TØI report 1699/2019

Tanu Priya Uteng
Andre Uteng
Ole Johan Kittilsen

Institute of Transport Economics
Norwegian Centre for Transport Research

RAMBØLL

Land use development potential and E-bike analysis

TØI Report
1699/2019

Land Use Development Potential and E-bike Analysis

A study of cycling and land use planning

Tanu Priya Uteng (TØI)
Andre Uteng (Rambøll Norge AS)
Ole Johan Kittilsen (Rambøll Norge AS)

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Forfattere: Tanu Priya Uteng, Andre Uteng, Ole Johan Kittilsen

Authors: Tanu Priya Uteng, Andre Uteng, Ole Johan Kittilsen

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Sammendrag:

Å lykkes med å øke sykkelandelen i byområdene er en sentral del av det pågående planleggingsmandatet i de Norske by-regionene. For å lykkes med mandatet kan man ta i bruk tiltak på både mikro- og makroplanet. Mikro-planet innebærer utbygging av gang-og-sykkelstier og øvrige tilsvarende tiltak som bedrer sykkelinfrastrukturen og sykkelopplevelsen for de reisende. På makronivået, som utgjør det strategiske nivået, fremstår regulering av arealbruk og arealbruksplanlegging som et viktig verktøy. Denne rapporten analyserer potensialet for å bruke arealplanleggingen som et verktøy for å oppnå ønsket om økt sykkelbruk i by-regionene Oslo, Bergen, Trondheim og Stavanger. Analysen tar utgangspunkt I INMAP-modellens metodikk for arealplans-kvantifisering, en metodikk som tidligere er benyttet til å estimere sammenhengen mellom arealbruk og reisevaner i en rekke utredninger. Denne rapporten tilbyr kunskap om hvordan eksiterende og fremtidig arealbruk og arealbrukplanlegging kan inngå i sykkelstrategien i byområdene.

Summary:

Increasing cycling shares is a part of the urban and transport planning mandate for the Norwegian urban regions. The pathways to increase bicycling shares can be plotted at both macro and micro levels. At micro levels, road designs and measures to both improve the conditions for cyclists and make cycling paths safer can lead to potential increase in bicycling. At the macro level, land use planning can assist in increasing bicycling usage. In this report, we analyse the issue at a macro level for the four largest cities in Norway – Oslo, Bergen, Trondheim and Stavanger. Analysis is based on INMAP model, which has previously been employed to estimate the mutual effects of land use plans, infrastructure provision and transportation in Norway. This study strongly recommends integrating the impact of E-bikes with land-use planning processes and decisions. Through active land-use management, the municipalities and regional development authorities can steer urban mobility to a more sustainable direction.

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Transportøkonomisk Institutt
Gaustadalléen 21, 0349 Oslo
Telefon 22 57 38 00 - www.toi.no

Institute of Transport Economics
Gaustadalléen 21, N-0349 Oslo, Norway
Telephone +47 22 57 38 00 - www.toi.no

Preface

This report is part of the research project *Reducing fossil energy use and CO_2 emissions from transport by paving the way for more bicycles and E-bikes (Cycle-2-zero)* financed under the aegis of the research programme ENERGIX (Project Number: 255628) of The Norwegian Research Council (NRC).

In this research project, we have developed both new methods for data collection and analysis. This report focuses on a new method of analysing the land use data, both existing and future plans, to comment on the potential of E-bikes to cater to commuting trips. This report addresses the work package 2 of the Cycle-to-Zero project.

The report provides the foundation for additional analyses, for the case of Oslo and Stavanger, undertaken and presented in the following projects:

- *Climate change and everyday mobility – social impacts, adaptation and mitigation strategies (CLIMAMOB)* financed under the aegis of the research programme KLIMAFORSK (Project Number: 244137) of The Norwegian Research Council (NRC).
- *Sustainable Horizons in Future Transport (SHIFT)* – a Nordic Flagship Project funded by The Nordic Energy Research (grant number 77892).

Data sources from the Regional Transport Model (RTM), and land use plans have been used to plot the linkages between bicycling and the current and future strategy plans of the four biggest cities of Norway.

The report is written by Tanu Priya Uteng, Andre Uteng, Ole Johan Kittilsen. Andre Uteng and Ole Johan Kittilsen are transport consultants at the engineering consultancy firm Rambøll Norge AS, and have worked in close collaboration with Tanu Priya Uteng at the Institute of Transport Economics to develop this study.

Tanu Priya Uteng has been the project leader of Cycle-2-zero during the preparation of this report. Aud Tennøy has been quality manager for this report. Secretary Trude Kvalsvik has been responsible for organizing the report for publishing.

Oslo, March 2019

Institute of Transport Economics

Gunnar Lindberg	*Silvia Olsen*
Managing Director	*Research Director*

Content

Summary

Sammendrag

1 Introduction 1

1.1 Report structure 2

2 INMAP 3

3 Measuring accessibility with bicycle and E-bike 5

3.1 Estimated travel time by E-bike 6

3.2 Willingness to pay 8

3.3 Results 10

4 Estimation of growth potential based on land use plans, and its importance .. 15

4.1 The City of Bergen 19

4.2 The Cities of Stavanger, Sandnes and Sola 22

4.3 The City of Trondheim 27

4.4 The City of Oslo 28

5 Analysis 31

5.1 The City of Bergen 32

5.2 The cities of Stavanger, Sandnes and Sola 34

5.3 The City of Trondheim 36

5.4 The City of Oslo 38

6 Conclusion 40

7 References 41

Appendix 43

Summary

Land use development potential and E-bike analysis

TØI Report 1699/2019
Tanu Priya Uteng, Andre Uteng, Ole Johan Kittilsen
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Increasing cycling shares is a part of the urban and transport planning mandate for the Norwegian urban regions. The pathways to increase bicycling shares can be plotted at both macro and micro levels. At micro levels, road designs and measures to both improve the conditions for cyclists and make cycling paths safer can lead to potential increase in bicycling. At the macro level, land use planning can assist in increasing bicycling usage. In this report, we analyse the issue at a macro level for the four largest cities in Norway – Oslo, Bergen, Trondheim and Stavanger. Analysis is based on INMAP model, which has previously been employed to estimate the mutual effects of land use plans, infrastructure provision and transportation in Norway.

The White Paper 26, 2012-2013 (NTP) states that any future growth in person transport in the larger cities should be absorbed by public transport, cycling and walking. In order to realize this ambitious goal, government wants to implement measures to stimulate 'green' person transport, and one of the popular measures towards this end is through extending financial support for policy packages in the city-networks. This report provides knowledge on how current and proposed land use and transport policies can be effectively interlinked to promote bicycling in the four cities. The results can assist in designing specific measures and paths of adoption for such measures, which can form a vital input for making decisions on policy packaging by the cities.

As per the trip-making characteristics, almost half of the trips registered in the National Travel Survey (NTS 2013/14) of Norway are less than 5 km, and close to 50 percent of these short to medium length trips were taken with cars. This indicates a potential to reduce car use and increase cycling in Norway which can be addressed through suitable land use planning. The results presented in this report can assist in designing specific measures and the paths of adoption for such measures, which can form a vital input for making decisions on policy packaging by the cities.

In this report, we have interpreted the interactions between bicycle accessibility and land use planning through the INMAP methodology. In this methodology, the 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 in the areas.

Accessibility with bicycle and E-bike

The methodology for estimating accessibility used in INMAP is based on the approach developed for the Land use and transport interaction (LUTI) model for the metropolitan area of Santander (Coppola et. al. 2013). Accessibility is modelled as a function which combines the willingness to pay (for a given travel cost to a zone) with the number of jobs that can be acquired (from travelling to the zones).

Estimated accessibility for bicycle and E-bike for the four case cities have been plotted and figure S1 presents the case of Bergen. Accessibility is measured as the number of jobs that are accessible within each ward. The top figure depicts accessibility to jobs by bicycle, and accessibility for E-bike is provided in the bottom figure.

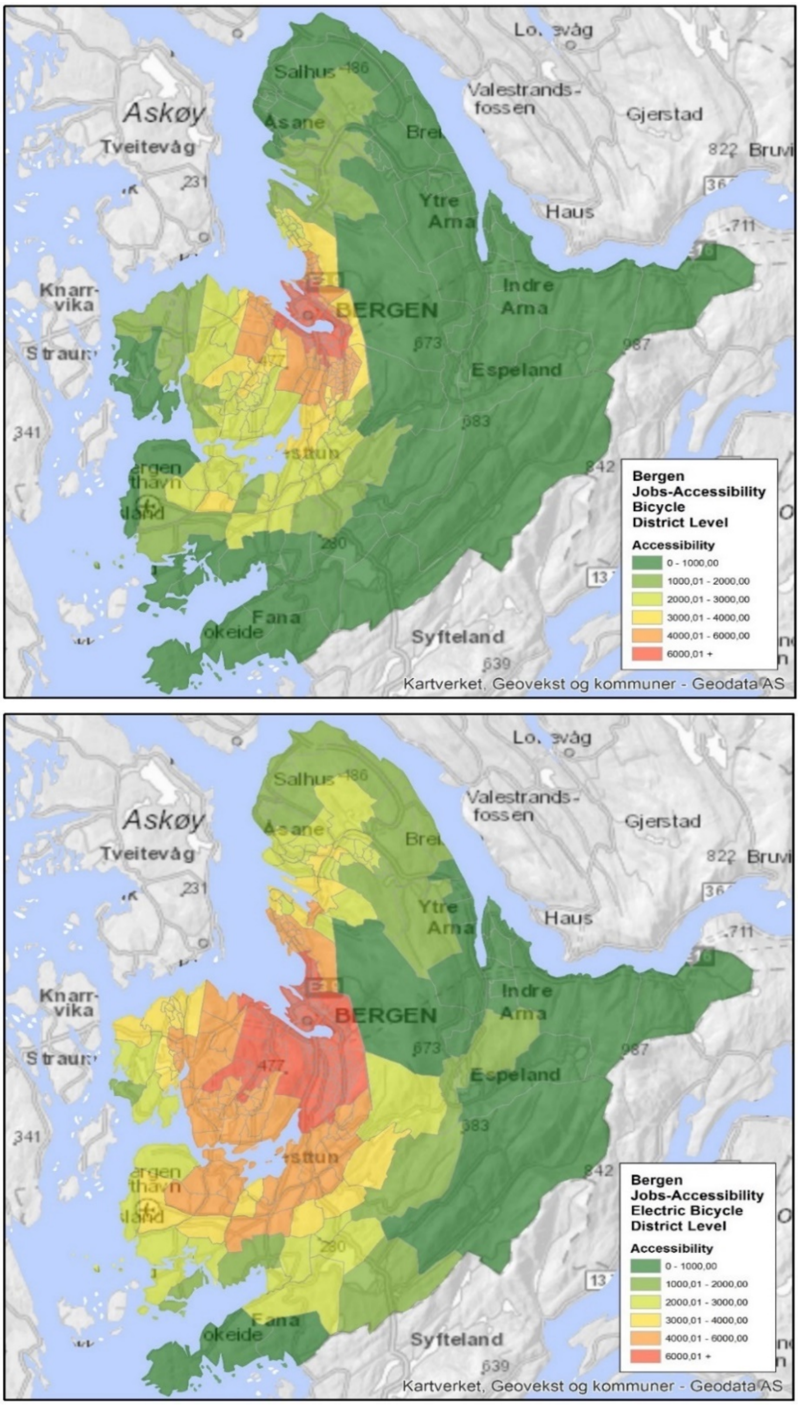

Figure S-1: Accessibility by bicycle and E-bike to workplaces. Bergen.

Growth potential based on land use plans

The INMAP model builds on estimating the growth potential based on existing and future land use plans and strategies. In Figure S-2, the maximum growth potential of inhabitants according to the strategic general plan of Bergen on district-level has been highlighted. Blue colour marks growth potential of population according to the general plan, while existing population is shown in red. This mapping exercise assists in plotting the potential areas for future development. For example, half of the growth is located to the city center or the adjacent Bergensdalen *"Valley of Bergen"* (south of the city center). The biggest growth area, apart from the city center is Fyllingsdalen which is southwest of the city center. Other densification areas, such as Arna, Åsane, and the airport/Ytrebygda can be seen to the east, north and southwest. Similar plottings were done for each case city and the results fed into the final analysis and interlinking of accessibility (on bicycle and E-bikes) and land use growth potential.

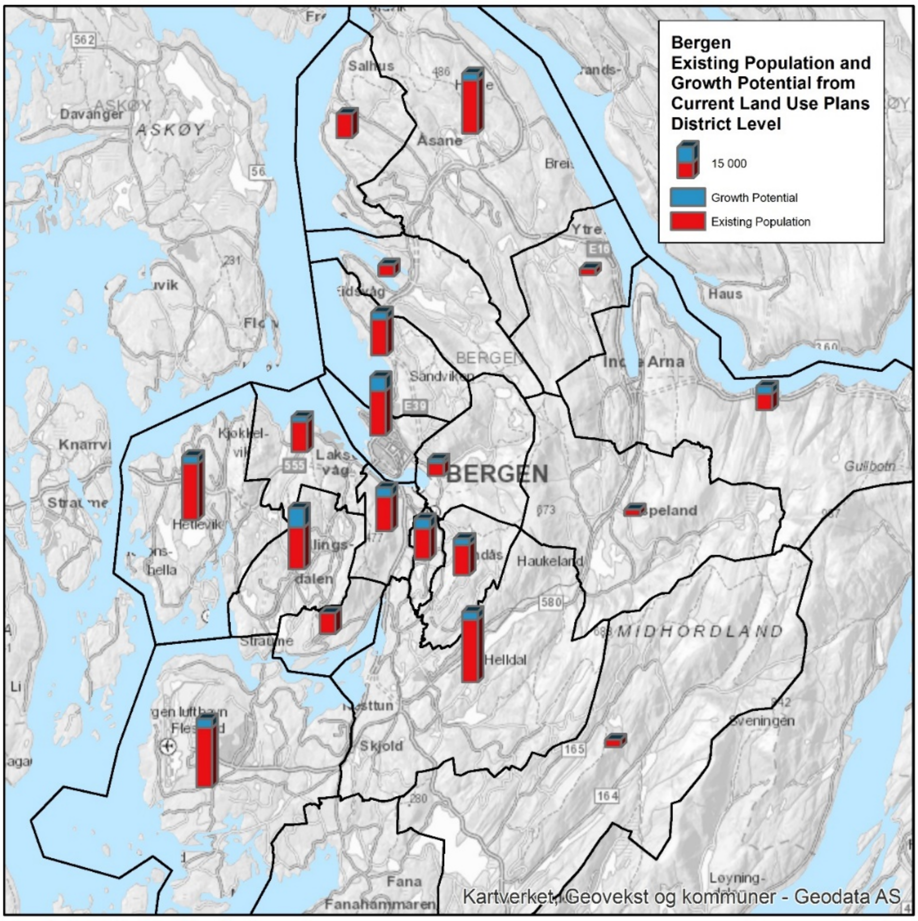

Figure S-2: Estimated growth potential according to the strategic general plan City of Bergen.

Analysis: outlining the interlinkages between bike accessibility and land use plans

For each city, accessibility maps were plotted to highlight the number of jobs that are accessible with E-bikes contra bicycles in the different parts of the city. These figures provide vantage points to critically reflect on the general land use plans for the cities.

For example, the accessibility map for bicycle for Bergen shows access to 6 000 or more jobs in the central parts of the city centre, and an equivalent level of accessibility spreads throughout the city centre and growth areas in Bergensdalen and Fyllingsdalen when E-bikes are inserted in the system. The City of Bergen has already, in the new general plan, removed limitations on density for the central areas as long as certain criteria are met by the developers. Our analyses support this move by the city authorities.

While the strategic general plan sets out that growth should occur in the city centre, adjacent area of Bergensdalen, as well as local centres and transportation nodes, our analysis (based on E-bike accessibility) suggests that increased accessibility to jobs would be achieved if a larger share of the growth takes place in the city centre and Bergensdalen, along with Nesttun.

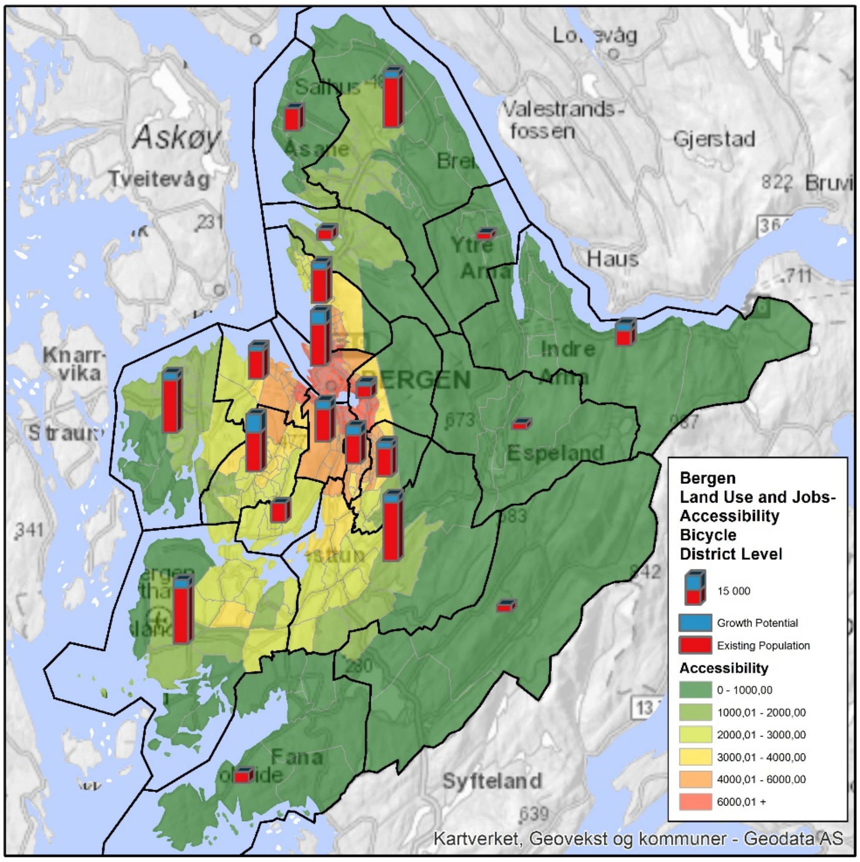

Figure S-3: Accessibility with bicycle and growth potential, Bergen.

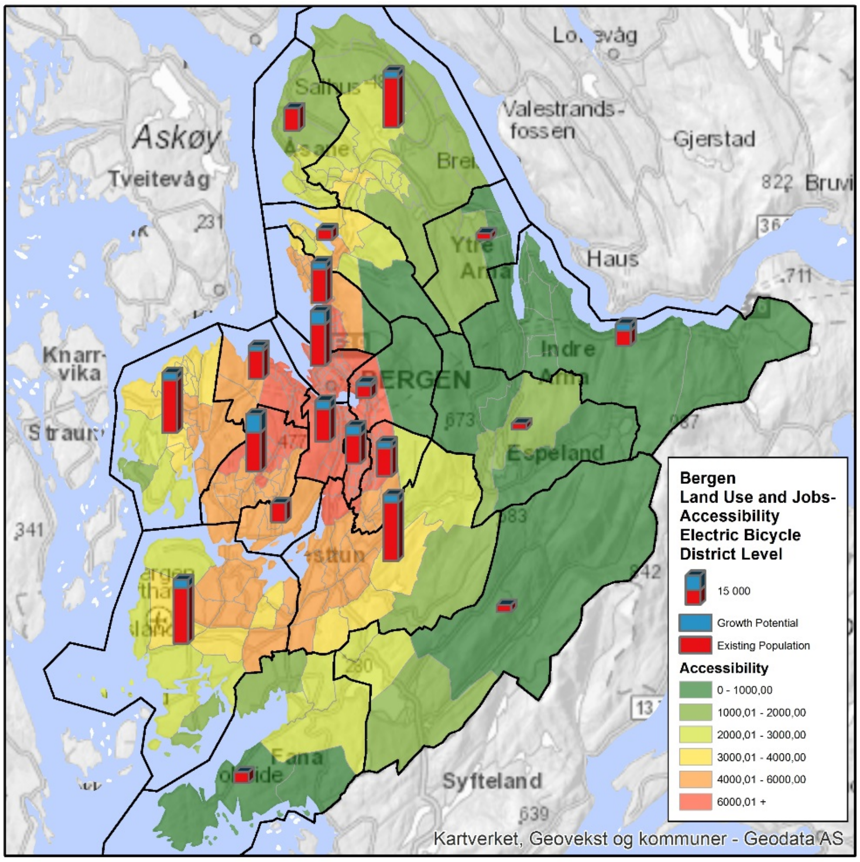

Figure S-4: Accessibility with E-bike and growth potential, Bergen

Conclusion

This report has considered the relationship between job accessibility with bicycle and E-bike, and the land use plans of the four biggest cities in Norway. Understanding this relationship is important as E-bikes allow for a substantially higher average speed than normal bicycles, thus making it a viable option for a larger area than normal bicycles.

From comparing E-bike accessibility with the land use growth potential, we found that it is possible to develop land use strategies to enhance the use of E-bikes. Each city has areas close to the city centre with limited development potential according to the existing plans, but high job-accessibility with E-bikes. High job-accessibility with E-bikes close to the city centres supports the current general strategy of pursuing high density developments or transformation projects in these areas. The findings of this report suggest that these areas should be considered for further development. This is especially true as the green field development areas are, in general, not found to provide any substantial accessibility with E-bikes.

Findings further suggest that the E-bikes may have a bigger impact in Stavanger than in Trondheim and Bergen. Oslo will, by far, have the biggest increase in accessibility.

To conclude, this study strongly recommends integrating the impact of E-bikes with land-use planning processes and decisions. Through active land-use management, the municipalities and regional development authorities can steer urban mobility to a more sustainable direction.

Sammendrag

Arealbruk og El-sykkel analyse

TØI Report 1699/2019
Tanu Priya Uteng, Andre Uteng, Ole Johan Kittilsen
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Å lykkes med å øke sykkelandelen i byområdene er en sentral del av det pågående planleggingsmandatet i de Norske by-regionene. For å lykkes med mandatet kan man ta i bruk tiltak på både mikro- og makro-planet. Mikro-planet innebærer utbygging av gang-og-sykkelstier og øvrige tilsvarende tiltak som bedrer sykkelinfrastrukturen og sykkelopplevelsen for de reisende. På makronivået, som utgjør det strategiske nivået, fremstår regulering av arealbruk og arealbruksplanlegging som et viktig verktøy.

Denne rapporten analyserer potensialet for å bruke arealplanleggingen som et verktøy for å oppnå ønsket om økt sykkelbruk i by-regionene Oslo, Bergen, Trondheim og Stavanger. Analysen tar utgangspunkt i INMAP-modellens metodikk for arealplans-kvantifisering, en metodikk som tidligere er benyttet til å estimere sammenhengen mellom arealbruk og reisevaner i en rekke utredninger.

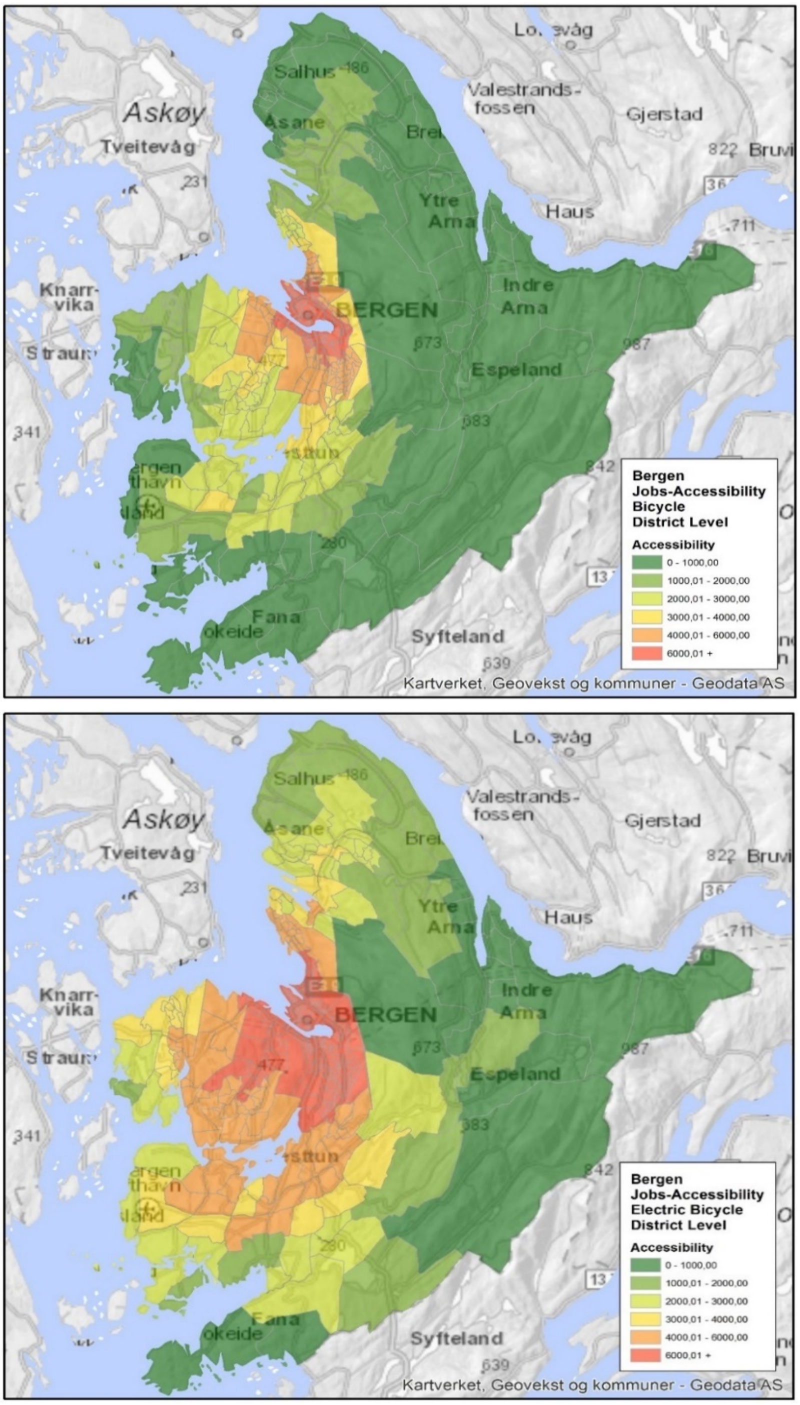
I henhold til National Transportplan (NTP) skal den fremtidige veksten i persontransporten i de største byene absorberes av kollektivtransporten, sykling og gange. For å realisere denne ambisiøse planen ønsker myndigheten å implementere tiltak for å stimulere «grønn» persontransport. Et populært tiltak består av å yte finansiell støtte til tiltakspakker i byvekstavtalene. Denne rapporten tilbyr kunskap om hvordan eksiterende og fremtidig arealbruk og arealbrukplanlegging kan inngå i sykkelstrategien i byområdene.

I henhold til den nasjonale reisevaneundersøkelsen er nesten halvparten av reisene kortere enn 5 km, og av disse korte og mellom lange reisen, ble nesten halvparten utført med bil. Statistikken indikerer et klart potensial for at bilturer kan overføres til sykkelturer. Denne rapporten presenterer en analyse av hvordan arealbruken og -formingen av de kommunale arealstrategiene kan bistå overføringen av bilturer til sykkelturer. I analysen ser vi på interaksjonen mellom vekstpotensialet som kommuneplanen tillater i de ulike grunnkretsene, og grunnkretsenes tilgjengelighet til arbeidsplasser med sykkel og el-sykkel. Her representerer vekstpotensialet (som beregnes med utgangspunkt i de gjeldende arealplanene for hver byområdet) tilbudet av land, mens etterspørselen etter land antas å (til dels) avhenge av arbeidsplasstilgjengeligheten de ulike arealene tilbyr.

Tilgjengelighet med sykkel og el-sykkel

Metodikken for estimering av arbeidsplasstilgjengeligheten benyttet i INMAP er basert på Land use and transport interaction (LUTI) modellen utviklet for storbyområdet for Santander (Coppola et. al. 2013). Tilgjengeligheten modelleres som en funksjon som kombinerer betalingsvilligheten/reisevillighet (for en gitt reisekostnad) mellom sonene, og antallet jobber i hver sone. Øvelsen resulterer i et estimat for antallet jobber/arbeidsplasser man kan nå i hver grunnkrets basert på transportinfrastrukturen (gang og sykkelveier osv.) og de omkringliggende næringsarealene.

I analysen har vi kartlagt arbeidsplasstilgjengeligheten med sykkel og el-sykkel for Norges fire største byer. Det øverste kartet i Figur S1 viser arbeidsplasstilgjengeligheten for Bergen med sykkel, mens det nederste viser tilgjengeligheten med el-sykkel



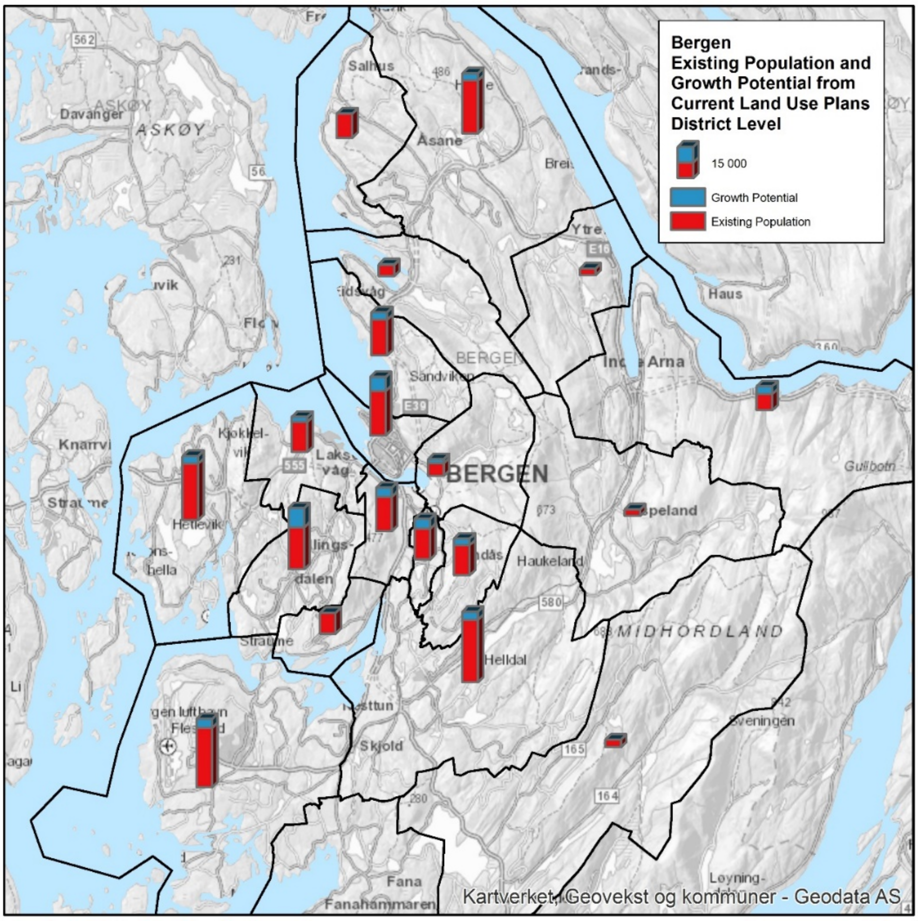
Figur S 1: Sykkel og El-sykkeltilgjengliehet til arbeidsplassen, Bergen.

Vekstpotensial og kommuneplaner

INMAP-modellen danner estimater for vekstpotensialet ved å ta utgangspunkt i føringene i kommuneplanens arealstrategi mht. dekar areal tilgjengelig, høyde-restriksjoner og øvrige restriksjoner som vil innvirke på områdenes potensielle utnyttelsesgrad. Gjennom å utføre øvelsen for hvert boligområde innenfor grunnkretsene får man estimert et mål for den maksimale bosettingen grunnkretsene kan inneha gitt de gjeldende begrensningene i planen. Figur S-2 illustrerer det maksimale vekstpotensialet og dagens bosetting i Bergen på distriktsnivå.

Høyden på hver bar angir den maksimale bosettingen som gjeldene plan tillater i hvert distrikt, hvorav den røde delen av barene representerer dagens bosetting i distriktet, mens den blå delen angir distriktenes samlede vekstpotensial.

Kartøvelsen gir en nyttig beskrivelse av kommuneplanens betydning for vekstomfanget i de ulike områdene. Kartet viser for eksempel at omtrent halvparten av veksten er lokalisert i Bergen sentrum og i den nærliggende Bergensdalen (sør for sentrum). Det største vekstområdet utenom sentrum er i Fyllingsdalen sørvest for by-sentrumet. Kartet viser også omfanget av øvrige fortettingsområder, heriblant Arna (øst for sentrum), Åsane (nord for sentrum) og flyplassen (sørvest for sentrum). I prosjektet har det blitt utarbeidet tilsvarende kart for hvert byområde, og disse har så blitt benyttet for å analysere sammenhengene mellom vekstpotensialet og tilgjengeligheten.

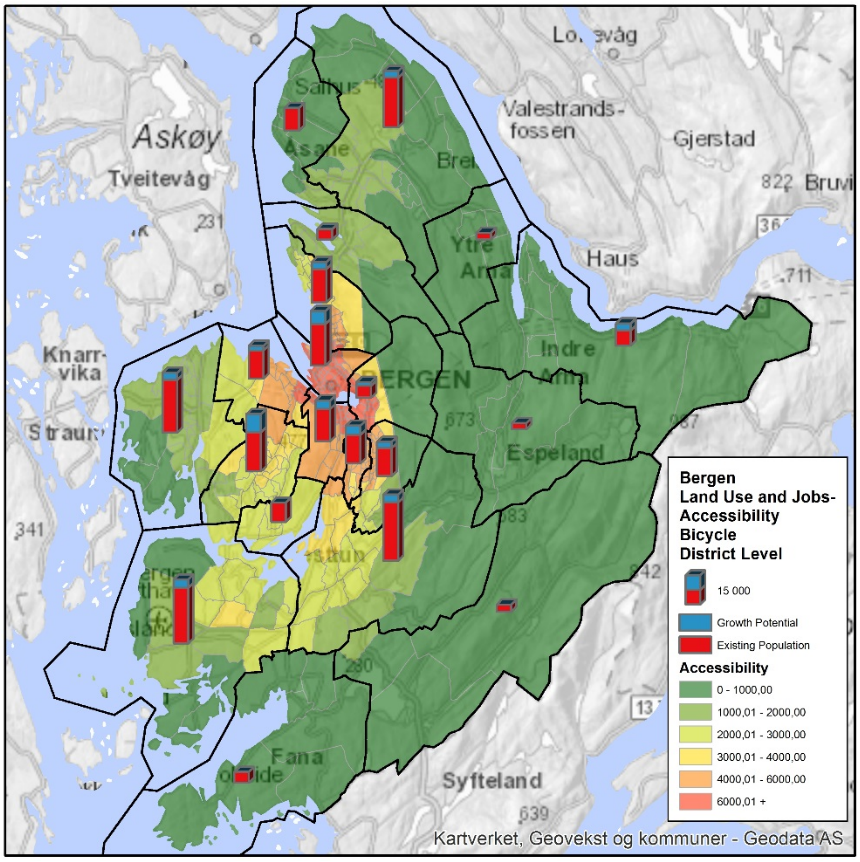


Figur S-2: Estimert vekstpotensial for Bergen basert på gjeldende kommuneplan.

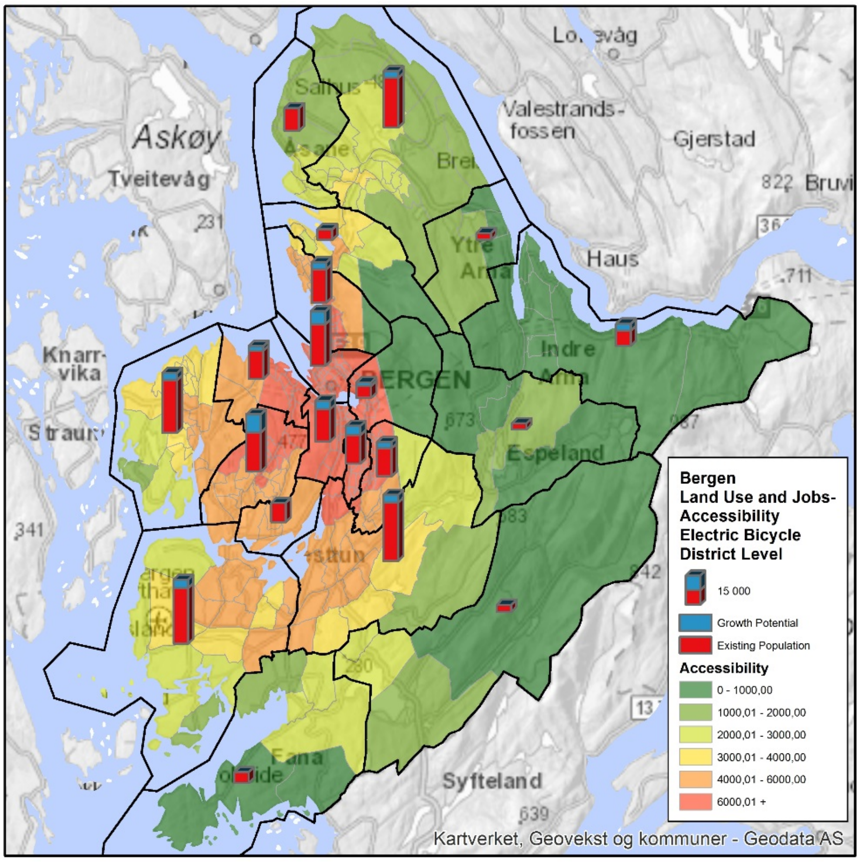
Analyse: Kartlegging av sammenhengene mellom sykkel-tilgjengelighet og kommunens arealstrategier

I analysen er det for hver by utarbeidet kart som gir en samlet fremstilling av jobb-tilgjengeligheten med sykkel og el-sykkel, og vekstpotensialet angitt av kommuneplanen. Basert på disse kartene kan man identifisere hvilke områder som får en økning i tilgjengeligheten ved introduksjon av el-sykkel, og hvorvidt kommuneplanen legger opp til vekst i disse områdene. Kartene gir med andre ord innsikt i hvorvidt kommuneplanene støtter opp innføringen av el-sykler eller ikke.

Figur S-3 og S-4 viser sammenhengene mellom vekstpotensialet og jobb-tilgjengeligheten med vanlig sykkel (S-3), og tilsvarende sammenheng for el-sykkel (S-4). Fra figurene ser man at man i dag har en tilgjengelighet på rundt 6000 arbeidsplasser i Bergen sentrum ved bruk av vanlig sykkel, og at denne avtar raskt med avstanden til sentrum. Ser man derimot på tilgjengeligheten med el-sykkel, har denne en tilgjengelighet tilsvarende den for sentrum med vanlig sykkel som sprer seg bredt utover i både nordlig og sørlig retning. Som det kommer frem fra kart S-3 har man med el-sykkel samme jobb-tilgjengelighet i Bergensdalen og Fyllingsdalen som man har med vanlig sykkel i sentrum. I henhold til Bergens nyeste planstrategi legges det opp til en reduksjon av tetthetsbegrensningene i byområdet så lenge gitte kriterier blir møtt av utbyggerne. Vår analyse indikerer at en slik fortettingsstrategi vil kunne gi en god effekt på overgangen til grønn persontransport i Bergen.



Figur S-3: Sykkeltilgjengelighet til arbeidsplasser og vekstpotensial, Bergen



Figur S-4: El-sykkeltilgjengelighet til arbeidsplasser og vekstpotensial, Bergen.

Konklusjon

Rapporten har vurdert sammenhengen mellom jobb-tilgjengeligheten med sykkel og el-sykkel, og vekstpotensialet på distriktsnivå basert på kommuneplanenes arealdeler for Norges største byer. Å oppnå forståelse for disse sammenhengene er viktig ettersom el-syklene tillater en betydelig høyere hastighet og krever en betydelig lavere ytelse av syklisten enn vanlig sykkel. Disse forholdene medfører at el-sykkel utgjør et reelt alternativ i større områder enn vanlig sykkel.

Gjennom å sammenlikne vekstpotensialet med el-sykkel tilgjengeligheten har vi funnet at det er mulig å tilpasse arealstrategien til å bygge opp under el-sykkelens fremvekst. Samtlige av byene har en strategi om å oppnå fortetting nært sentrum, og vår analyse viser at disse fortettingsområdene har en såpass høy el-sykkeltilgjengelighet at de kan forventes å kunne få samme sykkel-andel som de mest sentrumsnære områdene. Samtidig viser rapporten at byene også har relativt store områder med svært begrenset vekstpotensial og relativt høy el-sykkeltilgjengelighet. En fortetting i disse områdene vil kunne få en stor effekt på overgangen til grønn persontransport. Dette gjelder spesielt områdene med begrenset kollektivtilgang.

Basert på rapportens resultater kan man konkludere med at det å integrere tilgjengelighetsmål i arealplanleggingsprosessen kan gi innsikt i sammenhenger som man i dag ikke fanger opp, og at en slik integrering kan være en effektiv måte å oppnå et grønt skifte i persontransporten

1 Introduction

This report is a part of work package 2 (WP2) of the research project *Reducing fossil energy use and CO_2 emissions from transport by paving the way for more bicycles and E-bikes (Cycle-2-Zero)* financed under the aegis of the research programme ENERGIX (Project Number: 255628) of The Norwegian Research Council (NRC). Cycle-2-Zero is envisioned to be a multi-disciplinary project which aims at combining theories and data anchored in infrastructure planning, energy, economics, urban/transport planning and political science. The analysis presented here provides a foundation for energy mapping of future scenarios developed for Oslo and Stavanger for the following projects:

- *Climate change and everyday mobility – social impacts, adaptation and mitigation strategies (CLIMAMOB)* financed under the aegis of the research programme KLIMAFORSK (Project Number: 244137) of The Norwegian Research Council (NRC).
- *Sustainable Horizons in Future Transport (SHIFT)* – a Nordic Flagship Project funded by The Nordic Energy Research (grant number 77892).

WP2 of *Cycle-2-Zero* proposes to fuse data collected on the physical variables of bicycling infrastructure with other relevant parameters like area density and morphology, population characteristics, rate of bicycle usage, the national travel survey, proximity to public transport hubs, existing and planned cycling policies, user preferences etc. to arrive at a comprehensive value (index) depicting the existing levels of bicycle oriented development (BOD) at a location or an area.

Primary objectives of the WP2, which looks at the interplay between urban context and bicycle usage, were as following:

i. to examine and measure existing urban layout – by examining the positioning of bicycle lanes, urban densities, residential / employment centres / shopping locations, parking facilities and other physical determinants connected to bicycling;
ii. to measure and assess the impact of transport policies and urban policy packaging on bicycling;
iii. to comment on how cycling culture influences the level of cycling in Norwegian cities.

In this report, we have analysed the relationships between accessibility to jobs acquired by travelling with normal bicycles and electric bicycles (E-bikes), and the existing land-use plans within the city regions of Trondheim, Bergen, Stavanger and Oslo in Norway. 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 analysis builds on the assumption that there is 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 report have been performed using the Integrated Methodology for Land Use prognosis within Transportation Models (INMAP). The methodology has been developed by Rambøll on behalf of the Ministry of Local Government and Modernisation since 2015 for the task of generating land use forecasts for the Norwegian transportation models (Uteng and Kittilsen 2015)[1]. INMAP generates the forecasts through combining the following two approaches:

i. The first approach is based on a methodology that uses the strategic general plan of a city region to quantify the growth potential of the various zones and wards within an area.
ii. The second approach is based on a standard accessibility model which uses estimated travel times, travel surveys and official employment and populations statistics to estimate the accessibility to jobs, trade and services by car, public transport, walking and cycling.

This study puts forth the following three broad sets of analyses:

i. Accessibility-analyses for bicycle and E-bike for each city region.
ii. Estimation of growth potential in housing/inhabitants according to existing land use plans in the four cities of Oslo, Bergen, Trondheim and Stavanger.
iii. A combined analysis of the accessibility of E-bike, and the growth potential according to the land use plans, as well as a discussion on the possibilities for optimizing an increased accessibility thorough land use plans.

The report begins with giving a description of the INMAP-methodology in chapter 2 and the approach used to estimate the accessibility with cycle and E-bike in chapter 3. Following that, chapter 4 describes the methodology used for quantifying the municipality land use plans. In chapter 5, we analyse the relationships between the growth potential and the accessibility for each city-region and assess the extent to which the land use plans facilitate cycle and E-bike usage. Chapter 6 concludes the study.

1.1 Report structure

This report looks at the following topics in the four largest cities in Norway (Oslo, Bergen, Trondheim and Stavanger):

1. Brief introduction to the INMAP model.
2. Accessibility measurement with bicycle and E-bikes.
3. Estimation of growth potential based on land use.
4. Plotting of areas most suitable for future development in light of increasing bicycle usage.

[1] http://www.kit-samarbeidet.org/wp-content/uploads/2017/05/2015-12-10-RAPPORT-Rambøll-Arealutvikling-på-grunnkretsnivå-ny-plan-og-transportmodell.pdf

2 INMAP

INMAP is a model used for estimating the mutual effects of land use plans, infrastructure and transportation in Norway. The model has been developed by Rambøll Norge AS on behalf of the Norwegian Roads Authorities and the Ministry of Local Government and Modernisation since the autumn of 2015 (Uteng and Kittilsen 2015). This model currently provides the official methodology for land-use analysis in the Norwegian transportation modelling system, and the Ministry of Local Government and Modernisation recommends its usage for all public land-use estimations in Norway. So far, the model-tool has been used to estimate the effects of land-use planning on vehicle kilometers travelled in private cars in the city of Bergen, the municipalities of Arendal and Kongsberg, as well as the city region of Stavanger.

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.

At its core, INMAP is a stand-alone module that processes the traditional input data used by the transportation model to contain 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 commercial 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 impacts the travel times between the zones), and changes in the land use plans (as these impacts the growth restrictions of the zones).

INMAP, in other words, enhances the traditional transportation model to have capabilities normally reserved for more sophisticated Land Use and Transportation Interaction (LUTI) models. LUTI models typically plot the mutual relationships between the changes in transportation infrastructure, expected development of commercial and residential areas, and the expected development in traffic. However, where the more sophisticated LUTI models assume that the supply and usage of land is determined by the market, 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. The approach also 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, the INMAP methodology uses an estimated generalized travel costs between the zones in combination with official employment statistics to estimate the accessibility to jobs, trade and services within each zone with each available mode of travel. INMAP then assumes that, for everything else being equal, the population wishes to settle in the areas that has both available space (as determined by the land use plan) and the highest accessibility (as determined by the current land use and the 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 a 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 the accessibilities. 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.

Being a simplified LUTI model means that INMAP generates relatively simplistic forecasts as compared to sophisticated LUTI-models that take into account multiple factors in addition to accessibility and historic growth. However, 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 does enable its users to test the effects of changes to the infrastructure and land use plans for a given set of assumptions.

In this study, the 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 the largest Norwegian cities, and accessibility with cycle and E-bike. In the analysis we only consider the current situation, which means that we do not consider the effects of future changes in population and commercial land use. The analysis does also not consider the effects of seasonal variation. The results of the study do thus only apply for the seasons that allows for cycling.

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 section, we describe our approach for dealing with these issues.

3 Measuring accessibility with bicycle and E-bike

The methodology for estimating accessibility used in INMAP is based on an approach applied for development of the LUTI model for the metropolitan areas of Santander (Coppola et. al. 2013). This means that the accessibility has been estimated as a function of the generalized travelling costs within the regions, the 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 the 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 of these being that the transport model generates travel-time estimates for normal bicycle only. Generating corresponding travel times for E-bike 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 only doable for normal bicycle. Thus, for estimating the WTP for e-bike, we had to use distributions and parameters for bicycle. This means that the estimated WTP for e-bike might be skewed as it only contains the time saving benefits from e-bike. However, this limitation cannot be remedied until there exists a suitable sample of observations of e-bike trips.

In the following sections, we describe the approaches used for overcoming these challenges.

3.1 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 from 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, the coding of the transportation network, and the 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 by 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 Level of Service (LOS) matrix. Regarding the bicycle estimates, this means that the LOS-matrix contained information on both the minimum distance and the estimated travel time between zones. Using the estimated distances, we further generated comparable LOS metrics for E-bike through combining the estimated travel distance with bicycle with an estimate for the average speed with E-bike.

As an estimate for the average speed with E-bike, we relied on the results from the study performed 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.

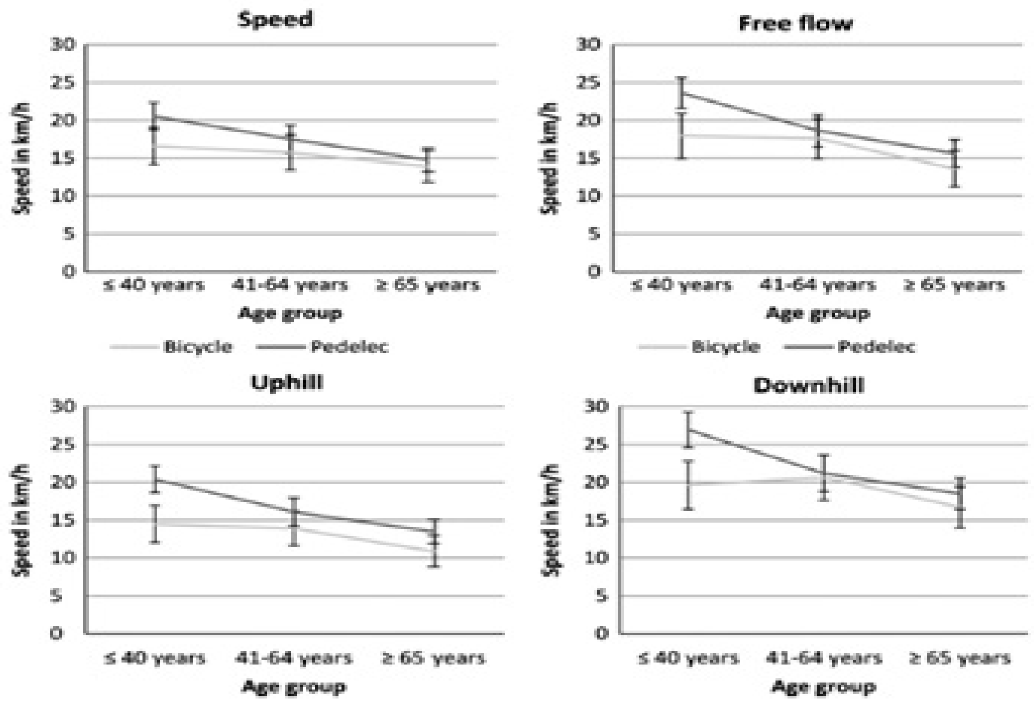


Figure 1: Measured speeds for bicycle, pedelec and S-pedelec[2]
Source: Schfeinitz et al (2017)

Figure 1 depicts the average speeds in free-flow, uphill and downhill for different age cohorts. The data depicted in Figure 1 is of high relevance for several of the potential weaknesses of relying solely on the RTM data.

One of the strongest objections to 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 cycle, 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 primarily occurs in the age cohort below 60 years of age, where the gap diminishes as the age of the traveller increase. Regarding the re-estimation of the LOS-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 LOS-matrices we therefore ignored the elevation effects, and re-estimated the travel times using the average speeds listed in Table 1.

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2 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/

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

Cycle type	Average speed (km/h)
Normal Cycle	15
E-bike	22

3.2 Willingness to pay

Having generated the travel time estimates for E-bikes, the next challenge consisted of measuring the willingness to pay for a trip with a given travel-cost. As stated above, the accessibility to jobs, trade and/or services is measured through combining the probability of a person being willing to pay the travel cost of traveling to a ward, 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 (trip) multiplied with the outcome of the event (the number of jobs in the destination). The total accessibility of each ward is equal to the sum of the accessibility between itself and the other wards in the model.

We have measured willingness to travel for a given cost based on The Norwegian National Travel Survey (NTS 2013/14). While the sample contains several thousand observations/trips, its usefulness for the task at hand is still restricted because it only contains information regarding the actual trips of the respondents on a single day of the year. The sample, in other words, contains information only on the trips the individuals took, and not on the trips they decided not to make.

To overcome these issues, we estimated the willingness to pay using the following approach. First, we restricted the scope of the analysis to cover work trips with lengths equal to or less than 70 km. These restrictions were put in place given that the work trips are easier to model than other trips, and because the transport model generates costs and trip estimates for trips up to 70 km only. In the next step, we accessed the National Travel Survey (NTS) and extracted work trips by bicycle (morning trips) within the city regions with a length of up to 70 km (there are very few bicycling 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 min. The properties of the bicycle trips are listed in Table 2.

Table 2: Sample properties for bicycle trips in 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 extracted the data, we transformed the travel times with bicycle for each trip into travel costs using the national standards for the monetary value of time. From this exercise, we acquired a trip cost distribution for each work trip by bicycle within the city regions, covering the ratio of the total trips that fell within each cost estimate. In the final step, we assumed that for each cost observation, the respondent would have been willing to pay less but not more for the same trip. This is of course a strong assumption as there are multiple reasons to why the observed trips are of specific length/cost, and for many instances, the travellers may have been willing to travel longer if a better option had been available. However, for comparable options it is not unreasonable to assume that the travellers chose the cheaper option.

Building on the assumption that for each observation, the individual would have been willing to pay less for the trip, but not more, we represented the willingness to pay measurement through using the reverse cumulative distribution for the costs-distribution. The willingness to pay was thus represented by the ratio of observation at a certain cost (those who paid the given cost), plus the sum of the ratio of trips at a higher cost (those who paid more). The transformation from cost-distribution to the reverse cumulative cost distribution (RCCD) is illustrated in Figure 2.

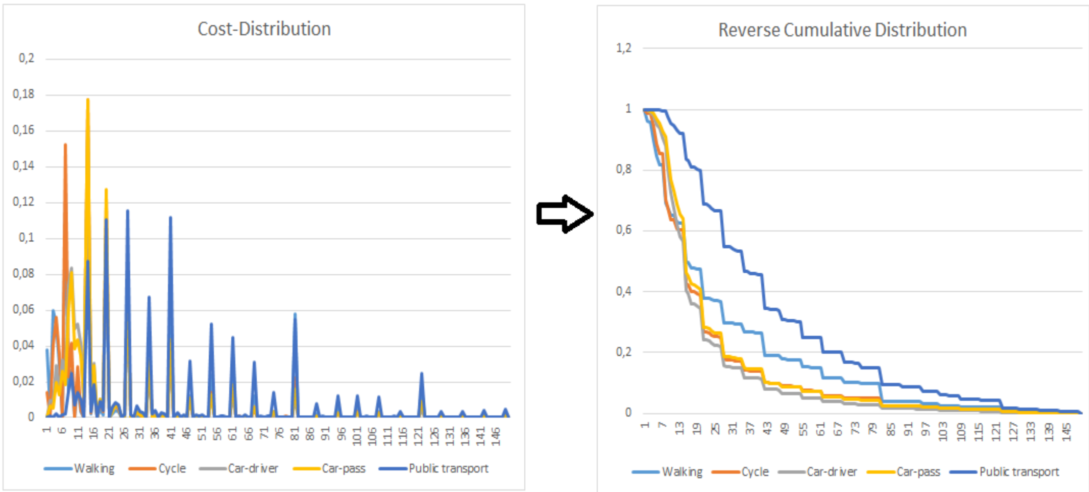


Figure 2: the cost distribution for each mode (left side) and their corresponding reverse cumulative distributions (right side).

The left graph in figure 2 shows the ratio of cost that belonged to each kroner value, while the right graph shows the corresponding RCCD for each mode. The left graph shows that the values are characterized by spikes. This is the result of the respondents tending to summarize the traveling time to the nearest 10^{th}. From observing the RCCD in the right graph, one sees that the estimated willingness to pay for car-drivers, car passengers and bicycle are highly comparable, while that of walking is somewhat higher than the other three. The highest willingness to pay is for public transport, a result which reflects the case that the public transport trips are in general of a longer duration than trips taken on other modes.

The final step of estimating the willingness to pay for a trip consisted of fitting a curve to the reverence cumulative cost distribution for bicycle, which could then represent the relationship between the costs (from the transportation model) and the willingness to pay (from the travel survey). This was done through programming a search-algorithm that identified the parameter-value that minimized the square fit-residuals between the accessibility estimate and the RCCD. The estimated fits between the RCCD and the fitted curve of the accessibility equations for each mode is depicted in Figure 3.

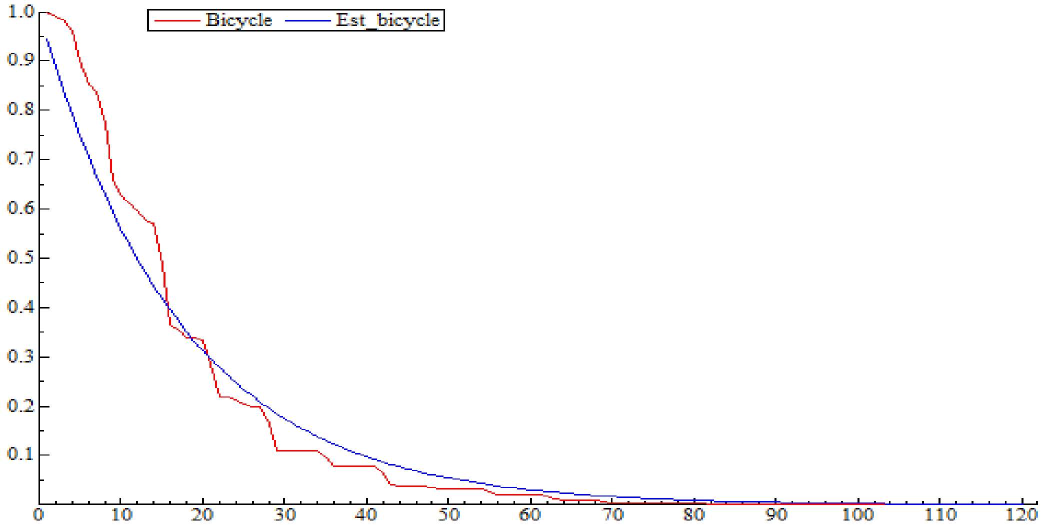


Figure 3: Estimated fit between the RCCD and the estimated curve fit from the accessibility equation for bicycle.

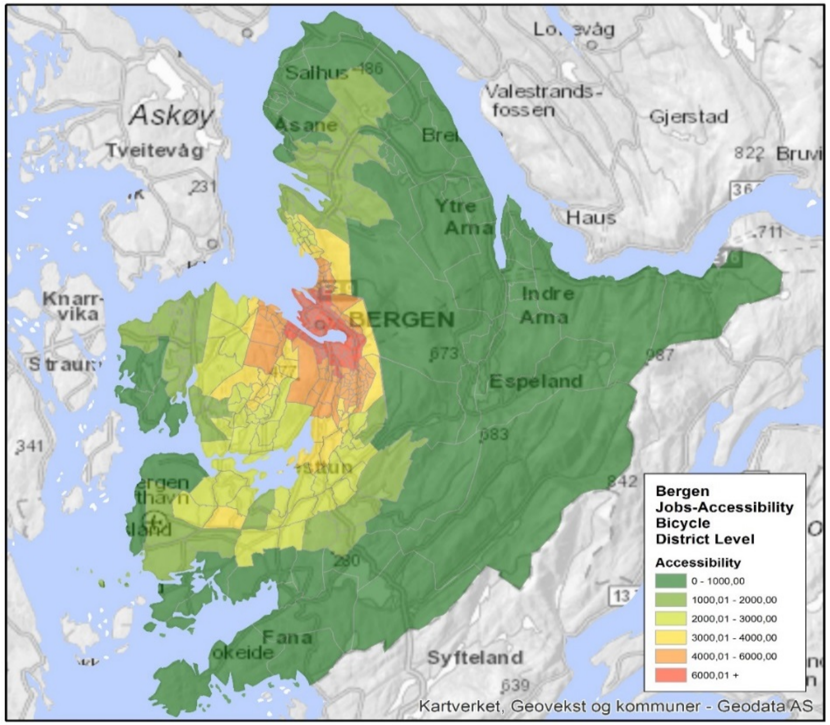
In Figure 3, the y-axis represents the willingness to pay (probability between 0 to 100%) while the x-axis depicts the costs in kroner. The figure shows that the curve-fitting algorithm provided a decent fit between the actual RCCD-curve and the implied distribution from the exponential accessibility-equation for cycling. As depicted by the figure, the distribution derived from the exponential equation implies a very high willingness to pay for trips at low costs and a low willingness to pay at high costs.

3.3 Results

The estimated accessibility for bicycle and E-bike for the different regions are depicted in figures 4 to 6. Each figure depicts the accessibility to jobs by bicycle in the left graph, and the accessibility for E-bike in the right graph. For each mode, accessibility is measured as the number of jobs that are accessible within each ward.

This section provides a graphical illustration and description of the accessibilities, and a more thorough discussion of the results is provided later when they are compared with the results from the land use analysis.

3.3.1 Bergen



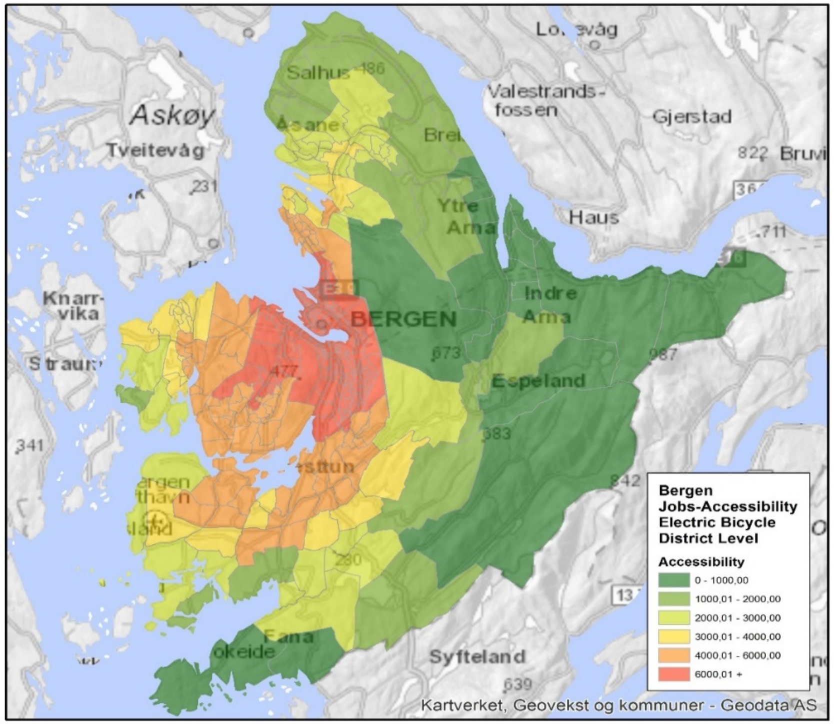


Figure 4: Accessibility bicycle (left) and E-bike (right) to workplaces, Bergen

The map to the left shows the accessibility with normal bicycle (average speed of 15 km/h), and the map to the right shows the accessibility with E-bike that has an assumed speed of 23 km/h. From comparing the accessibilities, Figure 4 shows that E-bikes extend the accessibility currently reserved for the city centre to a large share of the surrounding areas. This is especially true for the areas west and south of the city centre.

3.3.2 Trondheim

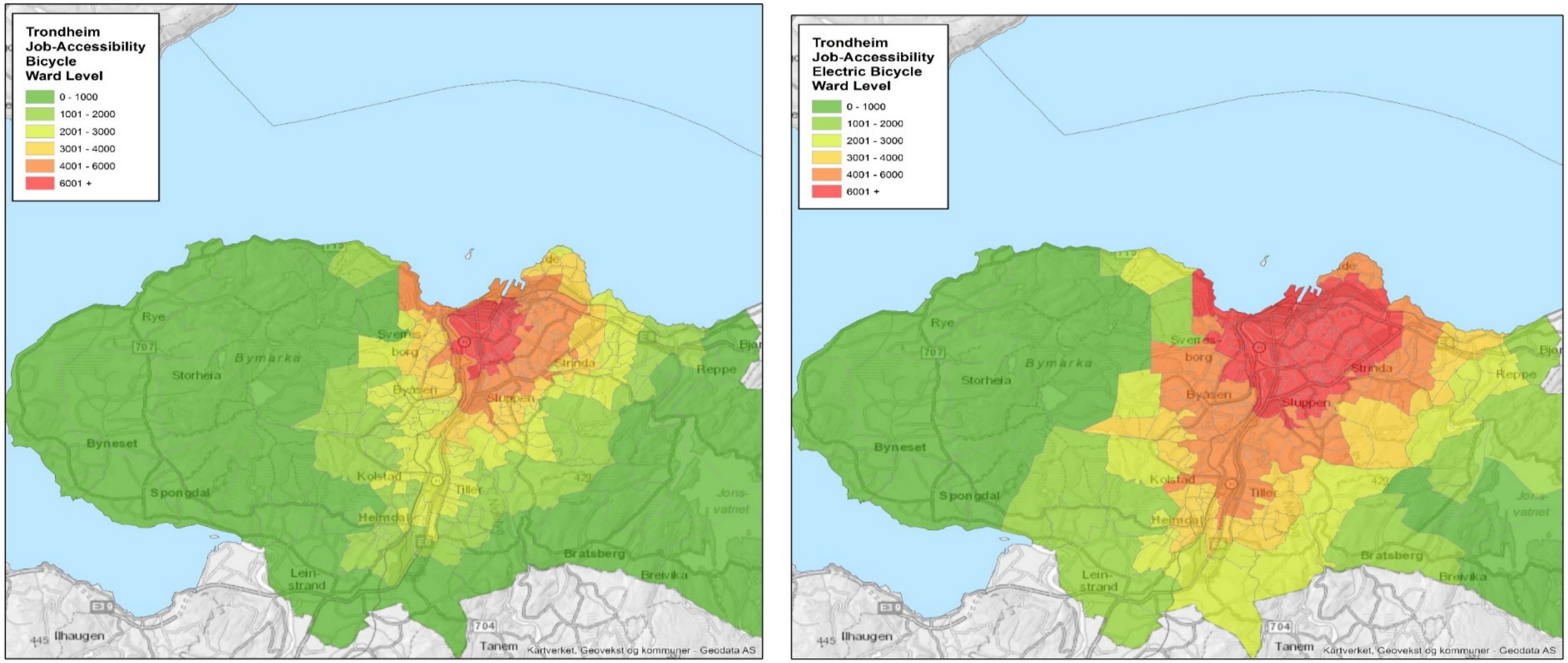


Figure 5: Accessibility bicycle (left) and E-bike (right) to workplaces, Trondheim

Figure 5 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.

3.3.3 Stavanger, Sandnes and Sola

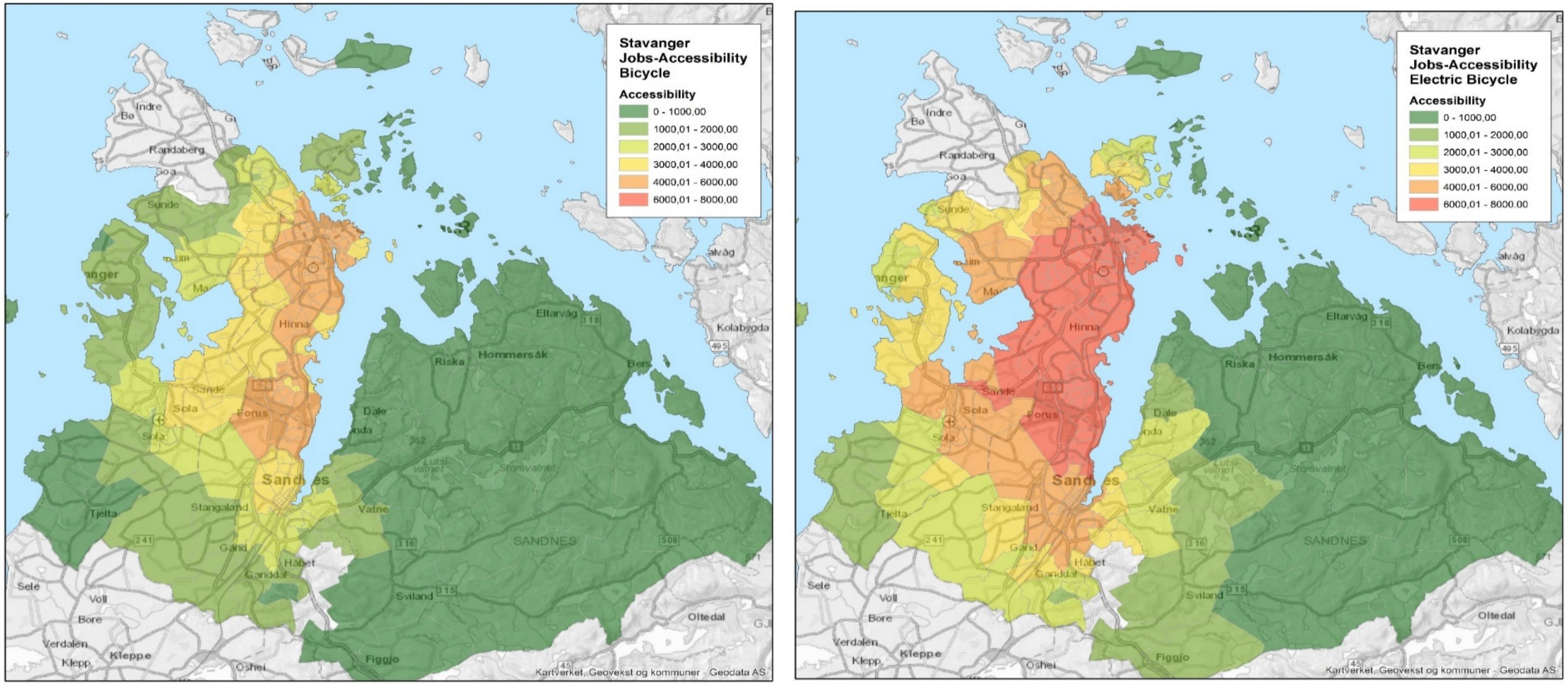


Figure 6: Accessibility bicycle (left) and E-bike (right) to workplaces, Stavanger, Sandnes and Sola

From comparing the accessibility with bicycle and E-bike, the maps show that E-bike greatly increases accessibility compared to normal bicycle. The map to the left shows that there are no areas that has an accessibility equal to more than 6000 jobs with normal bicycle, while E-bikes greatly enhance this constrained accessibility to jobs.

3.3.4 Oslo

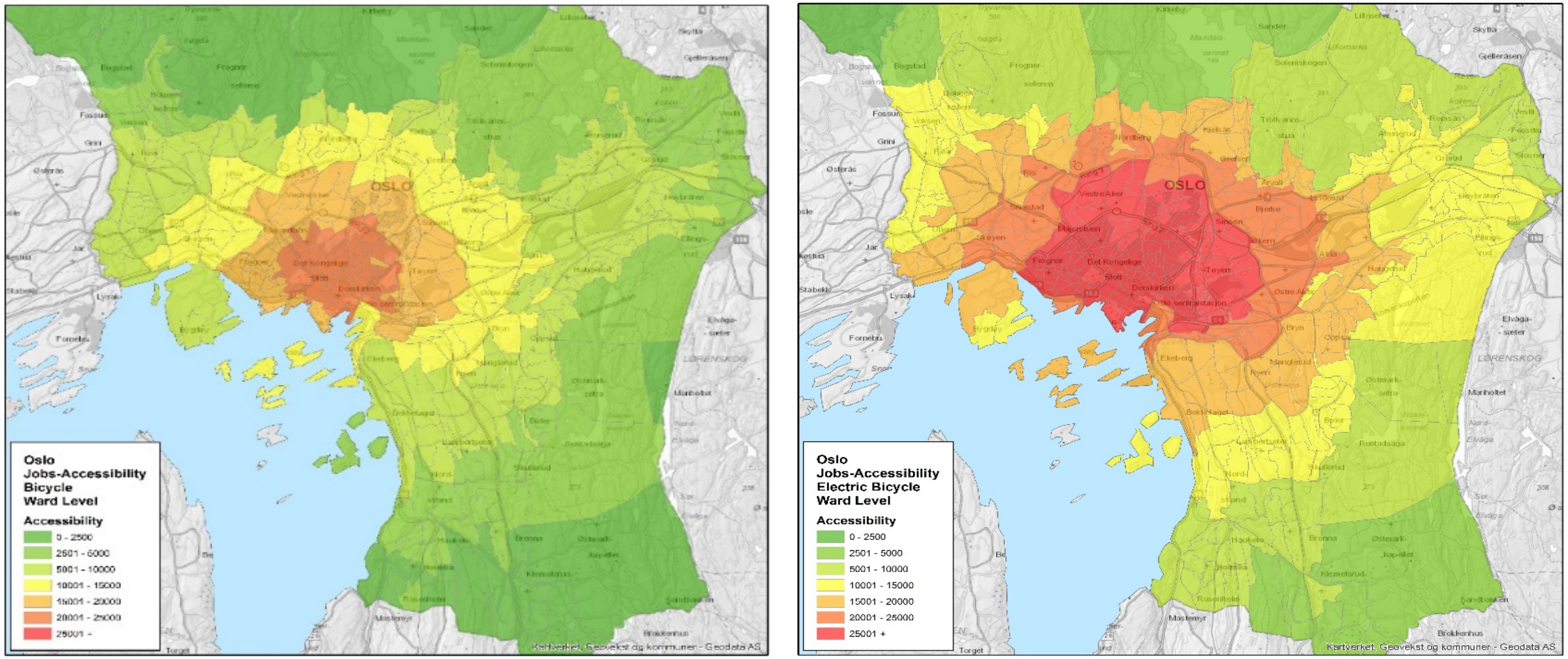


Figure 7: Accessibility bicycle (left) and E-bike (right) to workplaces, Oslo

Figure 7 shows that the E-bike greatly increases the accessibility of the travellers compared to normal bicycle in Oslo. A large part of the area surrounding the city centre has a higher accessibility with E-bikes than one acquires in the inner city with normal bicycle. The figure furthermore shows that the E-bikes extend the accessibility currently reserved for normal bicycle to a wider area surrounding the city.

4 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 important because, from experience such as the example given below, land use determines a major part of the transportation demand.

Figure 8 shows the growth areas according to the strategic general plan of the City of Bergen (2016-2040). The plan is the guideline for land use and the more detailed land use planning such as the zoning plans. Figure 8 shows the contours of the wards in red, and the existing urban area in yellow and brown. The brown areas represent the growth areas. The growth is designated to seven densification zones including the city centre as well as other centre localities.

Striped areas are future green field developments that were removed from the plan as part of the revision process.

The new general plan of Bergen has a strategy consisting of the removal of some of the future green field areas (which are future development areas away from the city center), increase the growth in the city area and at the public transport oriented centres. As one of the main objectives in Norwegian land use and transportation planning is to reduce growth in private car traffic in the major cities, Rambøll has previously worked on estimating the change in vehicle kilometers travelled by private car in several scenarios (Uteng and Kittilsen 2017b). The report is published online in Norwegian[3] and is used as a reference in the following analysis.

As part of the analysis, the sum of population growth from the start year (2016) till the year of analysis (2040) was distributed differently according to the different scenarios:

In scenario 0, approximately 45 % of the population growth was distributed to the future green field developments, as this was the estimated growth potential of these areas. The rest of the growth was distributed according to accessibility to jobs and historic growth rates. This resulted in the following distribution:

- City centre and Bergensdalen: 26 %
- Other centre areas: 11 %
- Other urban area within the municipal limits: 18 %.

In scenario A, the population growth was distributed amongst the city and local centres. Approximately 45 % of the growth was located in the city centre and the adjacent Bergensdalen, while the rest were located in the other local centres.

[3] http://www.kit-samarbeidet.org/wp-content/uploads/2017/12/2017-11-17-Rapport-Ramb%C3%B8ll-Transporteffekter-av-ny-kommuneplan-for-Bergen.pdf

The goal of the calculations was not so much to test how realistic these alternatives were (even if the estimated growth is achievable within the defined densities of the land use plan), but to estimate the effects on modal split according to different land use strategies.

Table 3: Population distribution according to two different land use scenarios for the City of Bergen: Old and new general plan

Zone	Population growth Alternative 0: Old plan	Population growth Alternative A: New plan
Other urban area	9 600	1 800
Arna	350	3 300
Green field developments	22 800	0
Fyllingsdalen	1 340	8 000
Loddefjord	480	3 300
Nesttun	1 300	3 400
Sentrum and Bergensdalen	13 500	24 800
Ytrebygda	650	3 300
Åsane	1 200	3 300
Sum	**51 300**	**51 300**

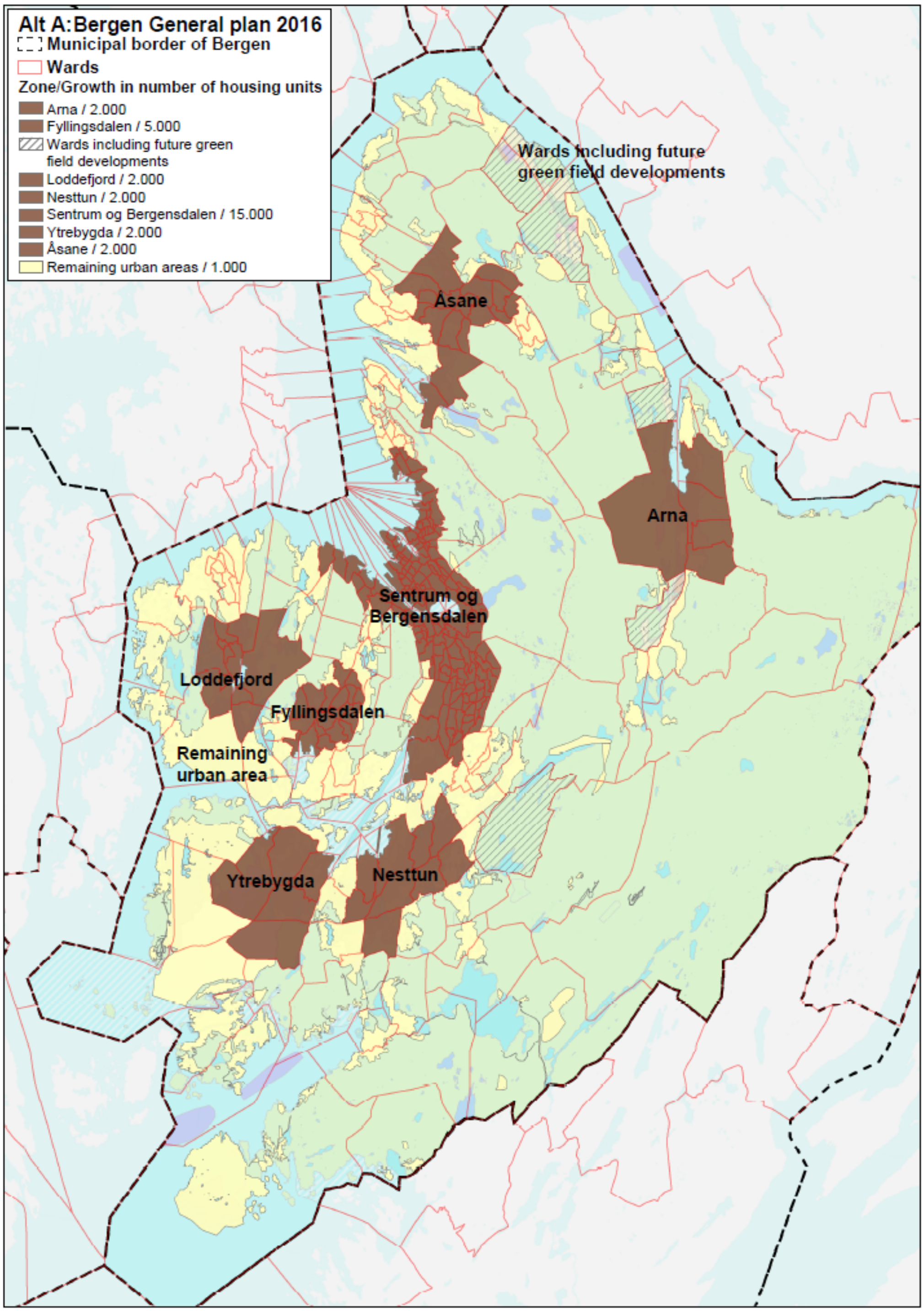


Figure 8: Visualization of growth areas in the City of Bergen according to the new general plan of 2016. Former green field developments removed from the plan are shown as striped areas.

Table 4: Change in estimated vehicle kilometers travelled for private car driver according to different land use scenarios Bergen, Norway

Name	SUM Vehicle km (1000)	GROWTH Vehicle km 2016-2040 (1000)	GROWTH % 2016-2040	REDUCED GROWTH Vehicle km vs. Alternative: Former General Land use plan
Today's situation	5 195	-	0,00 %	-
National transportation plan forecast	6 400	1 203	23,19 %	**13 %**
Former general plan including green field developments	6 577	1 382	26,59 %	-
New general plan green fields excluded and growth redistributed to densification areas (only changed future distribution of inhabitants)	6 263	1 068	20,55 %	**23 %**
Optimized localizing according to walkability, bike and public transport within growth limits of the general plan for future inhabitants	6 169	974	18,75 %	**29 %**
New general plan (distribution of future inhabitants and parking)	5 986	791	15,22 %	**43 %**
New general plan (distribution of future inhabitants, employees and parking)	5951	756	14,55%	**45%**

Source: Uteng and Kittilsen, 2017a

The results in Table 2, first and foremost, illustrate the importance of considering land use plans, and secondly, taking into account the new development areas. The difference between alternatives illustrate how green field developments disproportionately affect transportation demand, and further how densification and the following lower car parking accessibility per capita gives less car use.

Even if the results above are related to change in car usage and not E-bike, the results show the significance of taking account of land use plans or planned major housing developments while engaging in transportation analysis and planning.

The INMAP-tool however, allows for several ways of estimating or taking account of the growth potential. In short, the first task is to do analyses with INMAP and GIS based on the land use objectives/zoning, the extent of the surface area in the land use maps, allowed density, and the consumption of space per capita. The steps in the process are schematically illustrated in Figure 9, and described in further detail in section 4.2. The second task is to plot an existing analysis into the INMAP-tool. The latter comes in handy when the local government has already made an estimate and analyses of growth potential. The former is the more complex way of performing this task and is the one that we will describe more in depth in section 4.2. For Bergen and Stavanger, we originally used the former method. The Bergen General plan however has later been revised and thus we have made a revised and simplified estimate based on the new strategic general plan which is described in section 4.1. For Oslo and Trondheim, we have used the existing data generated by the cities themselves and only processed the data to the level of analysis (ward) in the INMAP-tool.

Rambøll had, prior to this study, already estimated growth potential for the cities of Bergen, Stavanger and Trondheim as well as their neighbouring municipalities using the INMAP-tool. These data sets have been used as a foundation to estimate the effects on transportation related to different land use scenarios for the City of Bergen, Trondheim and the Region of Greater Stavanger (Jæren).

We further collected and processed data from the city of Oslo and adapted these into the INMAP tool. The level of analysis is the municipality's land use plans and related data sets. The general plan lays out the areas that are to be developed, their land use, contains coarse data on density and development potential, and earmarks the areas to be preserved. More detailed levels of analysis (e.g. by taking account of detailed zoning plans) is possible but time consuming. As our aim was to analyse the effects on transportation, we consider the level of detailing provided by the general plan to be sufficient for the purpose.

We have estimated the growth potential for housing/inhabitants, and the estimation of growth potential for employees is not included.

A prior, or a basic knowledge of the land use planning system in Norway or the other Nordic countries will be an advantage to the reader. A coarse description of the Norwegian planning system is given in English at the following link: https://www.regjeringen.no/en/topics/planning-housing-and-property/plan--og-bygningsloven/planning/id1317/

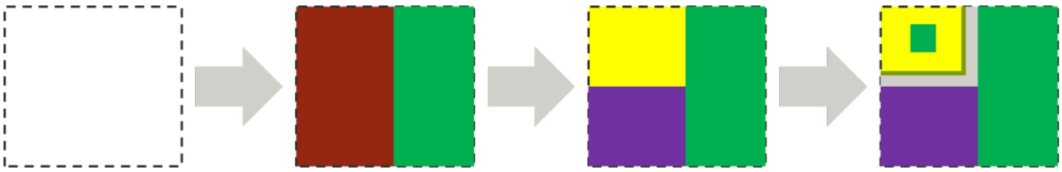


Figure 9: The process of estimating growth potential, on ward level, illustrated.

Figure 9 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 estimate the maximum potential growth. 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. Specific examples of degrees of density, gross to net developable land, average floor space consumption etc. are given in section 4.2 where we have used the cities of Stavanger, Sandnes and Sola as a case-study.

In the following section, we describe the estimates of growth potential according to land use general plans for the four cities. We begin by describing the estimates for Bergen which are probably the most coarse estimates of the four cities. The description of Stavanger in the next section gives a more thorough description of the INMAP-tool, while the descriptions of Trondheim and Oslo show how different kinds of data may be used to estimate the land use growth potential.

4.1 The City of Bergen

Figure 8 shows the growth areas according to the strategic general plan of the City of Bergen (2016-2030). The plan is a guideline for detailed land use planning. The map shows the wards in red lines, and the existing urban area in yellow and brown. The brown areas represent the growth areas. Future growth is earmarked in seven densification zones including the city centre as well as other central localities. Striped areas are future green field developments that were removed from the plan as part of the plan's revision. The municipality had estimated an average of 1,8 persons per new unit which gives the following potential in housing and inhabitants:

Table 5: Distribution of housing units in the growth areas according to the strategic general plan.

Densification zone	Number of new inhabitants	Number of new housing units	Percentage of growth
Fyllingsdalen	9 000	5 000	16,67 %
Loddefjord	3 600	2 000	6,7 %
Nesttun	3 600	2 000	6,7 %
Sentrum og Bergensdalen	15 000	15 000	50 %
Ytrebygda	3 600	2 000	6,7 %
Åsane	3 600	2 000	6,7 %
SUM	**54 000**	**30 000**	**100 %**

As the INMAP-tool operates and delivers data to the transportation models on ward-level, it was necessary to convert the data from the zonal level to the ward level. Continuing with the example of Bergen, the internal distribution of housing units in each zone has been done schematically by distributing the future housing units according to the size of existing population. Thus, wards with a high population today get a higher number of the future units, making the estimates on ward-level a bit coarse. However, for identifying the core growth areas and their growth potential, this method gives sufficient data.

As the map plotting growth potential on ward-level becomes quite detailed, conveying information becomes tricky. Therefore, we have aggregated the wards into districts. The districts are based on the numbering of the wards and in case of Bergen, districts are made up from old townships that have since been merged but are still locally known units. As highlighted in the following sections, we have merged the wards for all the four cities.

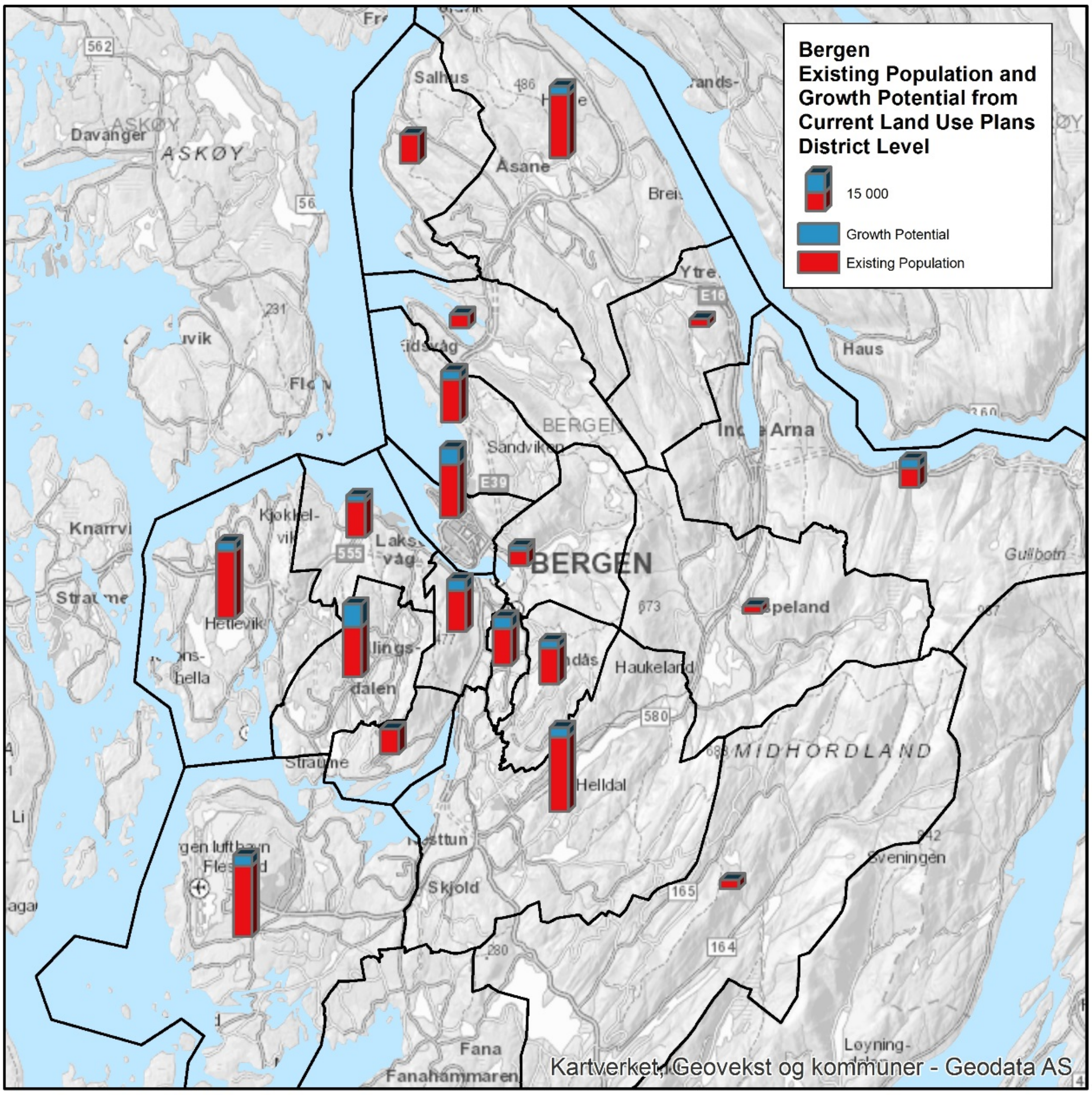


Figure 10: Estimated growth potential according to the strategic general plan for City of Bergen.

Figure 11 shows the maximum growth potential of inhabitants according to the strategic general plan of Bergen on district-level[4]. Blue colour marks growth potential of population according to the general plan, while existing population is shown in red. Half of the growth is located to the city center or the adjacent Bergensdalen (South of the city center). The biggest growth area, apart from the city center is Fyllingsdalen which is southwest of the city center. Other densification areas, such as Arna, Åsane, and the airport/Ytrebygda can be seen to the east, north and southwest.

The above example from Bergen shows how INMAP enables us to use the coarse data delivered from the local government. However, it does not show the potentials of the INMAP-tool to full extent. In the section below, we give an example of detailed analysis that we did for the Greater Stavanger Region (Jæren).

4 The population column is located in the midst of the ward, thus this location may not always be at the same spot as the actual development areas.

4.2 The Cities of Stavanger, Sandnes and Sola

This section describes the estimates of growth potential for the city of Stavanger. As the functional urban area of Stavanger stretches into its peripheries and includes the city of Sandnes along with the municipality of Sola, these two municipalities have also been included[5].

We further describe how we have used the general plan's elements like maps, planning standards or codes, guidelines and descriptions, to estimate the growth potential in each ward. The full description of the estimation is given in Uteng and Kittilsen (2017b). Though our focus has been on housing, the estimates have been created taking into account land reserved for commercial, public services and other land uses.

The starting point of the analysis was to use the digital- and PDF-map of the general plan to identify each of the potential development areas and overlay the general plan map onto the map of wards. The digital map is the main starting point, however there may be textual documents or other information in the physical map (PDF) which gives supplementary information. For Stavanger, this was the case for the densification-areas along the public transport axes as these were not included in the digital map. The reason being that this is more a strategy than a judicially binding land use.

We have differentiated between three kinds of development areas:

- Green field areas: Existing undeveloped land which is planned for future development.
- Densification areas: The general plans of the three municipalities are all based on a common structure containing densification axes along public transportation network.
- Areas of transformation: Areas which are currently in use for other purposes such as manufacturing, harbour, other industries, or built vaccant space.

After specifying the future land use and location of each development, the next step was estimating the future growth potential of an area. This was done by using the degrees of density as given in the land use plans.

Normally the future green field areas are shown in a particular colour in the PDF-map and given a particular number in the digital map. However, when a plan is being revised, it sometimes happens that formerly green field areas get named as existing areas even if they are not yet built. Thus, we used aerial maps and manually checked whether areas could be considered future green field areas.

5 The regional airport is located in Sola.

Table 6: Allowed density in different areas in the city of Stavanger (General plan of 2014-2029)

STAVANGER Floor/area-ratio						
Land use	**Share Land use**	**Density**				
		City centre	**Public transport axes**	**Other development areas**	**Green field**	
Housing	100% housing 0% commercial/other	180	150	70	Minimum 20 units per hectare	
Commercial/ Services/Other	0% housing 100% other	300	240	150	-	
Transformation areas	70% housing 30% commercial / other	160	160	160	-	
Centre areas	10 % housing 90 % commercial /other/ preservation	220	220	-	-	
Combined land use areas	60 % housing 40 % commercial/other	200	200	-	-	

Table 6 provides a summary of allowed maximum density in different areas according to the general plan of Stavanger. Similar information was given in the plans of Sandnes and Sola and used accordingly in the estimates. Only the share of land available for housing was included in the estimates for population growth. The shares of land use given for the city centre areas were schematically estimated by us as information on this was not given in the general plans. In short, the central areas have restrictions on development such as conservation areas, land reserved for commercial development etc. In order not to exaggerate the development potential for housing within the city centres, we capped the surface that may be used for future housing development at 10 % of the total surface.

Evidently, the maximum degree of density is quite high. The degrees given are however used as guidelines and applicable for projects containing more than 10 housing units/1000 m2 floor space. This means that the regulations are applicable for smaller areas within the urban area. As shown in Figure 13, densification areas include large parts of the existing urban areas. If one uses the allowed floor/are-ratio for densification areas to estimate the sum of development potential in each ward, this will result in an allowed density which is superficially high.

To give a more realistic estimate of the development potential in the densification areas, we made a desktop study on the change in the total growth potential when a part of the area becomes densified or transformed. The desktop study is included in Uteng and Kittilsen (2017b) chapter 6.3.2 and 6.3.3. It shows that the growth potential within existing housing areas is limited. An example is given below:

Figure 11: Existing housing area with detached houses in Sandnes (green line). Densified with 18 units (red line). Density increased from approximately 10 to 15 units per hectare.

Our desktop study found that the maximum growth potential of densification areas rarely exceeds 50 % of the existing population. For existing areas not included in development/densification areas, the growth potential is even more limited. We therefore ascertained a maximum growth percentage of one percent per year.

Concerning the transformation areas, we found that the allowed density of the general plans were realistic when comparing these to existing projects and areas. Combined with the land use plan, these degrees of density could be used to estimate future growth potential. However, the floor/area-ratio in the case of Stavanger is related to the net lot/zoning area available for development. The general land use plan is a coarse plan and the surfaces in the general plan thus includes land which, for different reasons, is unavailable for development (or need to be used for other purposes such as roads and streets, steep terrain, public squares, public green space etc). In previous projects conducted for the city of Bergen and Kristiansand, Rambøll investigated the share of land which should be excluded from the net floor/area-ratio. By comparing the estimated allowed density in the general plan against the density in existing areas in Bergen, we found that for city centre and transformation areas, approximately 25 % of the gross area in the general plan had to be subtracted from the surface to estimate a realistic net floor/area-ratio for the total area. This number was therefore used to deduct land from the gross surface for transformation areas in Stavanger. The ratio should not be considered applicable in all cases as there is a number of uncertainties that may affect the ratio (terrain, whether roads are included in the land use maps, type of area etc.). In case of Bergen and Kristiansand, we identified different ratios for the different types of developments (green field development, transformation/brown field, etc.). The deduction is also only applied in estimating growth potential based on floor/area-ratio. When the net growth potential was estimated, we used the Norwegian average floor space consumption per inhabitant to estimate the growth potential.

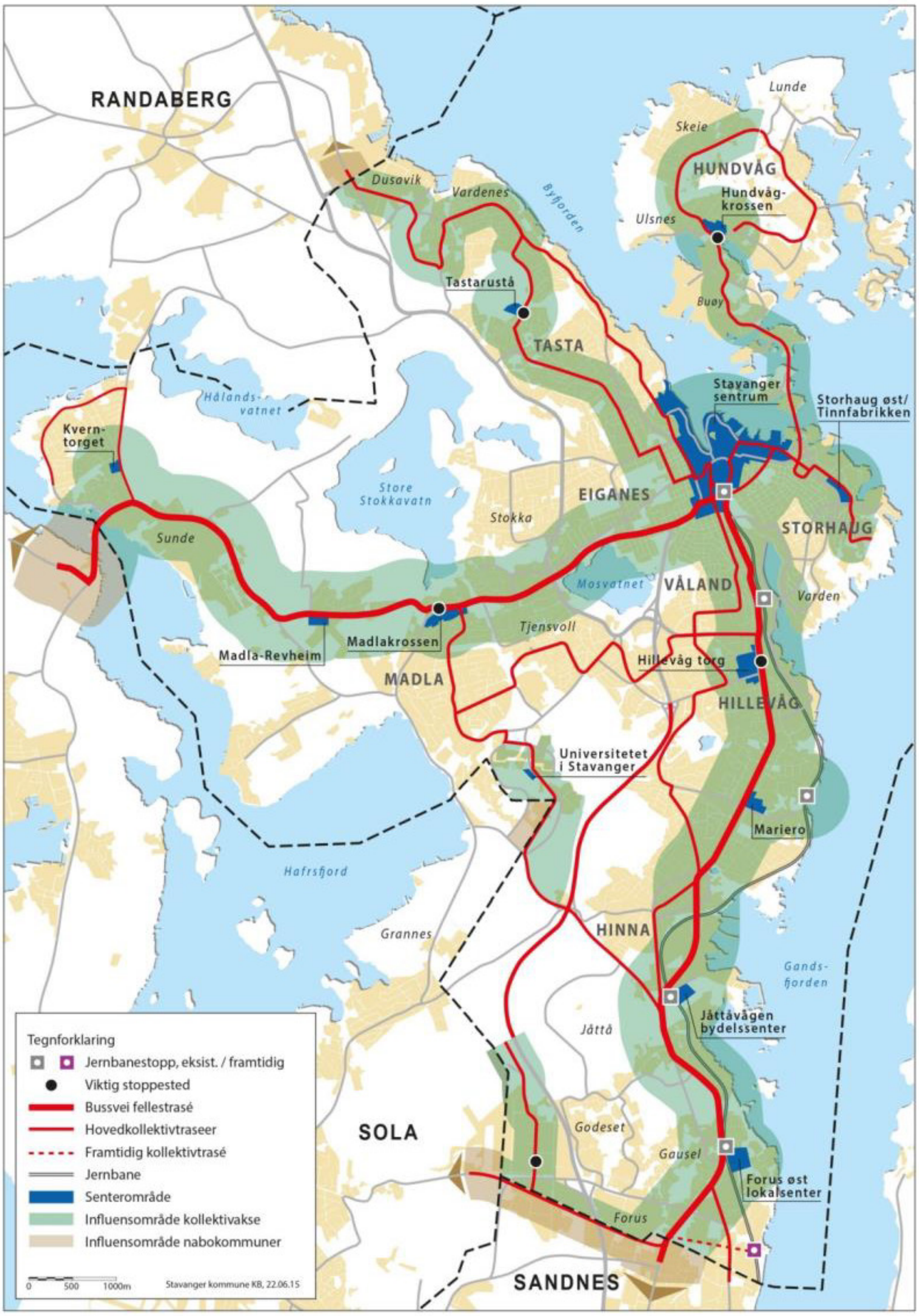


Figure 12: Map from the general plan of Stavanger showing the densification areas along the main transit arteries.

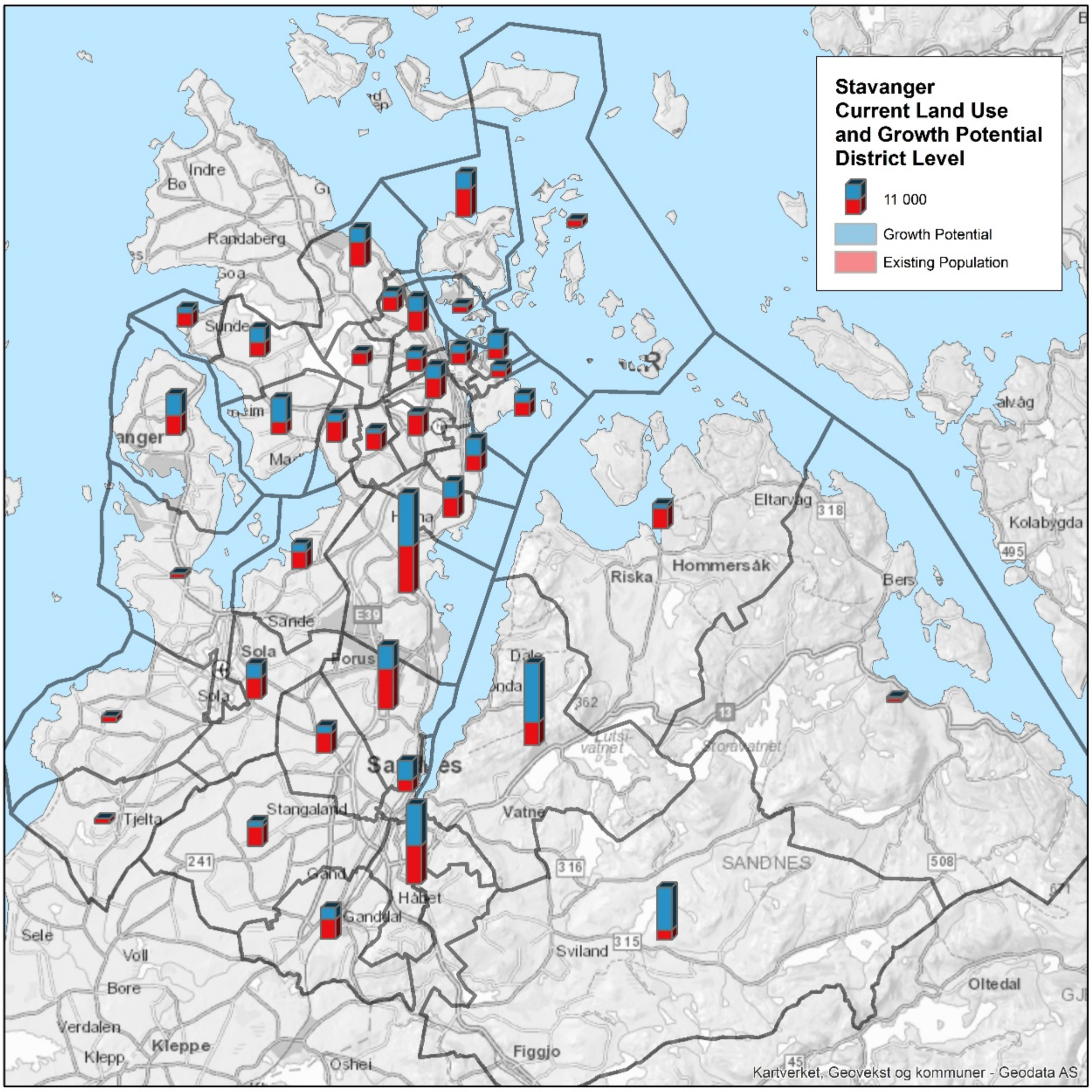


Figure 13: Estimated growth potential based on the general plans of Stavanger, Sola and Sandnes. District level.

In Stavanger, the waterfront and transformation developments surrounding the city centre contributed to the growth potential. The major green field development of Madla/Revheim is illustrated by growth potential in the western parts of the west-to-east densification axis. Existing detached housing areas adjacent to the city centre give little growth potential west of the city centre. Transformation areas at Forus/Forus Øst give high growth potential in the southern parts of the city. A similar situation can be seen in the northern parts of Sandnes, where growth potential in Lura/Forus is illustrated. In Sandnes, however, major growth areas are the green field developments to the southwest of the city – both the green field adjacent or close to the city centre such as Hana and Bogafjell/Skåralia, and the detached future green fields of Sviland. In Sola, the green field developments are concentrated in Tananger (northwest) while there exists estimated growth potential in the city centre and along the densification axis as well.

Table 7: Greater Stavanger-area: Growth potential measured in inhabitants as estimated by existing general plans

Area	Growth potential inhabitants as estimated by existing general plans and strategies
Regional centre and city centres (Stavanger, Sandnes and Sola)	17 000
Other subcentres	42 000
Other parts of the existing and planned urban area	130 000
Sum	189 000

The purpose of the estimation exercise is to identify maximum allowed growth in each ward according to the municipality's general plans. These maximum values therefore neatly visualize the development framework which the local governments face when determining the growth strategy. As discussed above, the allowed density in the densification areas contributes to a sum of growth potential which is probably exaggerated.

4.3 The City of Trondheim

As part of the general plan, the city of Trondheim has its own housing construction program (Trondheim Kommune, 2014)[6]. The program has specified number of housing units on address-level. The list all together contains approximately 38 000 housing units. We processed the list from address- to ward-level to estimate the maximum growth potential in each ward. 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. The Housing construction program is based on known construction or zoning projects.

Table 8: Distribution of housing units in the townships according to the housing construction program

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

[6] Trondheim Land-Use Plan, https://www.trondheim.kommune.no/tema/bygg-kart-og-eiendom/arealplaner/kommuneplanens-arealdeldelplaner/kpa12-24/

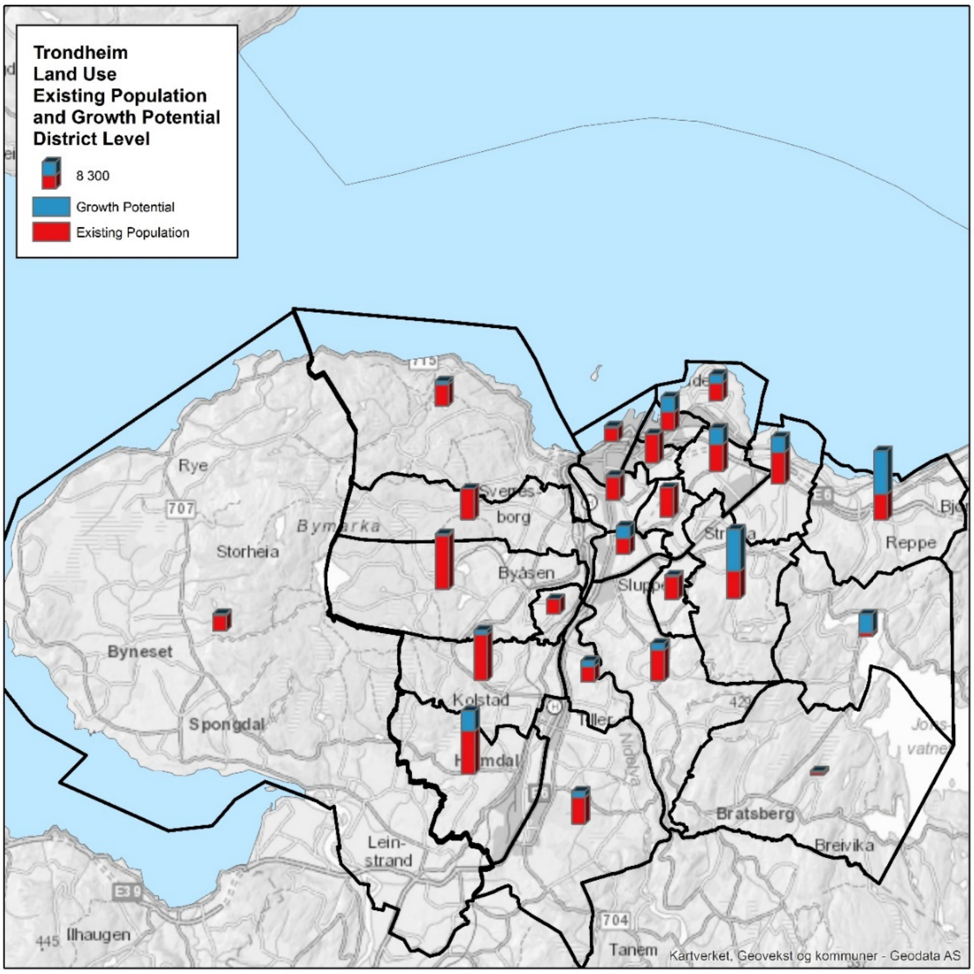


Figure 14: Estimated growth potential according to the housing construction programme of Trondheim. District level.

In Trondheim, the transformation areas of Lade, Leangen and Tunga is illustrated by the mapped growth potential to the east of the city centre. 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.

4.4 The City of Oslo

The city of Oslo has made its own estimates of housing growth potential. These estimates were given to us by the Oslo municipality as part of this project. For this exercise, we schematically set the household-size of the new units to two persons.

Table 9: 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**

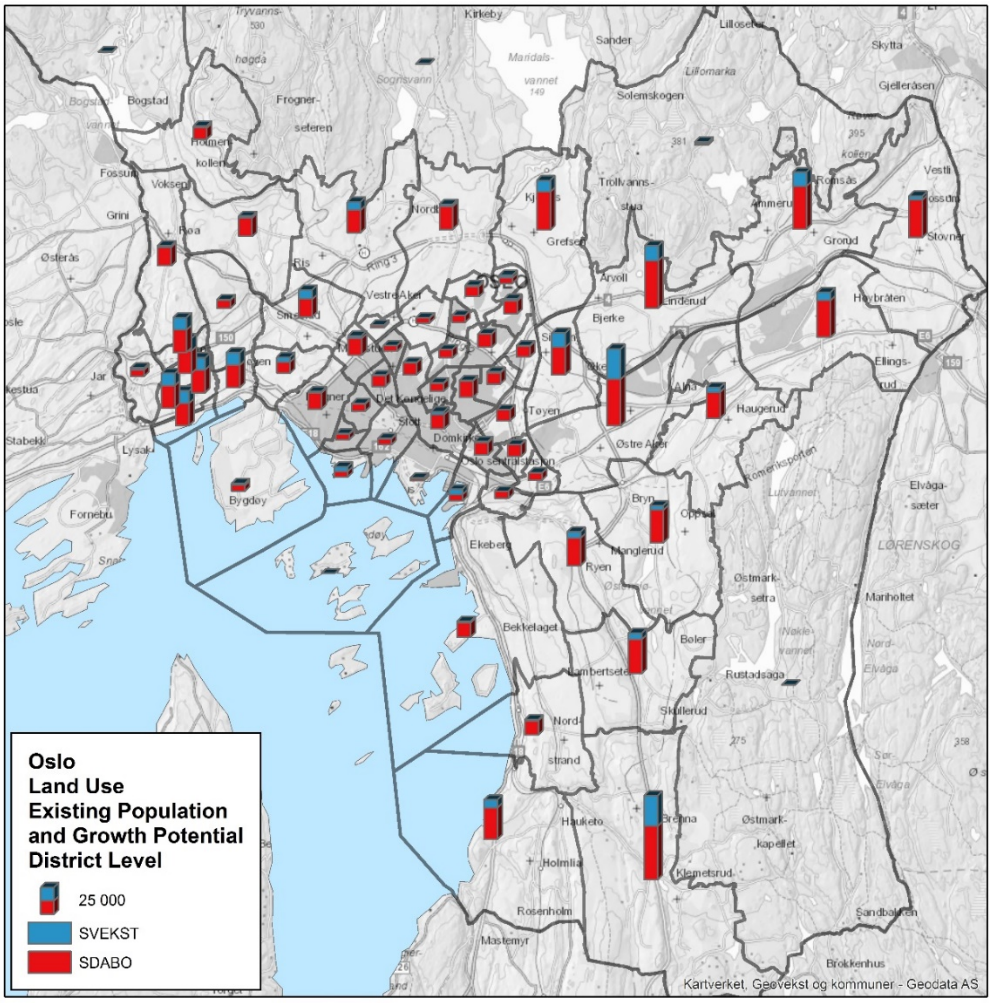


Figure 15: Estimated growth potential Oslo. District level.

Growth potential in the city centre is partially related to water front development at Sørenga. The northern and eastern transit-oriented developments along the ring metro 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 int the west. The last remaining future green field development of Oslo, Gjersrud/Stensrud, can be seen to the southeast.

5 Analysis

This section outlines the relationship between E-bike and growth potential based on the respective land use plans. We further discuss the possibilities of optimizing the increased accessibility based on E-bike usage through adapting the land use plans.

5.1 The City of Bergen

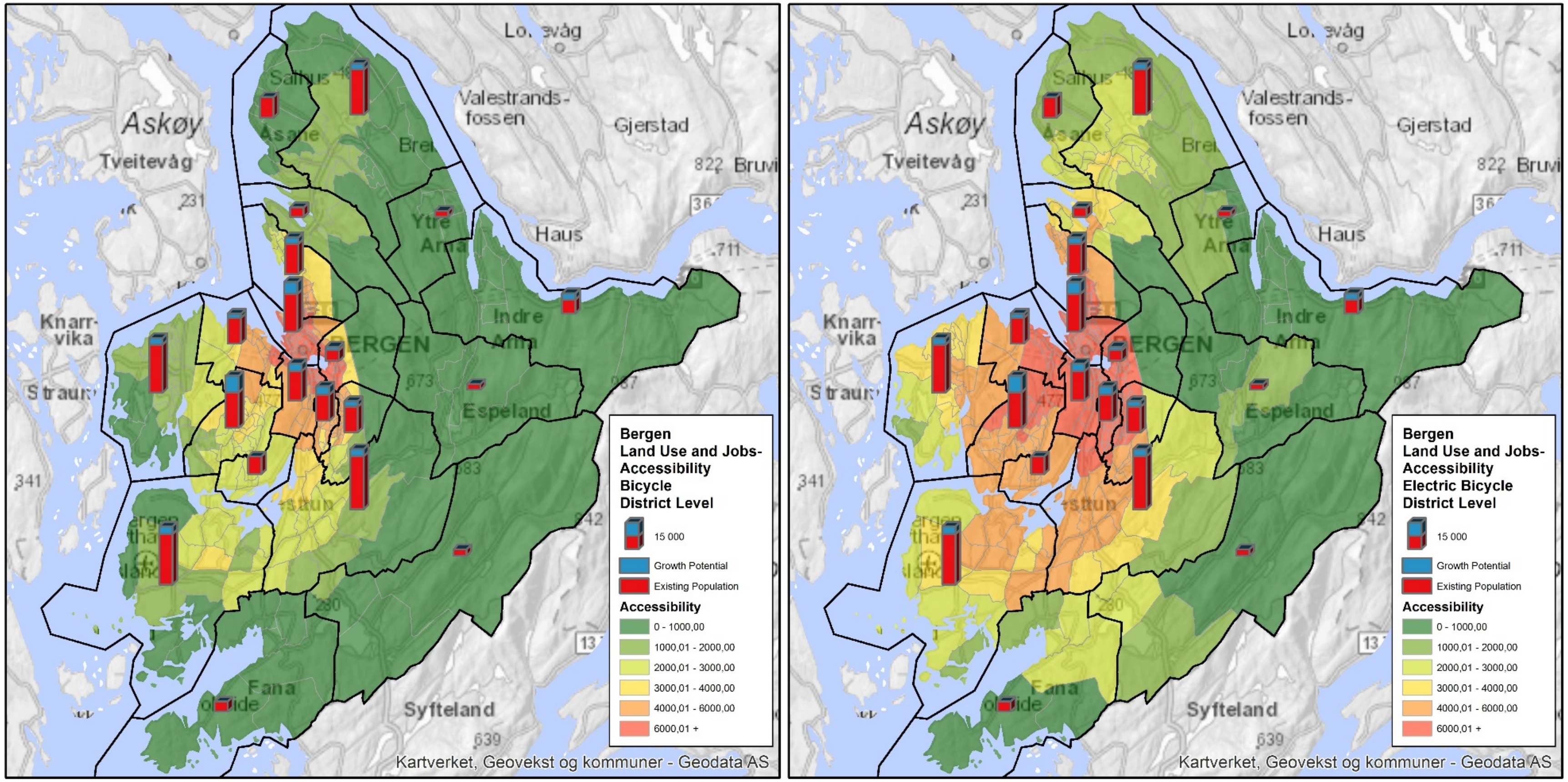


Figure 16: Accessibility bicycle and E-bike, and growth potential, Bergen

The accessibility map for bicycle shows access to 6 000 or more jobs in the central parts of the city centre. On introduction of E-bikes, an equivalent level of accessibility spreads throughout the city centre and growth areas in Bergensdalen ("Sentrum and Bergensdalen"), as well as to the growth area of Fyllingsdalen. In the bicycle map, accessibility to jobs in central parts of Bergensdalen is approximately 4-6 000 jobs. In the E-bike map, the level of accessibility is extended to the growth areas of Nesttun and Ytrebygda/Airport. Regarding the airport-area, a certain level of uncertainty on the number of jobs should be taken into account, as a number of jobs are probably related to the Oil and gas-sector and are therefore not necessarily physically located in this area. The growth areas of Loddefjord and Åsane witness a rise in accessibility with E-bike, while the same effects are not found in Arna.

The City of Bergen has already, in the new general plan, removed limitations on density for the central areas as long as certain criteria are met by the developers. Our analyses support this move by the City.

While the strategic general plan sets out that growth should occur in the city centre, adjacent area of Bergensdalen, as well as local centres and transportation nodes, our analysis on E-bikes suggest that increased accessibility to jobs would be achieved if a larger number of the growth happens in the city centre and Bergensdalen, as well as Nesttun. The city already plans for a significant part of the growth to take place in Fyllingsdalen, which is why we haven't mentioned this area more specifically here.

5.2 The cities of Stavanger, Sandnes and Sola

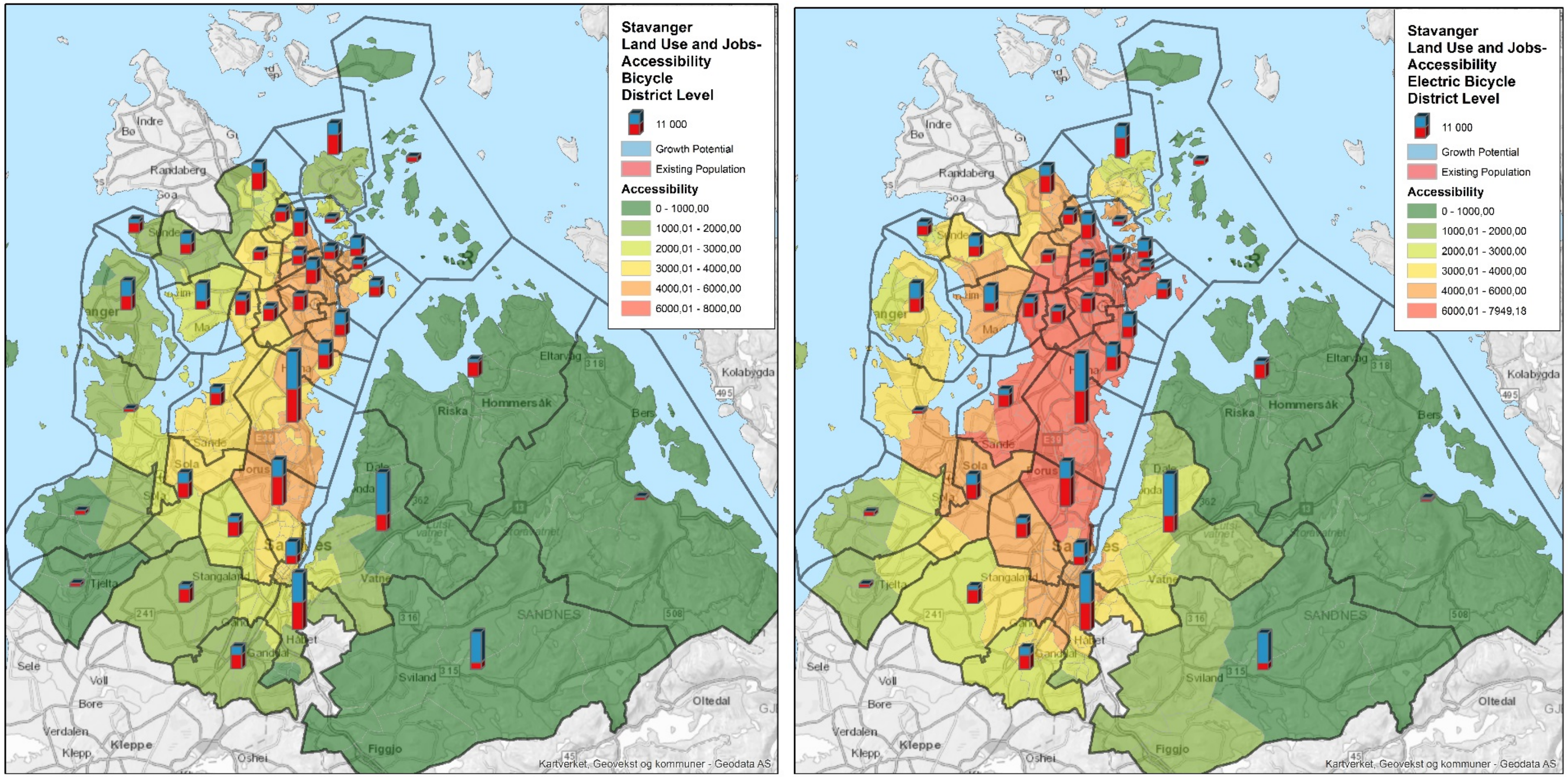


Figure 17: Accessibility bicycle and E-bike, and growth potential Stavanger, Sandnes and Sola

In the central parts of Stavanger and the industrial and commercial area of Forus, bike gives access to 4-6 000 jobs. Sandnes and Sola city centres, as well as most of the existing urban area in Stavanger, yield access to 3-4 000 jobs. On introducing E-bikes, job accessibility increases to 6-8 000 in the central urban areas of Stavanger, as far south as Forus, and as far west as the new location of the hospital at Ullandhaug. Job accessibility is highest in the central urban area of Stavanger, and along the public transportation axis going north/south between Forus and Stavanger city centre. Job accessibility in Sandnes and Sola city centres, as well as the northern and western parts of the urban area in Stavanger, increases to 4-6 000. Regarding the southern and eastern parts of Sandnes, the adjacent areas of the city centre witness an increase of 3-4 000 jobs while the increase is smaller in the more peripheral areas.

The central urban area of Stavanger, and the public transportation axis going north/south between Forus and Stavanger yield highest accessibility. The districts with transformation areas along this axis provides a high growth potential. Other parts of the urban core, especially the districts to the west of Stavanger city centre, do not have the same growth potential. In relation to job-accessibility with E-bike, these areas would be interesting to open for an increased growth in the land use strategy. Comparing the green field developments, Madla/Revheim, located in the western axis of the public transit (see figure 13) in Stavanger, yield higher accessibility than the green field development in Sandnes.

5.3 The City of Trondheim

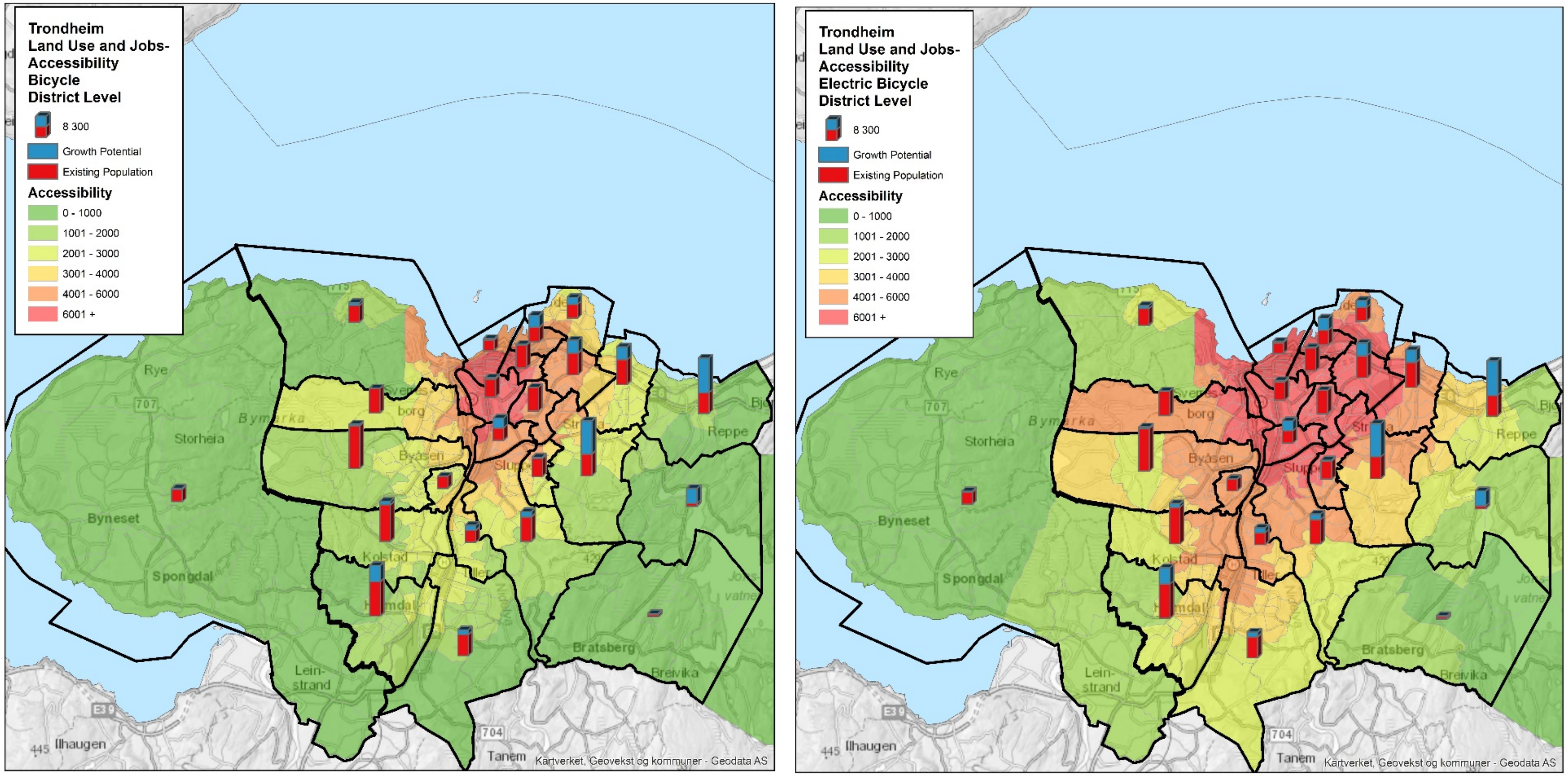


Figure 18: Accessibility bicycle and E-bike, and growth potential Trondheim

In Trondheim, job accessibility with bike is 6 000 + for the city centre, as well as the hospital- and university areas south of the inner city. When E-bike is introduced, 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 Strindheim/Tunga today.

The innermost districts do not have the same growth potential. The housing construction program, see chapter 4.3, 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. However, as we have described in the case of Stavanger -see chapter 4.2, densification in smaller scale projects have a smaller effect on growth potential compared to transformation projects.

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 the E-bike accessibility maps 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, an increased part 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.

5.4 The City of Oslo

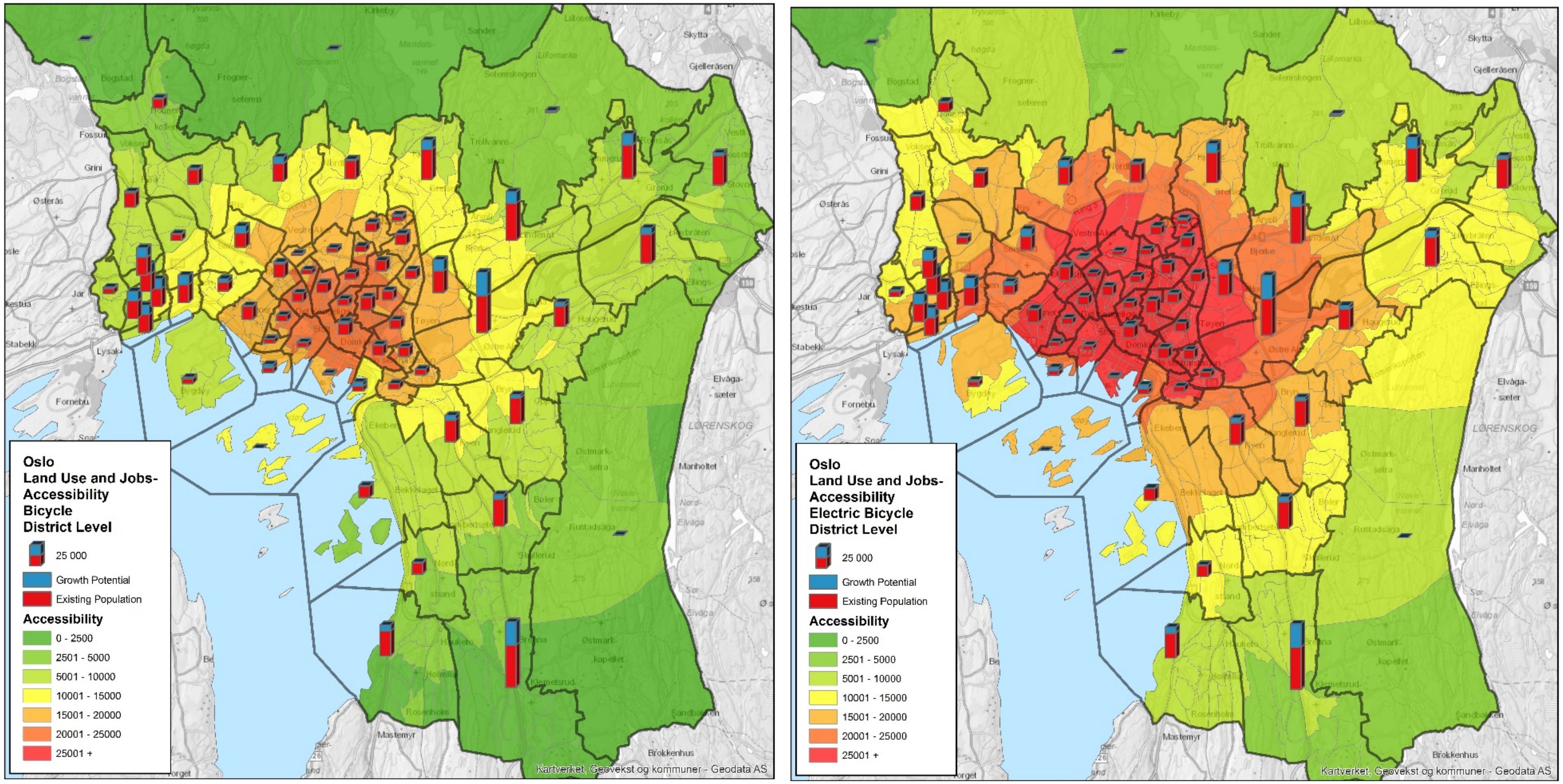


Figure 19: Accessibility bicycle and E-bike, and growth potential Oslo

On introduction of E-bike in Oslo, accessibility to jobs in the city centre increases from 20-24 000 to 28 000 +. This includes brown field developments such as the water front developments at Sørenga. The areas on, and/or, in between the 2nd and 3rd ring road/ring metro experience a growth in job accessibility from 16 – 20 000 to 24-28 000 compared to ordinary bike. The areas include the northern and eastern transit oriented developments along the ring metro.

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 are comparatively small.

An interesting finding regarding Oslo is that the accessibility to the number of jobs not only extends from the city centre and outwards, but also gives higher accessibility in the city centre itself. This is also true for the other cities but, as the illustrations highlight, 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 over a larger area than the other cities.

6 Conclusion

This report has considered the relationship between job accessibility with bike and E-bike, and the land use plans of the four biggest cities in Norway. The purpose of the analysis has been to assess the extent to which the introduction of E-bikes has implications for land-use planning in the cities. This question is of importance as the E-bikes allows for a substantially higher average speed than normal bicycles, which means that they are a viable option in a larger area than normal bicycles.

The insertion of E-bike provides a considerable increase in accessibility compared to normal bicycle in the areas surrounding the city centres. In general, E-bikes provide accessibility in the areas surrounding the city centre that is equal or higher than the accessibility acquired from using normal bicycle in the city centre.

From comparing E-bike accessibility with the growth potential, we have found that it is possible to develop land use strategies that will enhance the use of E-bike. Every city has areas close to the city centre with limited development potential according to existing plans, and high job-accessibility with E-bike. This generally high job-accessibility with E-bike close to the city centres supports the current general strategy of pursuing high density developments/transformation projects in these areas. The findings of this report suggest that these areas should be considered for further development. This is especially true as the green field development areas are in general not found to provide any substantial accessibility with E-bike.

The increase in accessibility from E-bike is quite comparable between the cities. However, Oslo and the Nord-Jæren area exhibit certain peculiarities. Nord-Jæren's (Stavanger) increase in accessibility is quite evenly spread over a large urban area between the city of Stavanger and Sandnes. This is different from that found in Bergen and Trondheim, where the accessibility increase lay as a belt around the city centre. The finding suggest that the E-bikes may have a bigger impact in Stavanger than in Trondheim and Bergen. Oslo also stands out as it has by far the biggest increase in accessibility. Our results show that the E-bike accessibility greatly exceeds that acquired from normal bicycle. This occurs to an extent where E-bike accessibility around the third ring-road equals or exceeds that currently acquired by normal bike in the city centre.

In general, the results in this report strongly suggest that the impacts of E-bikes should be integrated into the land-use planning process. The growing usage of E-bikes has the potential to lead to an increase in bike usage in areas where it is currently an unviable option. Through active land-use management and planning, the municipalities / development authorities and the regional development authorities may steer the development of the city mobility towards a more sustainable direction.

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Appendix

Appendix 1: Mathematical structure for the accessibility measurements

The methodology for estimating accessibility is based on the approach used in the development of the LUTI model for Santander[1]. This means that the 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. In the 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 costs 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 an exponential function that expresses the accessibility as a function of the generalized cost (GC) of traveling to the ward, the number of jobs in the ward, and a parameter alfa that states how quickly the probability of the trip occurring diminishes with a change in the generalized cost of the trip. The accessibility-equation is listed in equation I:

I. $Accessibility_{ij} = jobs_j \times e^{-alfa*GC_{ij}}$

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

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

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[1] LUTI Model for the Metropolitan Area of Santander, 2013. Coppola et. al. (2013)

Institute of Transport Economics (TØI)
Norwegian Centre for Transport Research

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Visiting and postal address:
Institute of Transport Economics
Gaustadalléen 21
NO-0349 Oslo

+ 47 22 57 38 00
toi@toi.no
www.toi.no