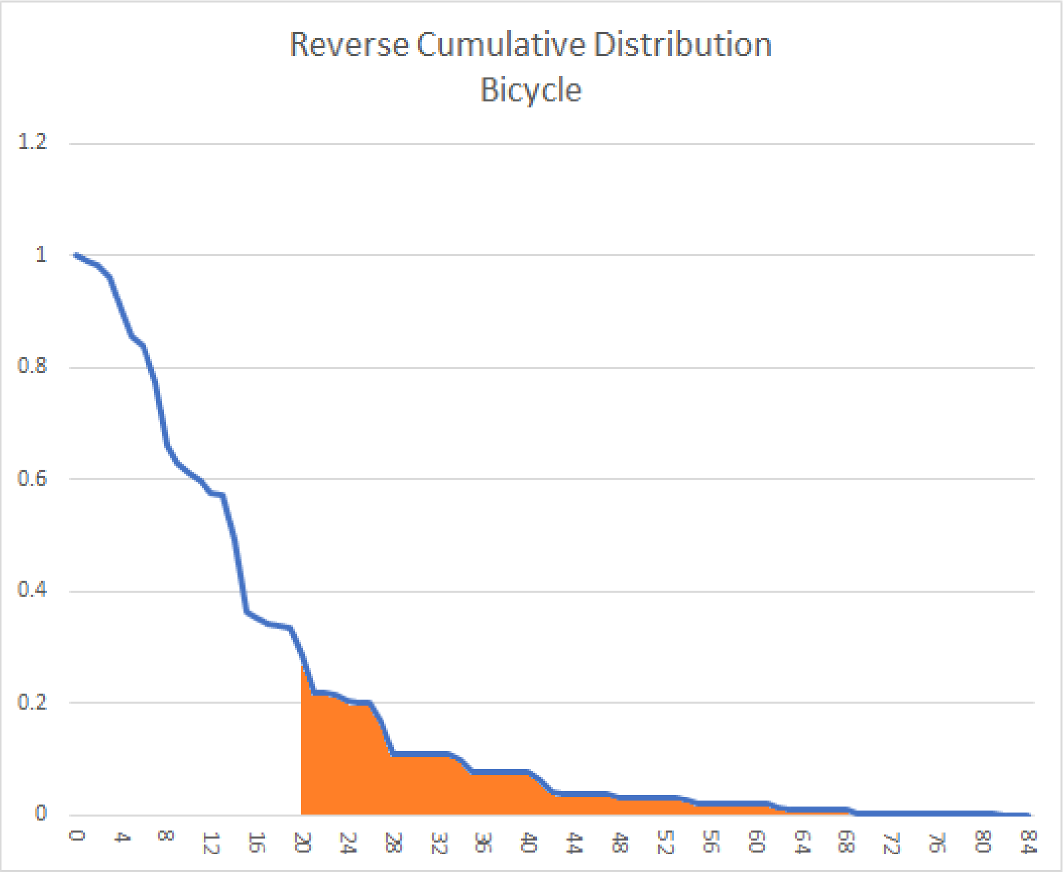

Figure 3: Estimated fit between the RCCD and the estimated curve fit from the accessibility equation for bicycle.

In Figure 3, the y-axis represents the willingness to pay (probability between 0 to 100%) while the x-axis depicts the costs in kroner. The final accessibility measurement is acquired through multiplying the probability of the trip, with the number of jobs in the zone. The total accessibility of the origin zone is then calculated through repeating this process for all the available zones.

As depicted in the figure, RCCD provides a framework where a high willingness to pay for trips at low costs and a low willingness to pay at high costs is made explicit.

5.0 Results

The estimated accessibility to jobs by bicycle and E-bike for the different regions are depicted in Figures 4 and 5. In these figures, accessibility has been normalized into an index ranging from 0-100, where 100 represents observations with the highest accessibility value and all others have been normalized in accordance with the maximum value. We have used the same index for both bicycle and E-bikes. For both Oslo and Trondheim, an index value of 80+ represents accessibility in the most central areas while 0-20 represents the areas with the lowest accessibility. The index presents five accessibility categories – low (0-20), low-medium (20-40), medium (40-60), medium-high (60-80) and high (80+). This section provides a graphical illustration and description of the accessibilities by bicycles and E-bikes, and a follow-up discussion of the results is provided in section 6.0 where accessibility values are added on top of the results emerging from land use analyses of Oslo and Trondheim.

Trondheim

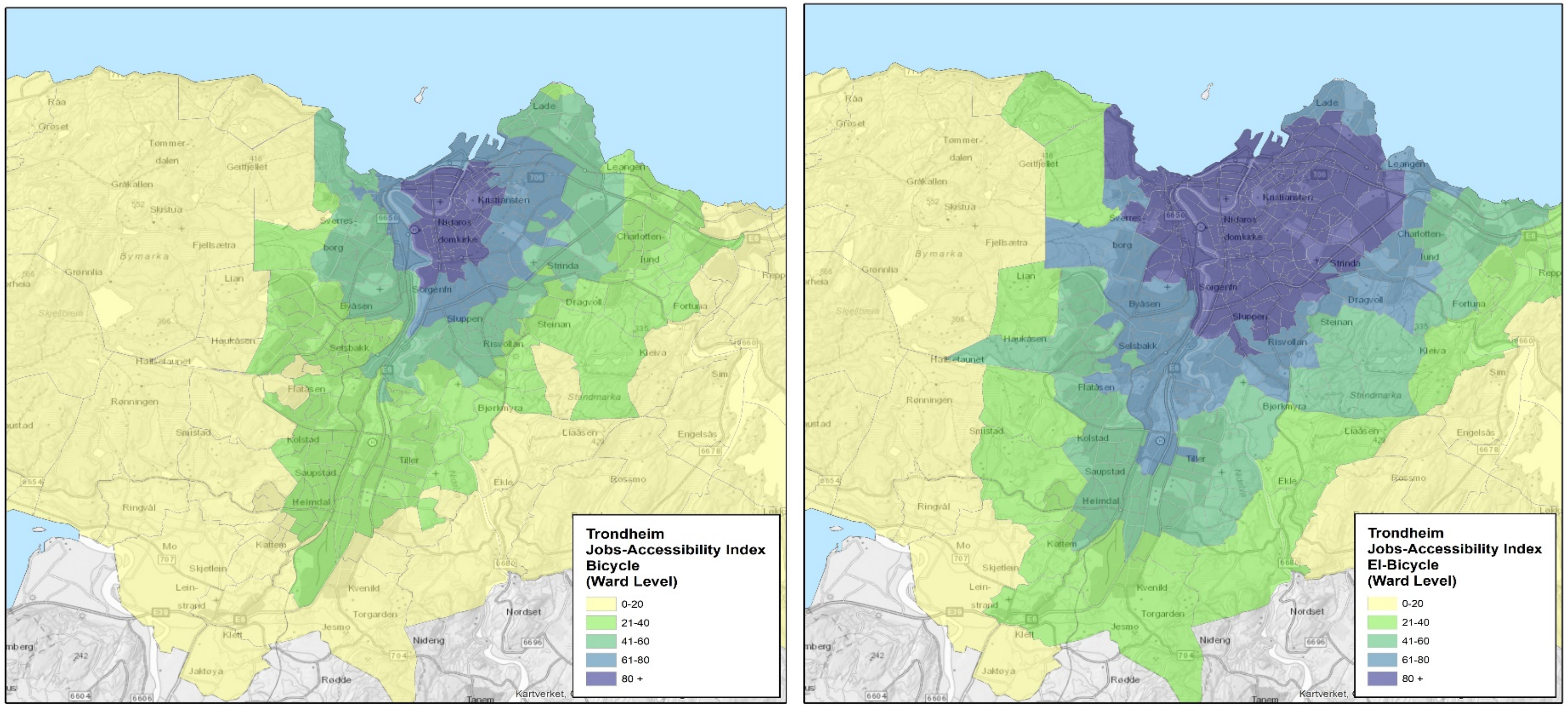

Figure 4: Accessibility bicycle (left) and E-bike (right) to workplaces, Trondheim

Figure 4 shows that the E-bikes extend the accessibility provided by bicycle, primarily concentrated in the central parts of the city, to large tracts towards the eastern and southern areas of the city. The centre-periphery dialectic, as evident through the restricted accessibility offered by normal bicycles, is to a great extent ameliorated by the high speed offered by E-bikes.

Oslo

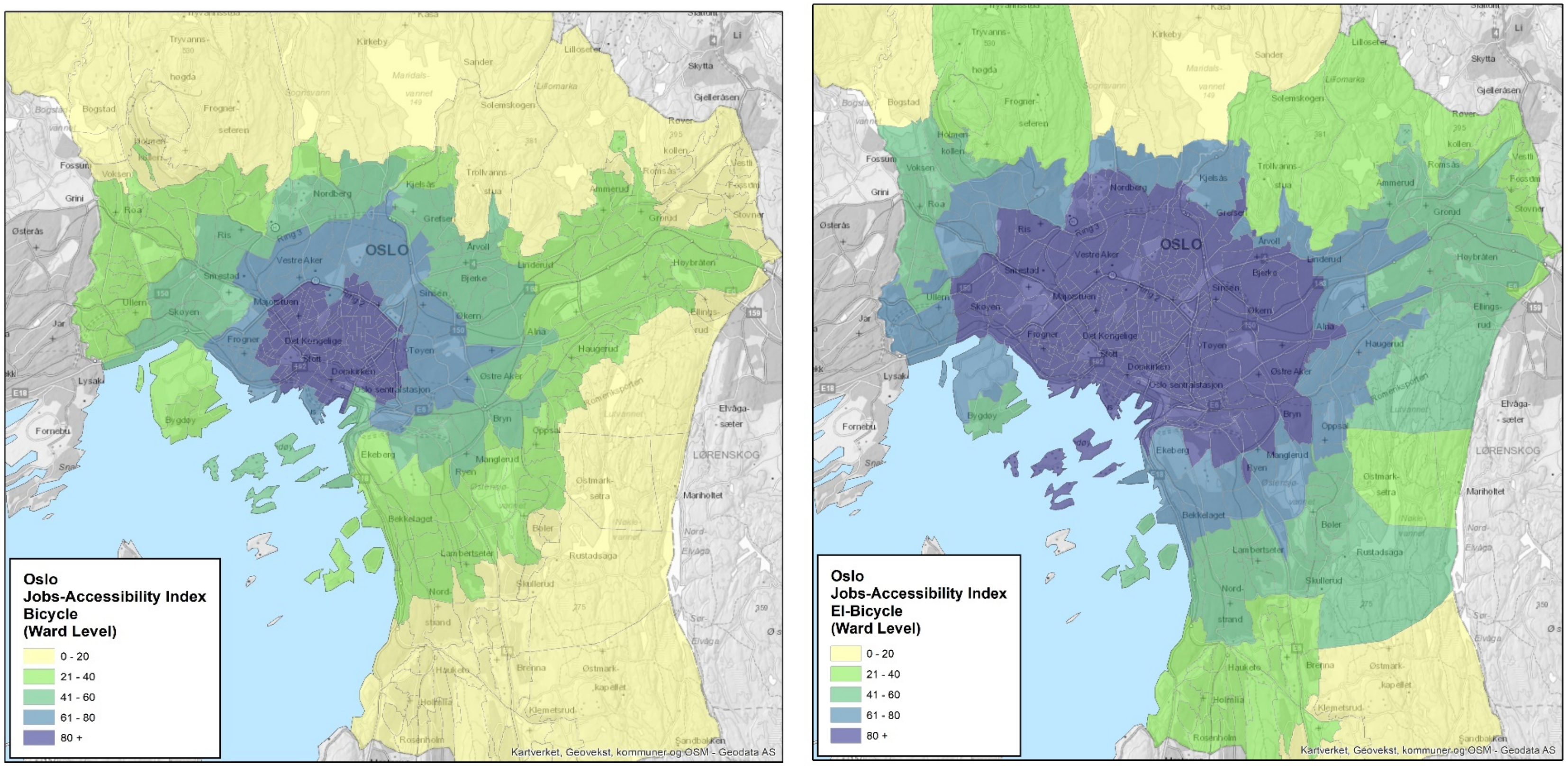

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Figure 5: Accessibility bicycle (left) and E-bike (right) to workplaces, Oslo

Figure 5 shows that a large part of the area surrounding the city centre has a higher accessibility with E-bikes than what one acquires with normal bicycle. The figure further highlights that E-bikes extend the accessibility currently reserved for normal bicycle to a wider area surrounding the city.

5.1 Estimation of growth potential based on land use plans, and its importance

An important step of INMAP modelling consists of estimating the growth potential according to existing and future land use plans and strategies. This is considered essential as land use determines a major part of the transportation demand (Cervero 2002). Uteng and Kittilsen (2015, 2017) estimated the growth potential for the city of Trondheim as well as its neighbouring municipalities using the INMAP-tool. This data set provides the foundation to estimate the effects on transportation related to different land use scenarios for Trondheim. We further collected and processed data from the city of Oslo and adapted these into the INMAP tool. The level of analysis is determined by the municipality's land use plans and related data sets. The general plan earmarks the areas that are to be developed and the respective land uses. It also contains coarse data on density and development potential, and highlights the areas to be preserved. As our aim was to analyse the effects on transportation, we considered the level of detailing provided by the general plan to be sufficient for the purpose of our study.

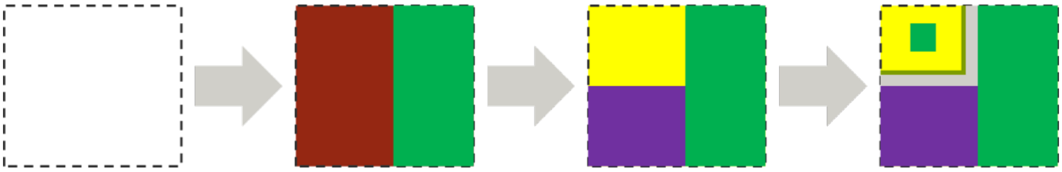

Figure 6: The process of estimating growth potential, on ward level, illustrated.

We further estimated the growth potential for housing. Figure 6 illustrates the process of estimating the growth potential according to general/municipal land use plans. From left to right, the rectangles symbolize the following: No. 1 illustrates the ward which is the level of detail in the INMAP tool; No 2. illustrates how parts of the ward, according to the general land use plan, may be designated for developments (brown colour), while other parts may be designated for preservation (green colour); No. 3 illustrates that certain parts of the development area (purple colour) may be reserved for other land uses than housing (yellow colour) such as commercial areas or public services; No. 4 illustrate how certain parts of the assigned land may be unutilized for net development (grey and green colours). Additionally, parts of the land must be assigned to roads including cuts and fills, streets, public green space, terrain not developable etc. Thus, the net developable land for housing is represented by the yellow area in the rectangle. By multiplying the net developable land with the densities given in the land use plans, we estimated the maximum growth potential. From this step, the maximum allowed floor space is converted to an estimate of inhabitants by dividing the floor space based on average floor consumption per capita.

In the following sections, we describe the estimates of growth potential for Trondheim and Oslo based on their land use plans. The descriptions of Trondheim and Oslo illustrate how different kinds of data may be used to estimate the land use growth potential.

The City of Trondheim

As part of its master plan, the city of Trondheim has its own housing construction program and this construction program is based on approved construction or zoning projects.

(Trondheim Kommune, 2014). The program specifies number of housing units on address-level and the list contains approximately 38 000 housing units. We processed the list from address- to ward-level to estimate the maximum growth potential in each ward (Table 3). When an exact address was not given, we manually checked other general plan attachments to locate the ward. Household-size of the new units was schematically set to two.

Table 3: Distribution of housing units in the townships according to the housing construction program, Trondheim

Township	Number of new housing units 2014-2040	Number of potential new inhabitants
Central area	3518	7 036
Strinda/Lade	9073	18 146
Ranheim	12970	25 940
Nardo	5634	11 268
Heimdal/Tiller/ Byneset	6360	12 720
Byåsen	590	1 180
SUM	38 200	76 400

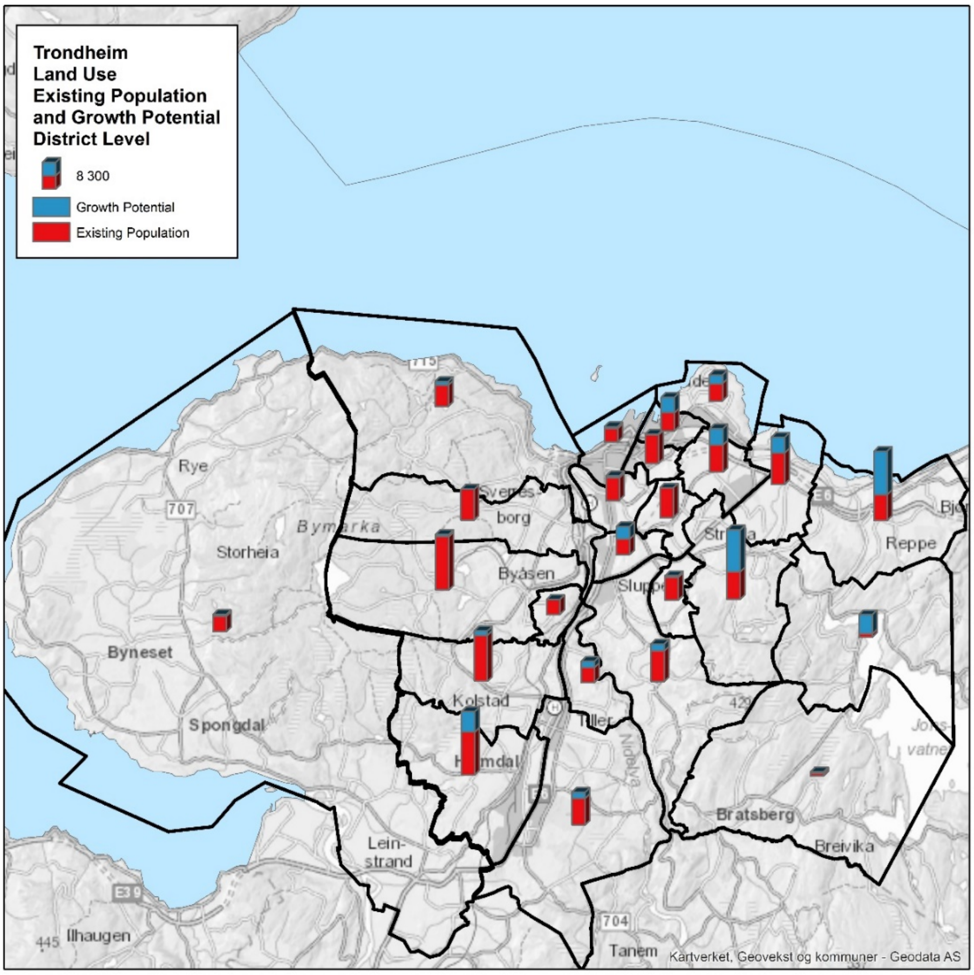

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Figure 7: Estimated growth potential according to the housing construction programme of Trondheim. Ward level.

In Trondheim, the transformation areas of Lade, Leangen and Tunga is illustrated by the mapped growth potential to the east of the city centre (Figure 7). The green field projects, such as Charlottenlund, Dragvoll, as well as development areas around Ranheim, is illustrated by growth potential in east and southeast. South of the city centre, there is growth potential in the transformation areas around Sluppen and Lerkendal-Nardo-Sommerfri.

The City of Oslo

The city of Oslo has made its own estimates of housing growth potential which have been further utilised in this paper (Table 4). For this exercise, we schematically set the household-size of the new units to two persons.

Table 4: Distribution of housing units in the townships according to the housing construction program

Township	Number of new housing units 2042	Number of potential new inhabitants 2042
01 Gamle Oslo	11 262	22 524
02 Grünerløkka	7 974	15 948
03 Sagene	2 836	5 672
04 St.Hanshaugen	1 358	2 716
05 Frogner	5 615	11 230
06 Ullern	10 936	21 871
07 Vestre Aker	5 877	11 754
08 Nordre Aker	9 852	19 704
09 Bjerke	11 808	23 616
10 Grorud	4 045	8 090
11 Stovner	5 493	10 986
12 Alna	9 291	18 582
13 Østensjø	4 086	8 172
14 Nordstrand	3 316	6 633
15 Søndre Nordstrand	17 342	34 683
16 Sentrum	787	1 574
17 Marka	645	1 290
SUM	**112 523**	**225 046**

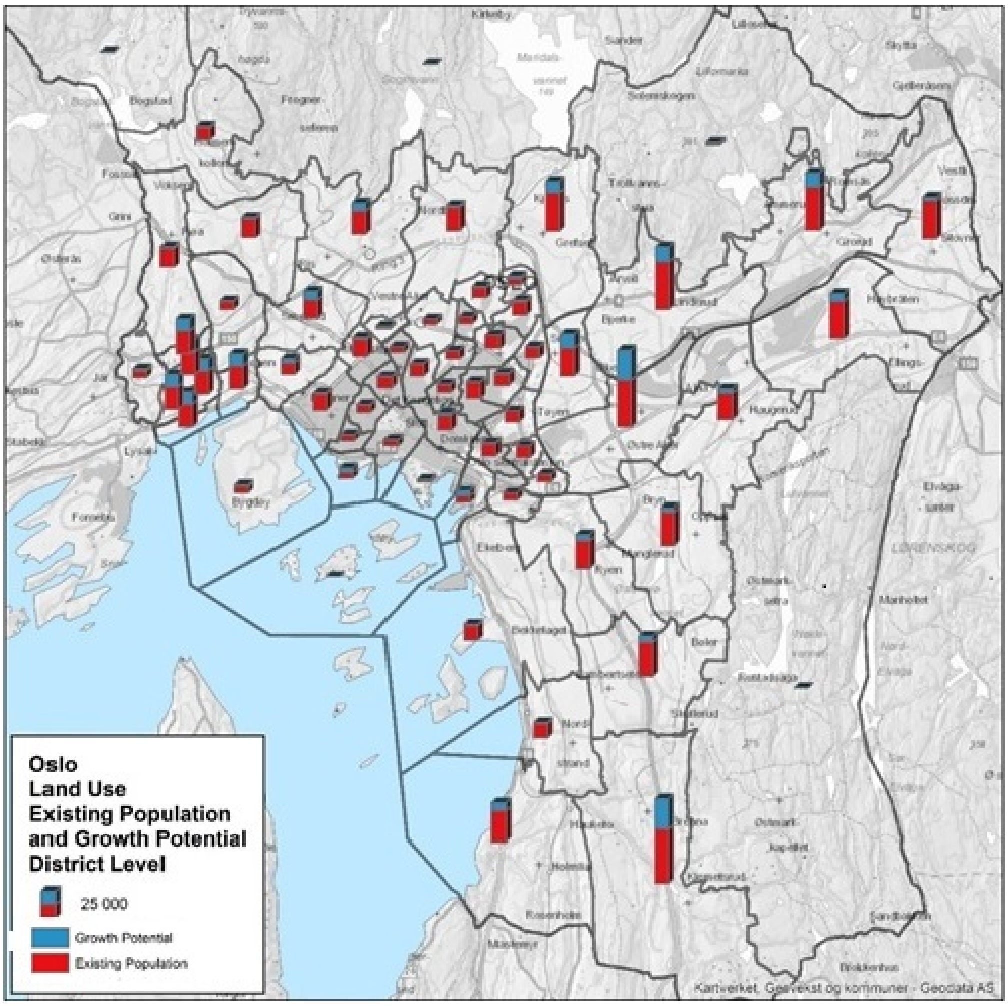

Figure 8: Estimated growth potential Oslo. Ward level.

Figure 8 illustrates that growth potential in the city centre is partially related to water front development at Sørenga. The northern and eastern transit-oriented developments along the metro line contributes to growth potential around the city centre. The areas on the eastern fringes of the 3rd ring road includes major transformation/redevelopment areas around Økern, Bryn, and Alna, commonly known as "Hovinbyen", while transit-oriented developments at Skøyen and Smestad are located in the west. The last remaining future green field development of Oslo, Gjersrud/Stensrud, can be seen to the southeast.

6.0 Analysis

This section outlines the relationship between accessibility offered by E-bikes and growth potentials based on the respective land use plans. We have simply layered the accessibility analyses by bicycles and E-bikes over the maps representing growth potentials of the two case cities. In the maps, accessibility is represented by accessibility index. The relationship between the index values and job accessibility values is given in Table 5 and Table 6 for Trondheim and Oslo respectively.

Table 5: Index and job-accessibility values, Trondheim

Index category	Index Value	Job-accessibility
Low	0-20	0 - 1500
Low-medium	21-40	1500 - 3000
medium	41-60	3000 - 4500
Medium-high	61-80	4500 - 6000
High	80+	6000 +

Table 6: Index and job-accessibility values, Oslo

Index category	Index Value	Job-accessibility
Low	0-20	0 - 5000
Low-medium	21-40	5000 - 10000
medium	41-60	10000 - 15000
Medium-high	61-80	15000 - 20000
High	80+	20000 +

An index of 0-20 implies that the zone provides an accessibility of up to 1500 jobs by bicycle, representing a low accessibility level by bicycles within the city of Trondheim. However, zones in which one can reach more than 6000 jobs represent the category which offers highest accessibility levels by bicycles.

For Oslo, as it is a bigger city, the accessibility within the categories are overall of higher value. This will be true for all modes. Thus, for Oslo, the lowest limit of accessibility offered by bicycles is up to 5000 jobs, while in the highest category, one can reach up to 20 000 jobs adjusted for travel costs.

We further discuss the possibilities for optimizing an increased accessibility based on E-bike usage through adapting the land use plans.

5.1 The City of Trondheim

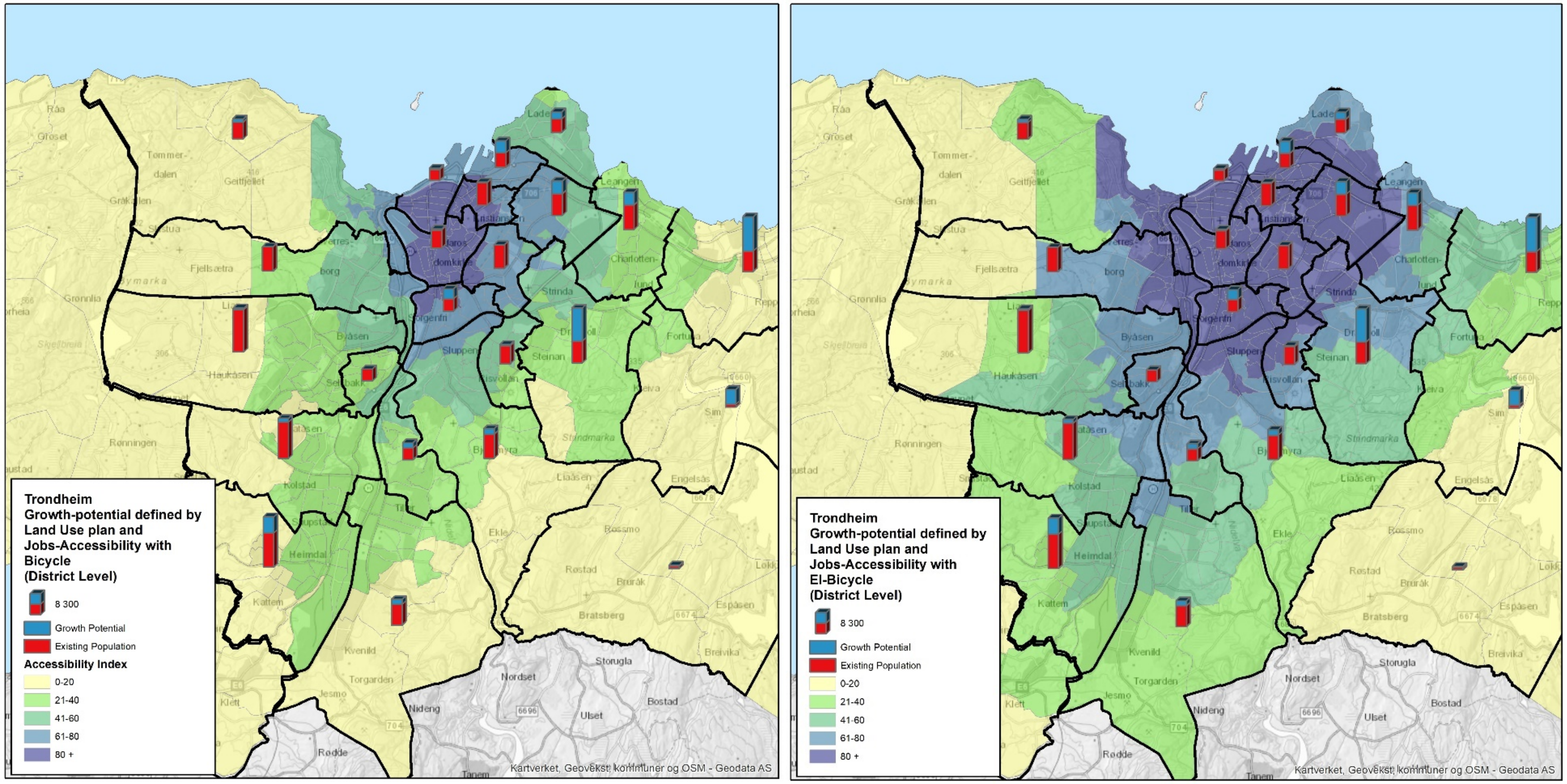

Figure 9: Accessibility bicycle and E-bike, and growth potential Trondheim

Figure 9 highlights that in Trondheim, job accessibility with bike is over 6 000 for the city centre, as well as the hospital- and university areas south of the inner city. On introduction of E-bikes in the system, accessibility extends to a triangular area covering Ila-Strindheim/Tunga-Sluppen. This is an extension from 6 km^2 (600 ha) to 18 km^2 (1 800 ha). This includes the earmarked transformation areas in Lade and Strindheim/Tunga (west of the inner city), as well as the triangle Lerkendal-Nardo-Sorgenfri. Areas as far south as Tiller is now included in the category of access to 4-6 000 jobs, which is comparable to the relatively central areas of Strindheim/Tunga today.

The innermost districts do not have the same growth potential. The housing construction program does describe a potential for further growth, but this has not been included in the program due to uncertainties regarding proposed projects, desired densification etc.

Figure 10 illustrates that the green field developments adjacent to Leangen, and northern parts of Charlottenlund, have an increase in accessibility on introduction of E-bikes, a situation which is similar to the current status of Tunga/Strindheim. The effects of E-bike on the easternmost green field developments, from Dragvoll and eastwards, are comparatively small.

The analysis of E-bike accessibility map supports the high-density transformation of areas such as Lade, Tunga, and the areas in the triangle Lerkendal-Nardo-Sommerfri. Our analysis further suggests that in order to increase accessibility by E-bikes, a higher share of future growth should take place in existing areas such as in the axis Sluppen-Tiller, thus replacing (planned) growth in green fields in the eastern parts of the city.

In Figure 10, the areas marked in red circles are areas which are largely unaffected by the introduction of E-bikes (measured in accessibility to jobs). Introduction of E-bikes is unlikely to affect the travel behaviour of these areas. For these areas, change in travel behaviour will have to come through other policies, like those focussing on public transport etc. But such approaches are more resource demanding.

For creating effective policies to combat climate change within limited resources or maximising available resources to combat climate change, providing incentives for building in the areas which have the highest benefit from E-bike usage appears to be a good approach. However, these results are built on the assumption that bicycle infrastructure is in place allowing for an average speed of 22 km/h. There are fixed costs associated with creating cycle infrastructure, but there are clear wins with such costs. For example, building bicycling infrastructure would provide benefit to both the new and existing built up areas and can contribute to a shift in travel behaviour. However, the actual costs of implementing this infrastructure versus gains is difficult to pinpoint as seasonal factors will also play a role in determining bicycling levels. Due to such uncertainties, further studies are required to complement the findings presented in this study.

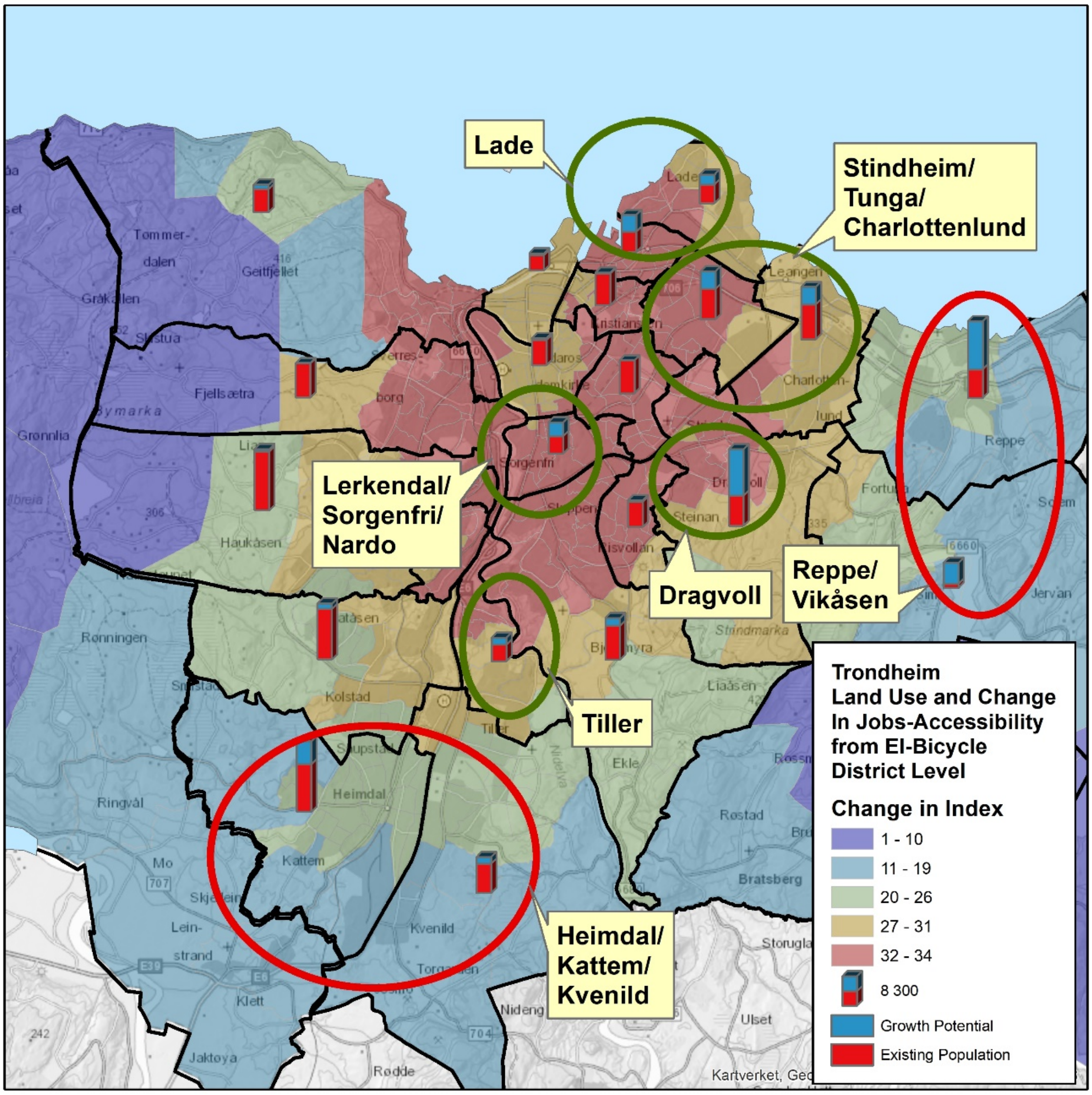

Figure 10: Difference between in accessibility index for E-bikes and bicycles, Trondheim

5.2 The City of Oslo

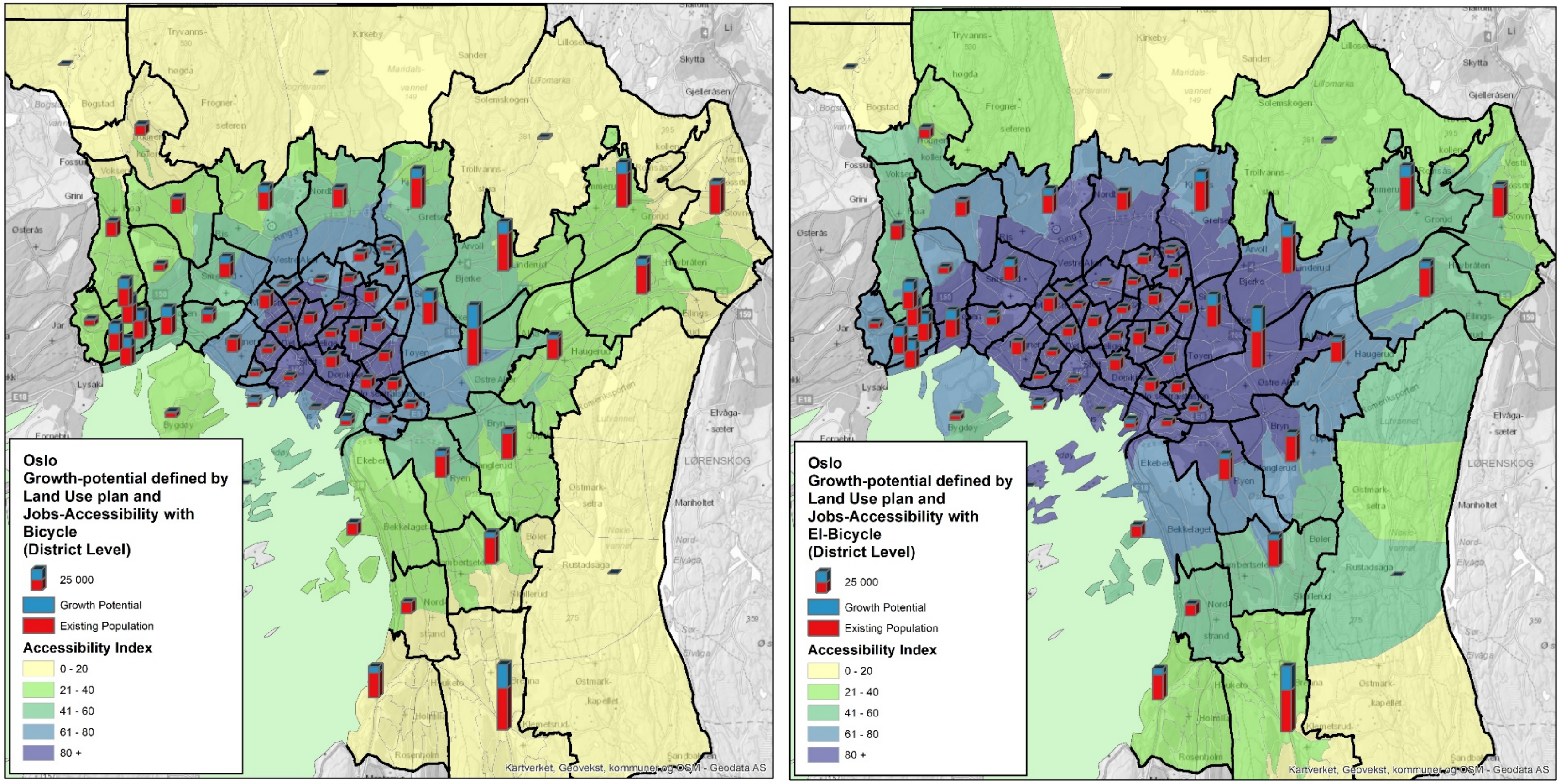

Figure 11: Accessibility bicycle and E-bike, and growth potential Oslo

Figure 11 and Figure 12 highlight a plausible situation on introduction of E-bikes in Oslo. Accessibility to jobs in the city centre increases from 20-24 000 to over 28 000, and this includes brown field developments such as the water front developments at Sørenga. The areas between the 2nd and 3rd ring road, which extend from the eastern part of the Smestad/Skøyen circle to the western part of the Hovinbyen circle, experience a growth in job accessibility from 16-20 000 to 24-28 000 compared to ordinary bikes. Areas on the fringes of the 3rd ring gain a similar increase in job accessibility with E-bike as one has in the city centre with ordinary bikes today. Such areas include the major transformation/redevelopment areas around Økern, Bryn, and Alna, commonly known as "Hovinbyen", transit oriented developments at Skøyen and Smestad, as well as lower density areas/existing neighbourhoods such as Nordberg.

The effects of E-bike on the future green field development of Gjersrud/Stensrud, as well as Grorud, are comparatively small (Figure 12). An interesting finding regarding Oslo is that accessibility to jobs not only extends from the city centre and outwards, but also within the city centre itself. This is also true for Trondheim but to a smaller degree. A possible explanation is that the city centre of Oslo has a high density of workplaces and relatively low density of housing spread over a larger area as compared to Trondheim.

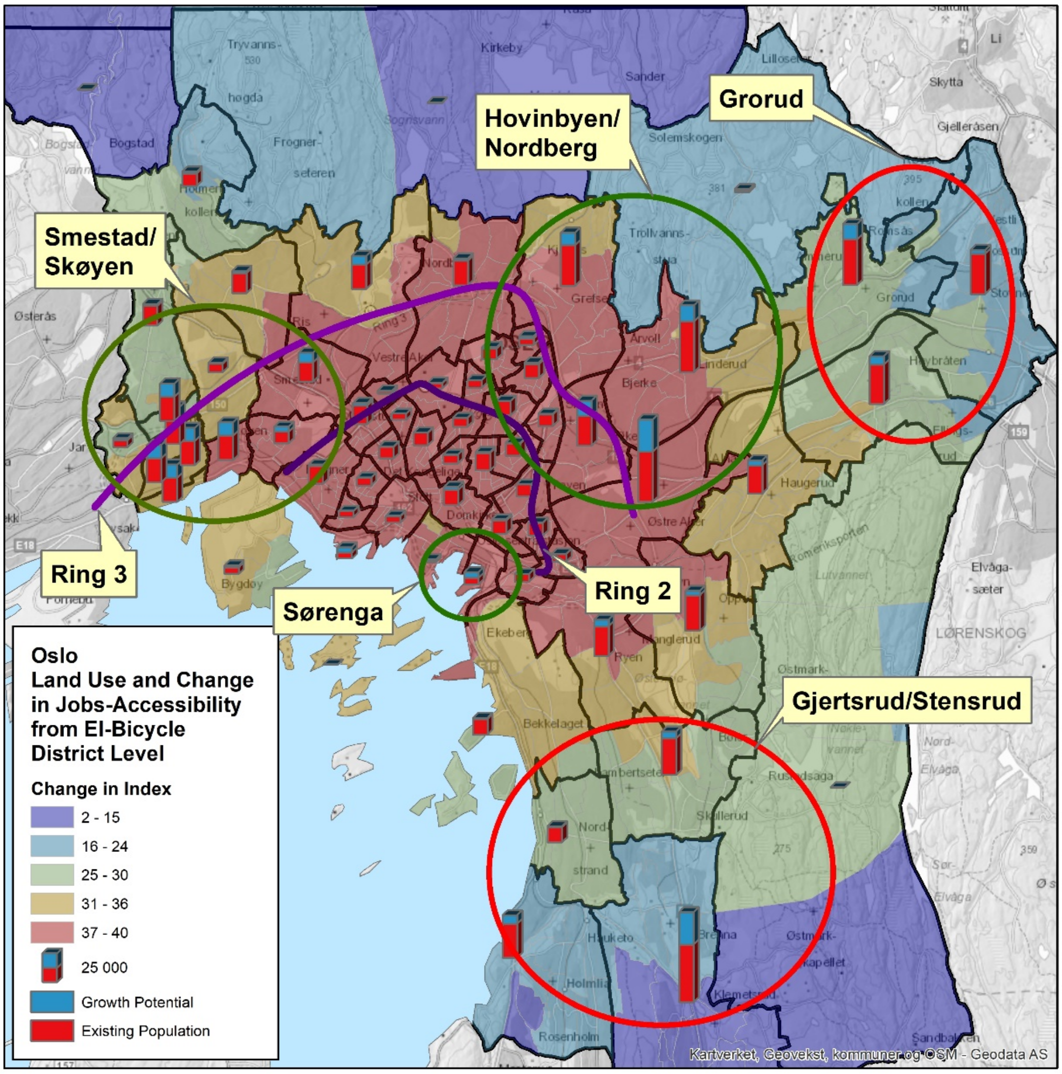

Figure 12: Difference between in accessibility index for E-bikes and bicycles, Oslo

7.0 Discussion and Conclusion

7.1 Methodological challenges and future studies

This study has proposed a new and innovative approach which needs further testing and improvement. This section elaborates on the methodological issues and proposes some thoughts for future studies. There are three broad categories of challenges which need to be addressed in future studies:

The first challenge concerns sample size. Cycling culture is still evolving in urban Norway and is marked by a relatively high proportion of training oriented cyclists who cycle as a form of exercise (Fyhri et al., 2017). As cycling shares are still low in Norwegian cities and since cycling sample is homogenous and limited, there is a danger of representational bias. Low sample size can lead to bias with regards to behavioural statistics of cycle usage, which can impact on the accessibility measurements. In order to increase the sample size, it is advised to link such analyses with dedicated data collected on a sample of cyclists drawn from various stages of life. Additionally, a new and upcoming methodology to plot travel behaviour based on mobile tracking can also be employed to both increase the sample size of cyclists per city and collate information of different kinds of cyclists. In any given approach, it is vital to distinguish between cyclists who are cycling for exercising/training purposes and those are strictly using it as a mode of transportation. Failure in doing so will lead to biased estimates in the mean travel time, travel distance and generalised willingness to pay travel costs.

Secondly, there are uncertainties related to average E-bike speed as estimates vary between studies. Despite the hesitations expressed on using constant link cycling speed as used in a majority of transport models (see section 3.2), we have used an average cycling speed of 22 km/h. This was done to plot an optimal scenario where cyclists are able to cycle at this average speed throughout the case cities, a decision taken to kick-off a discussion on this methodology and plot the best case scenario case for Oslo and Trondheim. In the next step, it is advisable to fine tune the methodology proposed in this study by using a more sophisticated speed model that captures area characteristics, gender and age cohorts.

Further on, the study has not quantified the potential effects on mode use from changes in accessibility levels. We do not estimate the effect of increased accessibility on mode shift and mode usage in the area. This step is important for assessing the volume of change in emissions and potential to achieve emission reduction goals. Future studies should look into this.

7.2 Discussion and conclusion

Much has been said and put forth as policies for combating climate change in the transport sector. But despite all these efforts, concrete and big shifts in either travel behaviour or emissions are not evident both at a global and local scale in Norway. A substantial amount of effort and incentivizing is going towards resource intensive solutions like the electric cars, whose contribution to all three pillars of sustainability – environment, economic and social – remains debatable (Priya Uteng et al., 2021). At this critical juncture, it is imperative to explore other plausible, long-term solutions to combat climate change in the transport sector. This study has discussed the "likely" outcomes from a targeted introduction of E-bikes as a module to achieve climate goals. It made an initial attempt to tackle the sustainability agenda in both urban and transport planning by plotting the relationship between job accessibility with E-bikes and land use growth potentials. Knowledge on this relationship can further inform planning decisions regarding the areas to be developed first to increase the opportunities for E-bike based commuting patterns.

Norway presents an useful case as both its land use approach and transport modelling exercise is similar to other European cities. Thus, the Norwegian cities of Oslo and Trondheim, as studied in this paper, provide suitable "experiments" to outline how urban planners can regulate land use in light of E-bike's potential.

Literature review highlights that in some cases, bicycle commuting had significant associations with some features of the built environment even when other demographic and socioeconomic factors are taken into account. Our analysis supports this finding as E-bikes provide a considerable increase in job accessibility, particularly in the areas surrounding the city centres. We emphasise the need to develop land use strategies like selected densification, a higher number of exclusive bicycle lanes, and greater connectivity between local streets that will allow for maintaining a high average speed of 22 km/h on E-bikes. The cumulative effect of these strategies will allow for a full realization of the commuting potentials offered by E-bikes. A generally high job-accessibility with E-bikes close to the city centres supports the current general strategy of pursuing high density developments/transformation projects in these areas. Our findings suggest that these areas should be prioritised for further development. It is important to emphasise that the green field development areas were not found to provide any substantial accessibility with E-bikes.

Though the increase in accessibility from E-bike is comparable between the cities, Oslo stands out as it has by far the biggest increase in accessibility. E-bike accessibility around the third ring-road equals or exceeds what is currently acquired by normal bike in the city centre. This is different from what we found in Trondheim, where accessibility increase lay as a belt around the city centre.

In general, the results strongly suggest that accessibility impacts of E-bikes should be integrated into the land-use planning and decision-making processes to address both climate change goals and map out a strategy for incorporating new modes of transport in land use decision making processes. The increasing presence of E-bikes can lead to a substantial increase in bike usage in areas where cycling is currently not a viable option.

An equally important line of enquiry is to ascertain the level of willingness to adopt E-Bikes disaggregated by geographical areas, age groups, gender, life stages and other socio-economic variables, which play a crucial role in shaping the preferences for different transport modes. Future studies should concentrate on identifying the limitations and (negative) impacts associated with E-bikes which can provide vital inputs for developing policies to promote E-biking. As these two aspects will vary significantly with local contexts and cultures, it is advised to promote this line of enquiry in different settings and undertake comparative analyses to comment on the findings for robust policy making exercises.

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References

Ahmed, F., Rose, G., Jakob, C., 2013. Commuter cyclist travel behavior: examination of the impact of changes in weather. *Transp. Res. Rec.* 2387, 76–82. https://doi. org/10.3141/2387-09

Arellana, J., Saltarín, M., Larranaga, ˜ A.M., Gonzalez, ´ V.I., Henao, C.A., 2020. Developing an urban bikeability index for different types of cyclists as a tool to prioritise bicycle infrastructure investments. *Transp. Res. Part Policy Pract.* 139, 310–334. https://doi.org/10.1016/j.tra.2020.07.010.

Bachand-Marleau, J., Larsen, J., & El-Geneidy, A. (2011). Much-anticipated marriage of cycling and transit: how will it work?. *Transportation Research Record: Journal of the Transportation Research Board*, (2247), 109-117.

Bertolini, L., le Clercq, F., & Kapoen, L. (2005). Sustainable accessibility: a conceptual framework to integrate transport and land use plan-making. Two test-applications in the Netherlands and a reflection on the way forward. *Transport Policy,* 12(3), 207- 220. doi:https://doi.org/10.1016/j.tranpol.2005.01.006

Bjørnarå, H. B., Berntsen, S., te Velde, S. J., Fyhri, A., Deforche, B., Andersen, L. B., & Bere, E. (2019). From cars to bikes–The effect of an intervention providing access to different bike types: A randomized controlled trial. *Plos One*, 14(7).

Blainey, S., Hickford, A., & Preston, J. (2012). Barriers to passenger rail use: a review of the evidence. *Transport Reviews*, 32(6), 675-696.

Boisjoly, G., Serra, B., Oliveira, G. T., & El-Geneidy, A. (2020). Accessibility measurements in São Paulo, Rio de Janeiro, Curitiba and Recife, Brazil. *Journal of Transport Geography*, 82, 102551. https://doi.org/https://doi.org/10.1016/j.jtrangeo.2019.10255

Broach, J., Dill, J., Gliebe, J., 2012. Where do cyclists ride? A route choice model developed with revealed preference GPS data. *Transp. Res. Part Policy Pract.* 46, 1730–1740. https://doi.org/10.1016/j.tra.2012.07.005.

Cervero, R. (2002). Built environments and mode choice: toward a normative framework. *Transportation Research Part D: Transport and Environment*, 7(4), 265-284.

Cervero, R., Duncan, M., 2003. Walking, bicycling, and urban landscapes: evidence from the San Francisco Bay Area. *Am. J. Public Health* 93, 1478–1483. https://doi. org/10.2105/AJPH.93.9.1478.

Cervero, R., Sarmiento, O.L., Jacoby, E., Gomez, L.F., Neiman, A., 2009. Influences of built environments on walking and cycling: Lessons from Bogota. *Int. J. Sustain. Transp.* 3, 203–226. https://doi.org/10.1080/15568310802178314.

Christiansen, L.B., Cerin, E., Badland, H., Kerr, J., Davey, R., Troelsen, J., van Dyck, D., Mita´ˇs, J., Schofield, G., Sugiyama, T., Salvo, D., Sarmiento, O.L., Reis, R., Adams, M., Frank, L., Sallis, J.F., 2016. International comparisons of the associations between objective measures of the built environment and transport-related walking and cycling: IPEN adult study. *J. Transp. Health, Built Environ. Transp. Health* 3, 467–478. https://doi.org/10.1016/j.jth.2016.02.010.

Christiansen, P., Engebretsen, Ø., Fearnley, N., & Hanssen, J. U. (2017). Parking facilities and the built environment: Impacts on travel behaviour. *Transportation Research Part A: Policy and Practice*, 95, 198-206.

Cole-Hunter, T., Donaire-Gonzalez, D., Curto, A., Ambros, A., Valentin, A., Garcia-Aymerich, J., Martínez, D., Braun, L.M., Mendez, M., Jerrett, M., Rodriguez, D., de Nazelle, A., Nieuwenhuijsen, M., 2015. Objective correlates and determinants of bicycle commuting propensity in an urban environment. *Transp. Res. Part D: Transp. Environ.* 40, 132–143. https://doi.org/10.1016/j.trd.2015.07.004.

Coppola, P., Ibeas, A., dell'Olio, L. and Cordera, R. (2013) LUTI Model for the Metropolitan Area of Santander, *Journal of Urban development and Planning* 139, pp. 153-165.

Deboosere, R., & El-Geneidy, A. (2018). Evaluating equity and accessibility to jobs by public transport across Canada. *Journal of Transport Geography,* 73, 54-63. https://doi.org/https://doi.org/10.1016/j.jtrangeo.2018.10.006

Desjardins, X., & Drevelle, M. (2014). Trends in the social disparities in access to jobs by train in the Paris region since 1975. *Town Planning Review,* 85(2), 155-171.

Dill, J., Voros, K., 2007. Factors affecting bicycling demand: initial survey findings from the Portland, Oregon. Region. *Transp. Res. Rec.* 2031, 9–17. https://doi.org/ 10.3141/2031-02.

El-Geneidy, A., Krizek, K. J., & Iacono, M. (2007). Predicting bicycle travel speeds along different facilities using GPS data: a proof of concept model Paper presented at the 86th Annual Meeting of the Transportation Research Board, Washington.

El-Geneidy, A., Levinson, D., Diab, E., Boisjoly, G., Verbich, D., & Loong, C. (2016). The cost of equity: Assessing transit accessibility and social disparity using total travel cost. *Transportation Research Part A: Policy and Practice*, 91, 302-316. https://doi.org/https://doi.org/10.1016/j.tra.2016.07.003

Forsyth, A., Krizek, K.J., 2010. Promoting Walking and Bicycling: Assessing the Evidence to Assist Planners [WWW Document]. https://doi.org/info:doi/10.2148/ benv.36.4.429.

Flügel, S., Hulleberg, N., Fyhri, A., Weber, C. & Ævarsson, G. (2019) Empirical speed models for cycling in the Oslo road network. *Transportation* **46,** 1395–1419. https://doi.org/10.1007/s11116-017-9841-8

Fyhri, A., Heinen, E., Fearnley, N. & Sundfør, H. B. (2017) A push to cycling—exploring the e-bike's role in overcoming barriers to bicycle use with a survey and an intervention study, *International Journal of Sustainable Transportation*, 11:9, 681-695, DOI: 10.1080/15568318.2017.1302526

Geurs, K. T., & Van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography*, 12(2), 127-140.

Guerra, E., Zhang, H., Hassall, L., Wang, J. & Cheyette, A. (2020). Who cycles to work and where? A comparative multilevel analysis of urban commuters in the US and Mexico. *Transportation Research Part D: Transport and Environment* 87, 102554.

Guti´errez, M., Cantillo, V., Arellana, J., Ortúzar, J.de D., 2020. Estimating bicycle demand in an aggressive environment. *Int. J. Sustain. Transp.* 1–14. https://doi.org/ 10.1080/15568318.2020.1734886.

Hamre, A., & Buehler, R. (2014). Commuter mode choice and free car parking, public transportation benefits, showers/lockers, and bike parking at work: Evidence from the Washington, DC Region. *Journal of Public Transportation*, 17(2), 4.

Handy, S. L., & Niemeier, D. A. (1997). Measuring Accessibility: An Exploration of Issues and Alternatives. *Environment and Planning A: Economy and Space,* 29(7), 1175- 1194. https://doi.org/10.1068/a291175

Handy, S., van Wee, B., Kroesen, M., 2014. Promoting cycling for transport: research needs and challenges. *Transp. Rev.* 34, 4–24. https://doi.org/10.1080/ 01441647.2013.860204.

Hansen, W. G. (1959). How accessibility shapes land use. *Journal of the American Institute of planners*, 25(2), 73-76.

Heesch, K.C., Giles-Corti, B., Turrell, G., 2014. Cycling for transport and recreation: associations with socio-economic position, environmental perceptions, and psychological disposition. *Prev. Med.* 63, 29–35. https://doi.org/10.1016/j.ypmed.2014.03.003.

Heinen, E., Buehler, R., 2019. Bicycle parking: a systematic review of scientific literature on parking behaviour, parking preferences, and their influence on cycling and travel behaviour. *Transp. Rev.* 39, 630–656. https://doi.org/10.1080/01441647.2019.1590477.

Hjorthol, R., Engebretsen, Ø., & Priya Uteng, T. (2014). *Den nasjonale reisevaneundersøkelsen 2013/14 -* nøkkelrapport. Transportøkonomisk institutt, Oslo, Rapport 1383/2014.

Kroesen, M., 2017. To what extent do e-bikes substitute travel by other modes? Evidence from the Netherlands. *Transport. Res. Part D: Transp. Environ.*, 53, 377–387.

Levine, J., Grengs, J., & Merlin, L. A. (2019). *From Mobility to Accessibility : Transforming Urban Transportation and Land-Use Planning*. Cornell University Press.

Levine, J. (2020). A century of evolution of the accessibility concept. *Transportation Research Part D: Transport and Environment,* 83, 102309. https://doi.org/https://doi.org/10.1016/j.trd.2020.102309

Ma, L., Dill, J., 2015. Associations between the objective and perceived built environment and bicycling for transportation. *J. Transp. Health* 2, 248–255. https://doi. org/10.1016/j.jth.2015.03.002

Mateo-Babiano, I., Bean, R., Corcoran, J., Pojani, D., 2016. How does our natural and built environment affect the use of bicycle sharing? *Transp. Res. Part Policy Pract.* 94, 295–307. https://doi.org/10.1016/j.tra.2016.09.015

Miranda-Moreno, L.F., Nosal, T., 2011. Weather or not to cycle: temporal trends and impact of weather on cycling in an urban environment. *Transp. Res. Rec.* 2247, 42–52. https://doi.org/10.3141/2247-06.

Morris, J. M., Dumble, P. L., & Wigan, M. R. (1979). Accessibility indicators for transport planning. *Transportation Research Part A: General*, 13(2), 91-109.

Moudon, A.V., Lee, C., Cheadle, A.D., Collier, C.W., Johnson, D., Schmid, T.L., Weather, R.D., 2005. Cycling and the built environment, a US perspective. *Transp. Res. Part Transp. Environ.* 10, 245–261. https://doi.org/10.1016/j.trd.2005.04.001.

Nielsen, T.A.S., Olafsson, A.S., Carstensen, T.A., Skov-Petersen, H., 2013. Environmental correlates of cycling: evaluating urban form and location effects based on Danish micro-data. *Transp. Res. Part Transp. Environ.* 22, 40–44. https://doi.org/10.1016/j.trd.2013.02.017.

Parker, K.M., Gustat, J., Rice, J.C., 2011. Installation of bicycle lanes and increased ridership in an urban, mixed-income setting in New Orleans, Louisiana. *J. Phys. Act. Health* 8, S98–S102. https://doi.org/10.1123/jpah.8.s1.s98.

Parkin, J. & Rotheram, J. (2010). Design speeds and acceleration characteristics of bicycle traffic for use in planning, design and appraisal. Transport Policy, 17(5), 335- 341. doi: http://dx.doi.org/10.1016/j.tranpol.2010.03.001

Priya Uteng, T., Knapskog, M., Uteng, A. and Sæterøy Maridal, J. (2021) Addressing climate policy-making and gender in transport plans and strategies, The case of Oslo, in G.L. Magnusdottir and A. Kronsell (Eds.) *Gender, Intersectionality and Climate Institutions in Industrialised States* (Abingdon and New York: Routledge). https://doi.org/10.4324/9781003052821

Pucher, J., Buehler, R., 2006. Why Canadians cycle more than Americans: a comparative analysis of bicycling trends and policies. *Transp. Policy* 13, 265–279. https:// doi.org/10.1016/j.tranpol.2005.11.001.

Pucher, J., Buehler, R., 2008. Cycling for everyone: lessons from Europe. *Transp. Res. Rec.* 2074, 58–65. https://doi.org/10.3141/2074-08.

Pucher, J., Dill, J., & Handy, S. (2010). Infrastructure, programs, and policies to increase cycling: an international review. *Preventive medicine*, 50, S106-S125.

Pucher, J., Buehler, R., 2010. *Walking and Cycling for Healthy Cities* [WWW Document]. https://doi.org/info:doi/10.2148/benv.36.4.391.

Pucher, J., Buehler, R., Seinen, M., 2011. Bicycling renaissance in North America? An update and re-appraisal of cycling trends and policies. *Transp. Res. Part Policy Pract.* 45, 451–475. https://doi.org/10.1016/j.tra.2011.03.001.

Redman, L., Friman, M., Gärling, T., & Hartig, T. (2013). Quality attributes of public transport that attract car users: A research review. *Transport Policy*, 25, 119-127.

Schleinitz, K., Petzoldt, T., Franke-Bartholdt, L., Krems, J. and Gehlert, T. (2017) The German Naturalistic Cycling Study – Comparing cycling speed of riders of different E-bikes and conventional bicycles, *Safety Science* 92, pp. 290–297.

Singleton, P.A., Goddard, T., 2016. Cycling by choice or necessity?: Exploring the gender gap in bicycling in Oregon. *Transp. Res. Rec.* 2598, 110–118. https://doi. org/10.3141/2598-13.

Small, K., Verhoef, E., 2007. *The Economics of Urban Transportation*, second ed. Routledge, New York.

Smith, D. A., Shen, Y., Barros, J., Zhong, C., Batty, M., & Giannotti, M. (2020). A compact city for the wealthy? Employment accessibility inequalities between occupational classes in the London metropolitan region 2011. *Journal of Transport Geography*, 86, 102767. https://doi.org/https://doi.org/10.1016/j.jtrangeo.2020.102767

Srinivasan, S., & Ferreira, J. (2002). Travel behavior at the household level: understanding linkages with residential choice. *Transportation Research Part D: Transport and Environment,* 7(3), 225-242.

Sun, T., & Fan, Y. (2018). Inequitable job accessibility across educational and hukou groups in Beijing. *Journal of Transport and Land Use*, 11(1), 791-803.

Sundfør, H.B. and Fyhri, A. (2017) A push for public health: the effect of e-bikes on physical activity levels, *Bmc Public Health*, 17 (1), 809. https://doi.org/10.1186/ s12889-017-4817-3

Trang, N.H.H.D., Hong, T.K., Dibley, M.J., 2012. Active commuting to school among adolescents in Ho Chi Minh City, Vietnam: change and predictors in a longitudinal study, 2004 to 2009. *Am. J. Prev. Med.* 42, 120–128. https://doi.org/10.1016/j.amepre.2011.10.006.

Trondheim Kommune (2014), *Kommuneplanens Arealdel, Boligbyggeprogram*. Available at: https://www.trondheim.kommune.no/tema/bygg-kart-og-eiendom/arealplaner/kommuneplanens-arealdeldelplaner/kpa12-24/ (accessed on 23.09.2019)

Uteng, A. and Kittilsen, O.J. (2015), *Landuse Development on a Ward Level – Integrating Landuse and Transportation Model (Arealutvikling på grunnkretsnivå – ny plan- og transportmodell)* (Oslo: Rambøll Norge AS). available at: http://www.kit-samarbeidet.org/wp-content/uploads/2017/05/2015-12-10-RAPPORT-Rambøll-Arealutvikling-på-grunnkretsnivå-ny-plan-og-transportmodell.pdf (accessed on 23.09.2019)

Uteng, A. and Kittilsen, O.J. (2017), *Quantifying the Landuse Plans in Major Norwegian Cities: Spatial Population Distribution (Kvantifisering av arealplaner i storbyene: befolkningsomfordeling)* (Oslo: Rambøll Norge AS)

Vale, D. S. (2013). Does commuting time tolerance impede sustainable urban mobility? Analysing the impacts on commuting behaviour as a result of workplace relocation to a mixed-use centre in Lisbon. *Journal of Transport Geography*, 32, 38-48.

Wardman, M., Tight, M., & Page, M. (2007). Factors influencing the propensity to cycle to work. *Transportation Research Part A: Policy and Practice*, 41(4), 339-350.

Winslott Hiselius, L. and Svensson, A. (2017) E-bike use in Sweden – CO2 effects due to modal change and municipal promotion strategies, *J. Cleaner Prod.,* 141, pp. 818-824.

Wolf, A., Seebauer, S., 2014. Technology adoption of electric bicycles: a survey among early adopters. *Transport. Res. Part A – Pol. Practice*, 69, 196–211. doi:10.1016/j.tra.2014.08.007.

Zhao, P., 2014. The impact of the built environment on bicycle commuting: evidence from Beijing. *Urban Stud.* 51, 1019–1037. https://doi.org/10.1177/ 0042098013494423.

Appendix 1: Mathematical structure for the accessibility measurements

Accessibility is estimated through combining the populations willingness to travel between the areas based on the generalized travel costs (the willingness represented by a probability) and the number of jobs within the zones (based on Coppola et al., 2013). In this analysis, we used the estimated generalized travel costs between the areas derived from the Regional Transportation model (RTM). The generalized costs are estimated by multiplying the time, distance and direct costs with the standardized monetary value for each element as determined by the Norwegian ministry of Finance. The different cost components included in the estimated costs of traveling between the zones with the different modes are listed in the following table:

Mode Costs	Cost Components
Bicycle and walking	Time Costs
Car	Time Costs Distance Costs Toll cost Ferry costs
Public Transport	Ticket Costs Transit time cost Waiting time cost Transfer time costs Access/ingress time costs

In mathematical terms, we represent the accessibility of having access to a ward using a probability function that expresses accessibility as a function of the generalized cost (GC) of traveling to the ward and the number of jobs in the ward. The accessibility-equation is listed in equation I:

$$\text{I.} \quad Accessibility_{ij} = jobs_j * \Pr(GC_{ij})$$

The total accessibility within a ward is represented by the sum of the accessibility to all of the other wards:

$$\text{II.} \quad Total\ accessibility_i = \sum_{j=1}^{n-i} Accessibility_j$$