TØI report 1700/2019

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Institute of Transport Economics
Norwegian Centre for Transport Research

Societal consequences of automated vehicles

Norwegian scenarios

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Tittel: Samfunnsmessige konsekvenser av automatiserte kjøretøy - norske scenarioer

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Sammendrag:

Automatiserte kjøretøy og litteraturen om dem er i rask vekst. Forventningene er at de vil gi bedre individuell mobilitet og trafikksikkerhet og redusere transportens miljøbyrder. Samtidig forventes betydelig mer kjøring og lengre distanser som vil kunne gi mer trengsel, byspredning, redusert kollektivtransport og mindre aktiv mobilitet. Samfunnsmessige konsekvenser av automatiserte kjøretøy vil avhenge av eierstrukturen, av bruksmønsteret og hvilken politikk som føres for å begrense eller legge til rette for private, delte eller kollektive ordninger. Dette avgjøres ikke av teknologi. For å utnytte mulighetene og takle utfordringene kreves en fortsatt aktiv og differensiert politikkutforming. Private selvkjørende biler egner seg i spredtbygde strøk, mens selvkjørende busser og baner egner seg for kollektivtransportens hovedlinjer. Spørsmålet er hvor og for hvem samkjøring med små selvkjørende minibusser i kollektivselskapenes regi vil egne seg best. På norsk er det disse kjøretøyene og ordningene vi allerede kjenner best og som antakelig vil bli videreutviklet først.

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Summary:

Automated vehicles, and the literature thereof, are in rapid growth. Improved mobility and traffic safety and reduced environmental burden are expected. However, automated vehicles might increase driving remarkably, inferring more congestion, urban sprawl, reduced public transport and less active mobility. Societal impacts depend on ownership and usage of the automated vehicles, and the policies to restrict or support the various private, shared or public schemes. This is not determined by technology. To exploit the possibilities and cope with the challenges an active and differentiated policymaking will be necessary. Private automated cars will be best suited in rural areas, whereas automated buses, trams and trains are best suited along the main public transport grid. The question is where and for whom ridesharing with small automated minibuses run by the public transport companies will be the most appropriate. These, already familiar, schemes will probably be the point of departure for the further development in the Norwegian context.

Language of report: English (last chapter Norwegian)

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Preface

In summer 2018 TØI won a bid for a regionally funded project on "Scenarios for societal consequences of automated vehicles". TØI's research team has consisted of the economists Alice Ciccone and Niels Buus Kristensen and sociologist Vibeke Nenseth, with the latter as the project leader.

The report is discussed and written in close cooperation in the project team. Alice Ciccone has been responsible for the systematic literature review, has written chapter 3 and has contributed in chapter 1. Niels Buus Kristensen has intensively commented and contributed in all chapters. Julie Runde Krogstad and Nils Fearnley have provided input on smart mobility and challenges for public transport.

Secretary Trude Kvalsvik has clarified and finished the report for publishing.

The project has been discussed and developed through montly workshops with regional stakeholders, providing valuable input and feedback during the project period.

Oslo, June 2019
Institute of Transport Economics

Gunnar Lindberg
Managing Director

Alena Katharina Høye
Research Director

Content

Summary

Societal consequences of automated vehicles – Norwegian scenarios

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Along with the ongoing rapid development of automation in transport, the literature on automated vehicles is overwhelmingly increasing. Overall, it is suggested that automated vehicles will have a great potential in improving individual mobility and traffic safety and reducing environmental burden, whereas goals of less driving and more active mobility will be challenged. The first automated vehicles are already driving around in some designated Norwegian settings. They have set a new agenda, highlighting the need for active preparation, not reactively waiting for the further technological progress. Steering the future direction depends on dedicated policies and organisational facilitation. Will the automated vehicles be private, shared or public and used for private or rideshared trips? Where, when and with what consequences? Based on these criteria we have selected five scenarios: Private automated cars for all; Curbing urban congestion; Shared automated car fleets; Automated vehicles for ridesharing; Automated vehicles in scheduled public transport. A further introduction of automated vehicles in the Norwegian context will probably draw primarily on the various sharing models, organised by a mixture of public or private transport network companies.

Assessing the societal consequences of automated vehicles for personal mobility

Automation is considered to be the next disruptive innovation in transport and are expected to become an integral part of future transport systems. Overall, it is suggested that automated vehicles (AVs) will have a great potential to positively contribute to solving many urban and environmental problems. They will improve mobility and traffic safety. However, AVs are also expected to present various challenges when it comes to important policy goals, such as zero-growth for car use in urban regions, reduced urban sprawl and improved public health.

The focus of the present study is to understand the possible societal impacts that AVs will have, rather than studying the technological solutions themselves. The emphasis is on the impacts on personal mobility, while the introduction of AVs for freight transport is outside the scope. As for many other innovations, this is a topic where no blueprint solution is available. Whereas the technological literature for the future of automated vehicles already is overwhelming, this study is the first in the Norwegian context presenting updated research to identify a set of possible future scenarios and schematically describe its *societal* consequences according to relevant policy goals.

The project has had the following main objectives:

i) Define and operationalise central terms and policy goals

ii) Update the knowledge of current and future development of automated vehicles and driving technologies (chapter 3)

iii) Assess how automated vehicles influence urban transport

iv) Show how the findings from ii) and iii) are relevant in a regional context

v) Put forward some policy implications for future urban and regional transport policies

Five scenarios for societal consequences of automated vehicles

The study considers the current and future development of automated driving technologies in connection with the five levels of automation and geographical differentiation and other conditional factors. We discuss the distinction between individual and public transport. AVs can be individually privately owned or included in more or less collectively organized solutions where the vehicles belong to a central fleet. The distinction within shared mobility between carsharing and ridesharing is drawn. We can conceive future ownership and organizational principles for AVs based on today's carsharing concepts such as B2C (business-to-consumer), CarCoop (cooperative, non-profit membership) models, and P2P (peer-to-peer) models.

Next we provide an overview of the literature that focuses on the societal consequences of AV technology. The societal implications of AVs are complex and involve several dynamic interactions. Through this review effort, we identify several main dimensions that are likely to stir the direction of such implications. To evaluate the implication of automated technology on different factors of society and urban transport, we separate implications of AVs in two categories, directly and indirectly. We define the more direct and immediate effects on urban transport and mobility in contrast to the societal or indirect impacts of AVs. More in detail, we discuss effects of AVs on travel cost and road capacity, demand and travel choice, ownership, transport infrastructure, accessibility, safety and security, energy consumption, air pollution, social equity, industries, and public health.

For a systematic scenario development we review some main principles and previous scenario analyses in transport and for AVs, in order to select the most relevant scenario criteria. Three significant dimensions are selected. We distinguish first between private or shared *ownership*; second, between private or shared *use* of the vehicles, and third, the *political* dimension, what kind of policies that will follow the introduction of AVs. We suggest five distinct scenarios:

- One where there will be cheap privately owned, *individual automated cars (AVs) available for all*, with no particular policy regulation
- One with policies aiming at *curbing congestion* of private AVs in urban areas
- One where the AVs is privately used and organised in a *shared AV fleet*, whether public or private
- One where there is a *rideshared use of the AVs*, primarily integrated in a mobility-as-a-service-solution
- And finally, a scenario where the main policy emphasis is on *intensified and automated dpublic transport.*

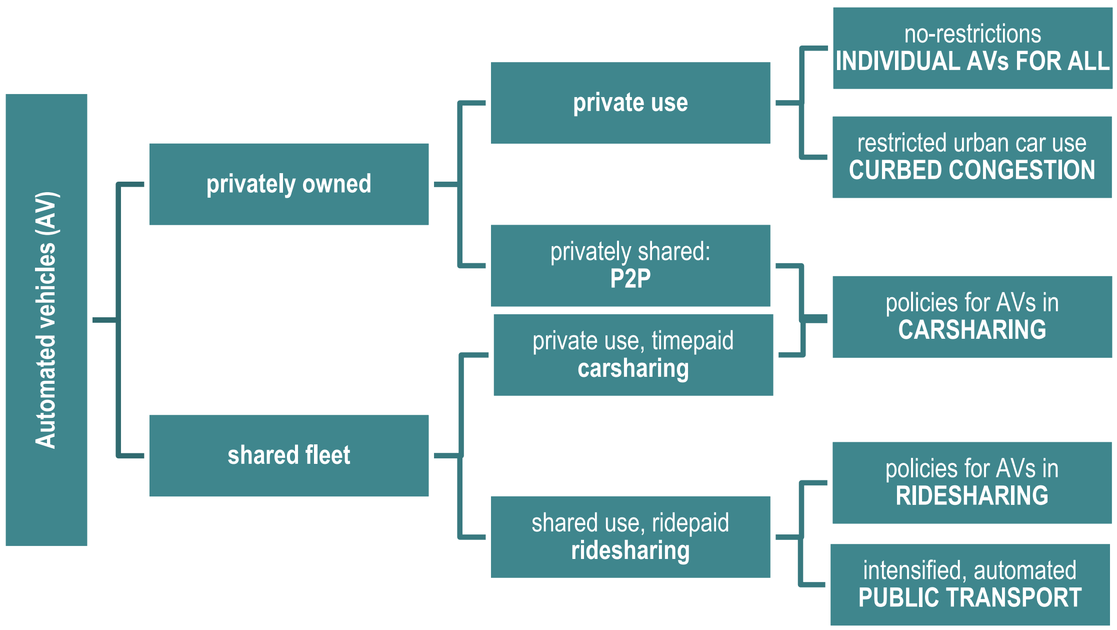

Figure 1.1: Societal consequences of automated vehicles. Five scenarios.

The possible impacts of the various scenarios are discussed. From the call the following impacts are in particular requested: 1) social impacts for the users, 2) consequences for the environment and land use and 3) consequences for the public transport. Table S1 sums up some of the assumed impacts and main characteristics of each of the scenarios, differentiated between urban, suburban and rural areas.

Table 1: Main impacts for the five scenarios, by regional differentiation (colours indicate positive (green) and negative (red) development and strength (darker))

		SCENARIOS				
		privately owned AVs			shared AVs	
		private use of AVs			shared use of AVs	
		AUTOMATED CARS FOR ALL	CURBED CONGESTION	SHARED FLEET OF AVs	RIDESHARED AVs	PUBLIC TRANSPORT
REGION	Urban	congestion		congested if empty cruising	feeding PT	scheduled (in MaaS)
	Suburban	queues on arterial roads	AVs for the few	(in MaaS)	(on-demand) (in MaaS)	
	Rural		irrelevant	P2P	on-demand	costly

Private automated cars will be best suited in rural areas, whereas automated buses, trams and trains in scheduled public transport will be best suited within the main public transport grid. The question is where and for whom ridesharing with small automated minibuses run by the public transport companies will be the most appropriate. These already familiar vehicles and schemes (as they are already tested in real traffic, e.g. in Fornebu, Forus and Kongsberg), will probably be the point of departure for the further development in the Norwegian context.

To sum up for the Norwegian context the shared models will be the most probable, either a shared automated car fleet for private car use, or shared rides in minibuses (microtransport) run by public or private companies. Only these companies, already having a legal permission for transport services, are legible to execute pilots with selfdriving vehicles in Norway.

National and regional policy goals of reduced urban car use make the policies and measures from the *curbed urban congestion* scenario necessary. At the same time, an intensified *public transport* scenario with automated trains and buses is highly probable. Only the latter will require public investments or financial support. On-demand automated vehicles in carsharing schemes will probably draw on today's carsharing providers. These vehicles will resemble a driverless taxis. Even if there is a limited use of private taxis today, the situation will be quite different when the cost of the driver is gone. An excessive use might easily be foreseen.

Different types of carsharing are well-suited both in urban, in suburban and rural districts. Private trips in carshared vehicles are, however, not very suitable for routinized travels (to work, for regular transport services for special groups, e.g.). This is a field where microtransport, in the form of small automated minibuses, will be relevant. These are schemes that might be run by public or private (commercial or non-profit) transport companies.

The expectations of the timing of the first introduction and further implementation of automated vehicles vary considerably. Some studies suggest automated vehicles on motorways early in the 2020s, and in urban traffic only a few years later. Some expect every 10^{th} vehicle to be conditionally automated in 2030, and 60 percent of the fleet fully automated in 2060. Also, the expectations of the changes in the modal split are highly uncertain. Since previous research is only based on simulations, it is only possible to indicate the internal shift in modal split (between private car usage; rideshared, public or active transport) on an ordinal level (more/less), not exact quantification.

In general, the potential for lower costs, reduced environmental burden and improved traffic safety substantiates that automated vehicles may change our transport system fundamentally in the decades to come. And – based on previous early transport policies and early initiatives in the Norwegian context (i.e. from the public transport companies Ruter, Brakar and Kolumbus), the expectations could be that much will occur in the Oslo, Buskerud and Stavanger region in the first place.

Sammendrag

Samfunnsmessige konsekvenser av automatiserte kjøretøy – norske scenarioer

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Sammen med den raske automatiseringen av kjøretøy som nå foregår, er det også en stor vekst i litteraturen om selvkjørende biler og kjøretøy. Generelt er det store forventninger til at automatiserte kjøretøy vil gi bedre individuell mobilitet og trafikksikkerhet og redusere transportens miljøbelastninger, mens mål om mindre kjøring og mer aktiv mobilitet vil bli utfordret. De første automatiserte kjøretøy i Norge har siden 2018 vært testet ute i reell trafikk i noen utvalgte områder. Det har satt selvkjørende biler på dagsorden, og fått fram at det ikke holder reaktivt å vente på teknologien for å påvirke den videre utviklingen. Utviklingen vil avhenge av en aktiv politikk og organisatorisk tilrettelegging. Vil de automatiserte kjøretøyene være privateide, delte eller offentlige, og vil de bli brukt mest for privatturer, som samkjøring, eller som dagens kollektivtransport? Og hvor, når og med hvilke konsekvenser vil de kjøre? Basert på slike kriterier har vi utviklet fem framtidsbilder: Private selvkjørende biler for alle, begrenset privatkjøring i byer, selvkjørende biler i delingsordninger, selvkjørende vogner til samkjøring og selvkjørende kollektivtransport. Den videre utviklingen i norsk sammenheng vil sannsynligvis dra veksler på ulike delingsordninger og fortsatt utprøving av samkjøring med selvkjørende minibusser.

Automatiserte kjøretøy – fem framtidsscenarioer

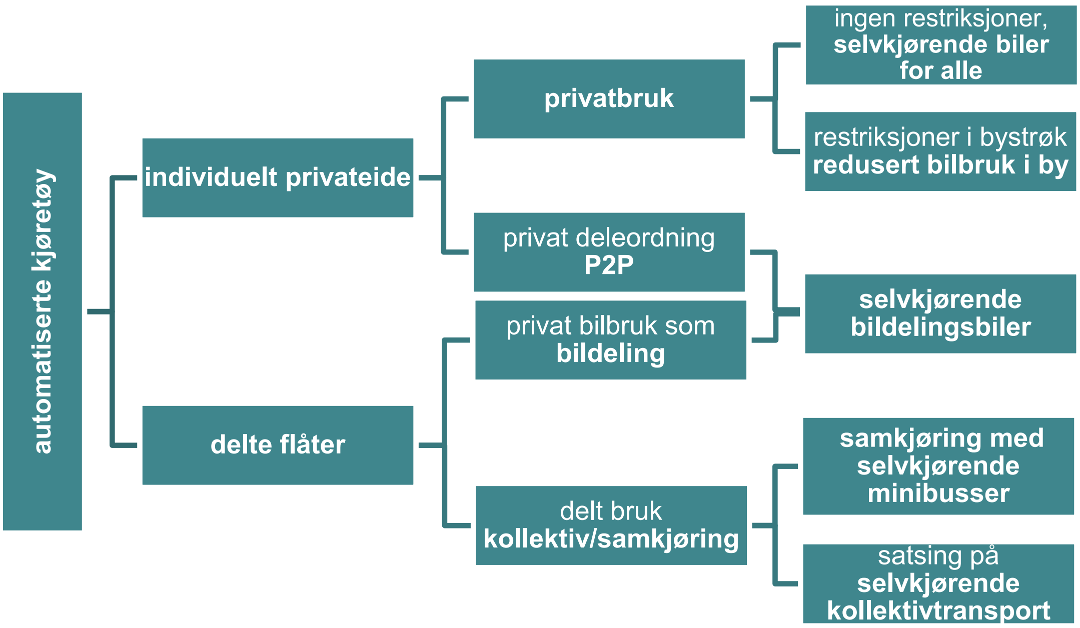
For å vurdere de samfunnsmessige konsekvensene av selvkjørende (automatisert kjøring under gitte forhold) og helt førerløse (fullstendig automatiserte) kjøretøy framover har vi utviklet fem distinkte scenarioer basert på tre hovedkriterier:

- Om de automatiserte kjøretøyene vil bli *individuelt privateide* eller om de blir organisert i en *delingsordning* (som enten kan være en *privat* ordning (kooperativ eller kommersiell) eller *offentlig*
- Om de automatiserte kjøretøyene vil bli brukt og leid til *private turer* (for seg selv eller egen familie) eller som en *samkjørings- eller kollektivtur*
- Om *politikken* ved innføring av automatiserte kjøretøy er lite inngripende, slik at utviklingen er mest *markedsstyrt* eller om politikken er *aktivt regulerende* ved å legge til rette for enkelte forretnings- eller organiseringsmodeller mer enn andre

Ut fra disse dimensjonene får vi en 2x2x2- matrise som spenner ut et tredimensjonalt scenario-kart. Siden den siste *politikk*-dimensjonen vil være ganske overlappende hva gjelder ulike bildelingsordninger, har vi slått dem sammen – og sitter igjen med fem ulike framtidsbilder. Hvert scenario kan ses som en respons på utfordringene gitt av det foregående.

1. Ett for private «**selvkjørende biler for alle**» der bilene vil være masseprodusert og billige å kjøpe, og flere enn alle som har privatbil i dag vil kunne ha sin egen. Med lett tilgang til egen selvkjørende bil vil det både bli flere biler, flere som kan bruke bil og mer bilkjøring. Uten aktiv politikk og regulative tiltak vil det bli betydelig mer trengsel i og rundt byene.

2. Ett for «**restriktiv bilbruk i by**» der innkjøring til, kjøring og parkering i tette bystrøk med biler (så vel selvkjørende som dagens) vil være sterkt regulert (etter hvert veipriset), men der enkelte grupper som trenger det (eksempelvis mennesker med funksjonsnedsettelser) kan bli prioritert.
3. Ett der politikken legger til rette for «**bildeling med selvkjørende biler**» der kooperative eller kommersielle bildelingstilbydere eller privatpersoner leier ut selvkjørende biler til dem som trenger en bil av-og-til.
4. Ett der politikken satser på å legge til rette for «**samkjøring med selvkjørende minibusser**» (mikrotransport), gjerne integrert i en sømløs og multimodal mobilitetstjeneste (MaaS) som henter folk (nær) der de, samkjører og frakter dem til og fra transportknutepunkt, bysentre, store arbeidsplasser, eller lignende.
5. Ett der den politiske innsatsen først og fremst satser på å videreutvikle **satsingen på automatisert rutegående kollektivtransport** når den gradvis blir mer selvkjørende og etter hvert helt førerløs.



Figur S1: Automatiserte kjøretøy – fem scenarioer.

Samfunnsmessige konsekvenser av automatiserte kjøretøy

Det første scenarioet med private **«selvkjørende biler for alle»** - innebærer at selvkjørende biler vil være rimelige og lett tilgjengelige for flere enn alle de som har førerkort og tilgang til bil i dag. Konsekvensene vil bli betraktelig mer kjøring, ikke minst tomkjøring når selvkjørende biler skal returnere. Private selvkjørende biler egner seg for spredtbygde områder, mens de i byområder og forsteder vil gi svært negative utslag for trafikkflyten. Når den individuelle mobiliteten blir forbedret blant annet ved at tilgangen til en privat selvkjørende bil blir alminnelig, vil det bli lettere å bosette seg i mer grisgrendte strøk, med en mulig byspredning som resultat. Mer trafikkaos i byene kan virke i samme retning – og redusere dagens urbanisering til fordel for et mer spredt og muligens mer segregert bosettingsmønster. Private selvkjørende biler tilgjengelige for alle, gjør bilbruk enda lettere enn i dag , noe som gjør at kollektivtransport på den ene siden og aktiv mobilitet (sykkel og gange) på den annen vil kunne bli betydelig redusert.

Det andre scenarioet - «**bilbruksrestriksjoner i by**» - viderefører det nåværende overordnete transportpolitiske målet om nullvekst i bilbruk i storbyene. Det vil klart redusere behovet for å ha og bruke egen selvkjørende bil til privatbruk i byene. I forstedene og omegnskommunene rundt byene, vil kjøringen inn til byene med private selvkjørende biler bli regulert av byspesifikke innkjøringsrestriksjoner, bompenger, rushtidsavgift og etter hvert veiprising. Mens i rurale strøk vil det ikke være nødvendig med restriksjoner på privatbilbruken.

I det tredje scenarioet, - **«selvkjørende bildelingsbiler»** - vil delebiler være tilgjengelige for privatbilbruk, gitt restriksjoner på bruk av privat(eid)e biler i bysentre. Selvkjørende delebiler vil kunne bestilles, spores og betales digitalt på ulike delebilselskapers plattformer, gjennom en bildelingstilbyder eller såkalt TNC (transport-network-company) som popper opp i stort monn for tiden. I praksis vil bruken av disse ligne på dagens taxier – biler som eies av et transportselskap, som spores og bestilles digitalt og som kjører fra dør-til-dør. Siden taxisjåføren i dag utgjør omtrent 70 prosent av taxiturens kostnader, sier det seg selv at taxilignende selvkjørende delebilskonsepter kan komme til å bli betraktelig billigere – og betydelig mer utbredt. Med sine erfaringer om bildeleres bruksmønster og preferanser vil antakelig de erfarne bildelingsselskapene spille en sentral rolle i videreutviklingen av slike delebilkonsepter også når det gjelder automatiserte biler framover. Det er vanlig å anta at bildeling egner seg spesielt godt i tettbygde strøk. Men med deleordningen med utveksling mellom privatpersoner – såkalt P2P (peer-to-peer)-ordning - kan denne like gjerne egne seg i rurale strøk der en privatperson kan leie ut bilen sin til en annen - til «naboen».

I det fjerde scenarioet vil den politiske innsatsen særlig være rettet inn mot å understøtte **«samkjøring med selvkjørende minibusser»** som vil kunne fungere som et alternativ til dagens privatbilbruk. Med andre ord et opplegg av den typen minibusser som allerede er – og vil bli videre - prøvd ut i reell trafikk (på Forus og snart Gjesdal i Rogaland, på Fornebu, på Kongsberg, langs Akershus-stranda og Nedre Bekkelaget i Oslo og i Drøbak i Akershus). Slike tjenester kan tilbys av så vel private som av offentlig kollektivselskap eller av offentlig-privat samarbeid. Denne typen selvkjørende mikrotransport vil særlig kunne spille en sentral rolle innenfor en multimodal, sømløs og integrert mobilitetstjeneste som MaaS (mobility-as-a-service). For å sikre et visst belegg om bord, er det opplagt at dette er en mobilitetsordning som egner seg best for byer og tettbygde strøk, men i mindre grad for helt rurale områder.

Det femte scenarioet - **«satsing på selvkjørende kollektivtransport»** - innebærer en storstilt satsing på automatisering i et hovedlinjenettverk mellom sentrale bysentre og tettsteder, i tråd med eksempelvis satsingen på 'Bussveien' i Rogaland. Et såkalt BRT (bus rapid transit)-tilbud som dette vil klart egne seg for videre automatisering. Når sjåføren er borte, vil en utfordring være mobilitetsservicen om bord for å bistå passasjerer som trenger det. En større satsing på førerløse busser og baner i et hovedlinjenett vil kreve et forsterket tilbud med små minibusser (*mikrotransport*) til og fra boligområder til busstopp eller til og fra større arbeidsplasser, og/eller en større satsing på aktiv mobilitet – sykkel og gange – eller annen '*mikromobilitet*' (el-sparkesykler, o.l.).

Tabell S1 oppsummerer konsekvenser av de ulike scenarioene fordelt på by-, suburbane eller rurale områder.

Tabell S1: Viktige konsekvenser av automatiserte kjøretøy, regionalt differensiert (farger indikerer positiv (grønn) eller negativ (rød) utvikling og styrke (mørkere))

		SCENARIOER				
		Privateide selvkjørende biler			Delte selvkjørende kjøretøy	
		Privat bruk av selvkjørende biler			Delt bruk av selvkjørende kjøretøy	
		Selvkjørende biler for alle	**Bilbruks-restriksjoner i by**	**Bildeling med selvkjørende biler**	**Samkjøring med selvkjørende minibusser**	**Selvkjørende kollektivtransport**
REGION	Urban	***trafikkaos trengsel***		***trengsel hvis mye tomkjøring***	***integrert I MaaS***	
	Suburban	***køer på innfartsveier***	***selvkjørende biler for de få***	***integrert I MaaS***		
	Rural		***irrelevant***	***p2p-ordning***	***bestillingstjeneste***	***kostnadskrevende***

Private selvkjørende biler egner seg i spredtbygde strøk, mens selvkjørende busser og baner egner seg for kollektivtransportens hovedlinjer. Spørsmålet er hvor og for hvem samkjøring med små selvkjørende minibusser i kollektivselskapenes regi vil egne seg best. På norsk er det disse kjøretøyene og ordningene vi allerede kjenner best (siden de allerede blir testet ut i reell trafikk) og som antakelig vil bli videreutviklet først.

For regioner som har en transportmiddelfordeling med høy privatbilbruk og lav kollektivandel, kan det være grunn til ekstra årvåkenhet overfor en storstilt innføring av *privateide automatiserte biler* når markedet og teknologien gjør det klart. Som kanskje kan skje ganske snart – allerede tidlig på 2020-tallet. Gitt at byvekstavtalene for storbyregionen opprettholdes, vil det kunne innebærer at bysentrene ikke belastes ytterligere med køer og trafikk, og det kan legges til rette for bedre bymiljø og byliv.

Siden norske deleordninger så langt er blitt etablert så å si uten finansiell støtte, er det grunn til å anta at også *automatiserte bildelingsordninger* vil kunne etablere og klare seg greit uten storstilt offentlig satsing.

Selv om det er for tidlig å dra veksler på erfaringene med selvkjørende minibusser i utvalgte områder – som for eksempel på Forus i Rogaland – framstår ikke forsøkene ennå som svært løfterike. Selvkjørende minibusser er etter sigende ennå ikke møtt med særlig entusiasme noe som blant annet skyldes lav fart og liten etterspørsel. Det er likevel interessant at det er kollektivselskapene i Oslo- og Stavanger-regionen, Ruter og Kolumbus, som er så tidlig ute med innovative mobilitetsordninger. Tidligere enn andre fylkers kollektivselskaper har disse satset både på selvkjørende busser. Dét vitner om, og skulle borge for, at satsingen på scenarioet med selvkjørende minibusser innen en sømløs og multimodal mobilitetstjeneste, basert på MaaS skulle egne seg spesielt godt for disse fylkene der piloter med **selvkjørende minibusser** nå foregår (Oslo, Buskerud, Akershus). Også betydelig satsing på en høykvalitets og høykapasitets rutegående kollektivtilbud i regionene gjør at det også er i disse fylkene en antakelig vil kunne realisere det siste scenarioet med en intensivert renessanse for høyfrekvent og høykapasitets **kollektivtransport.**

Oppsummert er det mest sannsynlig i en norsk kontekst at det er modellene med delte flåter av selvkjørende biler og minibusser som kommer til å bli introdusert først, med andre ord *scenarioet med bildeling av selvkjørende biler* til privatbilbruk (for dem som bare trenger en bil av og til) – og *scenarioet med minibusser for samkjøring* (til arbeidsreiser, til transport av særlige grupper, o.a.). Det er bare selskap med løyve som er gitt tillatelse til utprøving i norsk sammenheng, derfor er det lite sannsynlig at vi får selvkjørende biler i luksussegmentet på norske veier med det første (i motsetning til hva tilfellet er i enkelte studier internasjonalt).

For å verne om og videreutvikle bysentrene i ønskelig retning, i tråd med overordnete politiske mål, er det opplagt nødvendig å videreføre en politikk med *redusert privatbilbruk inn til og i byene* (det andre scenarioet). Som kjent er det i forbindelse med bompengemotstand og reforhandlinger av byvekstavtaler for tiden betydelig usikkerhet rundt disse mulighetene. Samtidig er det all grunn til å videreutvikle større satsinger med høyfrekvent og høykapasitets offentlig transport langs hovedlinjer («bussveger»). Ikke alle scenarioene krever mye av offentlig støtte eller investering. Det sier seg selv at dét særlig vil gjelde det siste scenarioet: en intensivert satsing på selvkjørende *offentlig kollektivtransport.*

Når det gjelder bestilling av selvkjørende biler i delebilordninger, er det sannsynlig at en rekke private bildelingstilbydere (Bilkollektivet, Hertz Bilpool, Move About, Hyre, o.a.) fremdeles vil være på banen – og kanskje nye komme til. Om bildeling utgjør en liten andel av den totale bilbruken i dag, vil det stille seg helt annerledes når sjåførkostnaden er borte. Da blir bildeling å ligne med en selvkjørende taxi – en robotaxi.

Ulike typer bildeling med selvkjørende biler vil kunne egne seg både i bystrøk (forutsatt begrensninger på tomkjøring), i tettsteder og forsteder, men også i grisgrendte strøk (som P2P-ordninger). Men bildeling for private turer, egner seg i liten grad for rutiniserte reiser, som daglige arbeidsreiser, faste transporttjenester (for eldre, skolereiser, barn til fritidsakviteter, o.a.). Det er på dette området mikrotransport i form av selvkjørende minibusser for samkjøring, vil gjøre seg gjeldende. De vil være mer fleksible enn dagens kollektivtransport med faste tider og traséer, samtidig som fleksibiliteten reduseres jo flere som skal samkjøre og hentes og leveres utenfor regulerte traséer. Også denne typen ordninger kan organiseres og driftes i offentlig (fylkeskommunal) eller privat (kommersiell eller non-profit) regi eller gjennom privat-offentlig partnerskap.

Når det gjelder forventninger til tidsaspektet, er variasjonen stor. Det er betydelig forskjell på når de *første* kjøretøyene på ulike teknologiske nivå er ventet på markedet og når de selvkjørende kjøretøyene vil dominere mer eller mindre fullstendig. Noen studier forventer selvkjørende biler på motorveier tidlig på 2020-tallet, mens andre antyder at bare hver tiende bil vil være selvkjørende i 2030 mens opp mot 60 prosent av bilflåten vil være helt førerløs i 2060. På samme måte som tidsaspektet varierer så mye er det høyst usikre anslag på *hvordan* automatiserte kjøretøy vil påvirke transportmiddelfordelingen. Det er bare mulig å *sannsynliggjøre* om andeler av henholdsvis privatbilbruk, kollektivtransport eller aktiv transport (sykkel og gang) vil økes – eller reduseres (på ordinalnivå). Når tidligere studier av automatisert kjøring fram til nå nødvendigvis er modellbaserte simuleringer, sier det seg selv at eksakt tallfesting ikke er mulig.

Generelt vil potensialet for lav pris, liten miljøbelastning og større trafikksikkerhet gjøre at selvkjørende og førerløse kjøretøy kan komme til å endre vårt transportsystem fundamentalt i de kommende tiårene. Ut fra tidlige transportpolitiske satsinger og initiativ fra framtidsrettete kollektivselskap som Ruter, Brakar og Kolumbus, er det grunn til å vente at mye vil skje aller først i de regionene som allerede har startet pilotforsøk med selvkjørende minibusser, i henholdsvis Oslo-regionen, på Kongsberg og på Forus i Stavanger-regionen.

Abbrieviations

AC	Automated cars
AV	Automated vehicles
B2B	Business to business
B2C	Business to consumer
BRT	Bus rapid transit
CarCoop	Cooperative (non-profi, memberbased) carsharing organisation
CAV	Connected automated vehicles
MaaS	Mobily as a Service
NTP	National transport plan
P2P	Peer to peer
PAV	Private automated vehicles
PT	Public transport
SAV	Shared automated vehicles
TNC	Transport network company
TOD	Transit oriented development
V2I	Vehicle to infrastructure
V2V	Vehicle to vehicle
VKT	Vehicle kilometre travelled
VMT	Vehicle miles travelled

1 Introduction

1.1 Background

Automation is considered to be the next disruptive innovation in transport and are expected to become an integral part of future traffic systems.[1] The literature on automated vehicles (AVs) is already overwhelming and rapidly increasing. Overall, it suggests that AVs will have a great *potential* to positively contribute in solving many urban and environmental problems, such as improving mobility and traffic safety. However, AVs are also expected to present various *challenges* when it comes to important policy goals, such as zero-growth for car use in urban regions, reduced urban sprawl and public health.

As for many other innovations, this is a topic where no blueprint solution is available. Whereas the technological literature for the future of automated vehicles already is overwhelming, this study is the first in the Norwegian context presenting updated research to identify a set of possible future scenarios and schematically describe its *societal* consequences according to relevant policy goals.

1.2 Purpose of the study

The focus of the study is to understand the possible societal impacts that AV technology will have, rather than studying the technological solutions themselves. We concentrate on the impacts on personal mobility, while the introduction of AVs for freight transport is outside of our scope.

The project has had the following main objectives:

i) Define and operationalise central terms and policy goals

ii) Update the knowledge of current and future development of automated vehicles and driving technologies

iii) Assess how automated vehicles influence urban transport

iv) Show how the findings from ii) and iii) are relevant in a regional context

v) Put forward some policy implications for future urban and regional transport policies

1.3 The structure of the report

We start by defining and operationalizing a series of key concepts that characterises the literature on the automation of future transport. AV technology and its impacts are presented in light of the main Norwegian transport and development policy goals derived

[1] "Automated vehicles: the coming of the next disruptive technology", https://trid.trb.org/view/1343797

from such as reduced urban car use and related emissions, and improved traffic safety and public health.

The study considers the current and future development of automated driving technologies in connection with the five levels of automation and geographical differentiation and other conditional factors. We discuss the distinction between individual and public transport. AVs can be individually privately owned or included in more or less collectively organized solutions where the vehicles belong to a central fleet. The distinction within shared mobility between carsharing and ridesharing is drawn. We can conceive future ownership and organizational principles for AVs based on today's carsharing concepts such as B2C (business-to-consumer), CarCoop (non-profit, memberbased) models, and P2P (peer-to-peer) models.

Next we provide an overview of the literature that focuses on the societal consequences of AV technology. The societal implications of AVs are complex and involve several dynamic interactions. Through this review effort, we identify several main dimensions that are likely to stir the direction of such implications. To evaluate the implications of automated technology on different factors of society and urban transport, we separate implications of AVs in two categories, directly and indirectly. We define the more direct and immediate effects on urban transport and mobility in contrast to the societal or indirect impacts of AVs. Specifically, we discuss effects of AVs on: travel cost and road capacity, demand and travel choice, ownership, transport infrastructure, accessibility, safety and security, energy consumption, air pollution, social equity, industries, and public health.

For a systematic scenario development we review some main principles and previous scenario analyses in transport and for AVs in order to select the most relevant scenario criteria. Three significant dimensions are selected. We distinguish first between private or shared *ownership*; second, between private or shared *use* of the vehicles, and third, the *political* dimension, what kind of policies that will lead to and follow the introduction of AVs. We suggest five distinct scenarios:

- One where there will be *cheap privately owned automated cars (AVs) available for all*, with no particular policy regulation
- One with policies aiming at *curbing congestion* of private AVs in urban areas
- One where the AVs is organised in a *shared AV fleet*, whether public or private
- One where there is mainly a *rideshared use of the AVs*, integrated in a mobility-as-a-service-solution
- and finally, a scenario where the main policy emphasis is on *intensified and automated public transport.*

The possible impacts of the various scenarios are discussed, discerning between social impacts for the users, consequences for the environment and land use and consequences for the public transport. Relevant findings from the literature review and from the scenarios results are regionally differentiated between urban, suburban and rural areas. Finally we conclude with some policy implications for urban and transport policy, based on the analysis of the possible consequences of automated driving technologies. The scenario analyses with policy implications can be used to inform decisions with the aim of achieving policy goals for urban and regional development.

2 Central terms and policy goals

2.1 Central terms – definition and operationalisation

Automated vehicles have come to be central in the policy and organisational innovations dominating the transport sector. In this section we will present the important terms characterising the field of automated vehicles. Not only the 'automated vehicle' term in itself, but also its relation to technological development stages, regional differentiation and other conditional factors. We draw the distinction between individual versus collective transport and private versus public transport. Also contemporary transport concepts like 'smart mobility', 'mobility-as-a-service' (MaaS), 'shared mobility', 'microtransport' and 'micromobility' are shortly described.

Automated vehicles

Automated vehicles have been defined as "…*those in which operation of the vehicle occurs without direct driver input to control the steering, acceleration, and braking and are designed so that the driver is not expected to constantly monitor the roadway while operating in self-driving mode.*" [2]

'Automated' is now the preferred term, instead of the previous much used 'autonomous', mostly because the latter indicates a machine designed and operating on its own, outside human control, which is obviously not the case.

The definition is, however, mostly presented together with what kind of automation level the vehicle has reached – as put forward by the Society of Automotive Engineers (SAE) in 2014):

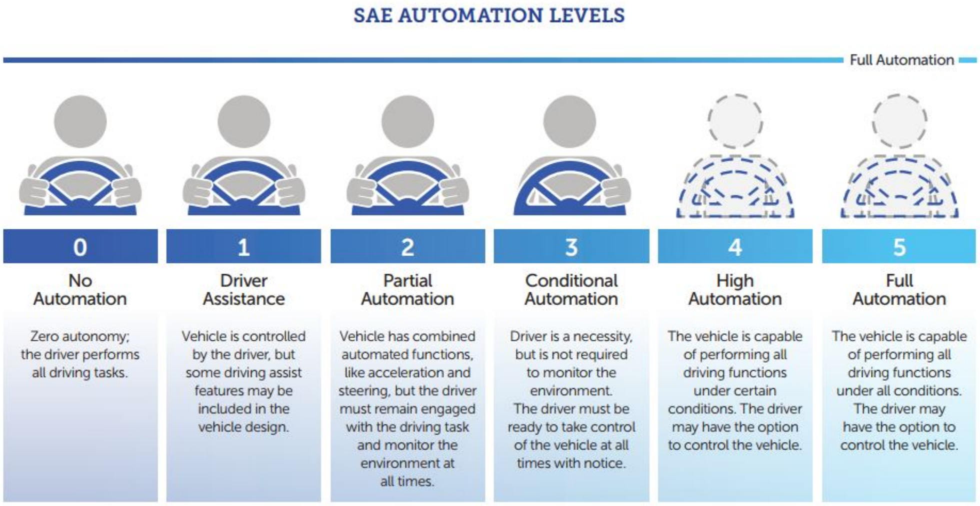


Figure 2.1: Automated vehicles according to the five automation levels (see footnote 2)

[2] By the U.S. Department of Transportation's National Highway Traffic Safety Administration, http://autocaat.org/Technologies/Automated_and_Connected_Vehicles/

Much used is the distinction between *self-driving* and *driverless,* for the two highest levels.

The automation level and the regional differentiation are closely related since AVs at different automation levels might be introduced and particularly suitable in specific geographical areas, zones or roads. Automation level 3, conditional automation, is highly risky outside strictly limited zones or campuses since the driver can have the illusion that the vehicle is fully automated, but must be prepared to take the control when the vehicle "requires" it. For the safety issue some car producers (e.g. Volvo) will skip it completely and go directly for level 4. The transition from level 4 to level 5 represents the shift from *some* conditional contexts to all – whether geographic areas, roadway types, traffic or weather conditions or incidents.

Other conditional factors related to AVs on level 4 and 5 are presented in the table below. (ITF, 2015; Kristensen, 2018). The ***time expectations*** are around 2025 for the self-driving vehicle (from level 4) on motorways, and only two-three years later in urban traffic.

Table 2.1: Different conditions that determine where and when high level AVs might drive.

Geography	Restricted to certain countries/states, regions, or in particular to specific urban or rural areas
Road type	Oncoming traffic, road infrastructure qualities, surface, curves, etc
Traffic type	Own lane or mixed traffic
Weather condition	Daylight, darkness, precipitation, slippery roads, etc
Events/incidents	Types of risk situations the AV envisages (e.g. different objects in the road)

Also transport mode matters. For instance, at level 4, high automation, public transport with fixed, scheduled routes, might work very well along specific (segregated) routes or lanes. Also, on-demand services at the automation level 4, might function well in specific areas or zones. With the transport mode of private driverless cars (close to automation level 5) also the specific zones and the regional differentiation need to be taken into consideration.

There have already been pilots of particular AVs in some regional settings in the Norwegian context, i.e. the small shuttle buses driving in real traffic in small areas: Forus and Fornebu, and in a small town centre in Kongsberg, along Akershus-stranda and in Bekkelaget in Oslo an in Drøbak in Akershus. The buses drive at very low speeds and are by and large by regional stakeholders not seen as very promising, yet. However, the results from systematic evaluations from these pilots are yet to come.

When combining automation level and regional conditions the launching of small pilots of AVs in real traffic (in campuses and restricted urban zones or roads) are more easily managed and executed than passively waiting for the technology, the next automation level, to arrive. Then it is more up to local and regional policy makers and businesses to influence and decide. Or as it has been put:

> *"Massive fleets of shared autonomous vehicles will be realized more quickly by starting now with constrained geographic applications rather than focusing on SAE (Society of Automotive Engineers) levels of increasing robotic capability and accommodating partially-robotic vehicles one-customer-at-a-time."* [3]

[3] Niles (2015): https://www.move-forward.com/transit-leap-what-autonomous-vehicles-can-do-for-transit/

Confining geography to a specific route or a subset of roads within a rather limited urban areas makes it possible to create a digital twin or virtual reality map of the driving areas so that the AV "knows its hood".

Smart Mobility

AVs are often related to the phenomenon of 'smart mobility'. The term *'smart',* related to information and communication technology, originally was an acronym for "*Self-Monitoring, Analysis and Reporting Technology*", that *"…basically monitors and analyzes hard drives*", with a main purpose "…to *keep your hard drive running smoothly and prevent it from crashing*"[4]. Obviously, due to the notion's resemblance with and leaning on the daily life word 'smart", as intelligent, quick and sharp, etc., the comprehension that it is an *acronym* has certainly faded.

Three core elements of the current development of 'smart mobility' have recently been identified: 1) The transition from ownership to usership, 2) the transition from a 'modal-centric' to a 'user-centric' system, and 3) the new role of the citizen as both a source and recipient of information, being one of many actors feeding information into the mobility system, and reducing the role of the government as the prime source of information. (Dockerty, Marsden, & Anable, 2018).

'Smart mobility' has also been divided into a 'techno-centric' and 'user-centric' approach, where automated vehicles (AVs) are seen as an example of techno-centric smart mobility. (Papa & Lauwers, 2015). The development is based on ICT and vehicle industry in cooperation with public authorities.

Mobility-as-a-Service – MaaS

Mobility-as-a-Service is already a well-known and widely used concept, strategically as well as rhetorically. Several stakeholders in different cities are actively testing out various MaaS platforms. Helsinki is a pioneer in the field, as the private company "MaaS Global" launched the Whim app in 2016. On this platform, users can plan and pay for all modes of public and private transportation within the city such as train, taxi, bus, carshare or bikeshare. Even if such multimodal systems are highly hailed, it represents only a tiny share of all travels (only 0,5 per cent of motorised trips other than private car use; Krogstad & Fearnley, 2018). There are also examples of public transport authorities who have teamed up with private transport providers and developed MaaS platforms such as Smile in Vienna, Beeline in Singapore and UbiGo in Gothenburg. (Matyas & Kamargianni, 2018).

Individual/collective transport and private/public transport

Automated vehicles (AV) do not necessarily challenge the distinction between individual or public transport, since AVs might be object to different business or organisational models:

- **Individually privately owned** vehicles, like today's private passenger cars
- **Collectively shared** vehicle fleet, either from a commercial carsharing company (business-to-consumer, **B2C**) or a cooperative membership carsharing organization (**CarCoop**) or a peer-to-peer carsharing, where privately owned cars are rented out to other private persons (**P2P**)
- An ordinary, publicly owned, **public transport** (**PT**) vehicle fleet.

A recent Danish report on "the future of mobility – four scenarios for 2035" (FRI, 2018) develops scenarios spanned by the two dimensions *individual versus collective* and *public versus private* transport solutions. Collective solutions are for instance *shared* and often provided by

[4] https://techterms.com/definition/smart

private actors. Thus, it follows that collective transport solutions are not necessarily public, whereas private transport solutions are not necessarily individual.

Shared mobility: Carsharing and Ridesharing

With the rise of the sharing economy particularly the last decade, also definitions and various aspects of the phenomenon of 'sharing' have come into focus. Sharing might essentially be defined as "…*consumers granting each other temporary access to under-utilized physical assets ('idle capacity'), possibly for money*" (Frenken & Schor, 2017).

Thus, shared mobility is defined relative to solely private use of the owner/user or his/hers family or household, and deals with using the ***idle capacity*** either in terms of time or occupancy – whether

- Lending/renting the vehicle for a specific time period (**carsharing**) or
- Increasing the vehicle occupancy per ride (**ridesharing**).

Microtransport

The concept of 'microtransit' (or microtransport in the European context) is much used in the context of AVs. It is (usually) an *on-demand transport service* that offers flexible routing and/or flexible scheduling of (private or public) minibus vehicles (10-14 passengers). It is enabled by the new mobility service applications or platforms, such as the many new transport network companies (TNCs) that have been launched recently. An important aim is to augment and supplement traditional public transport with its fixed-route and time-scheduled bus and train services. In principle, microtransport could offer all four possibilities: on-demand service and flexible route; on-demand service and fixed route; fixed schedule and flexible route, and fixed scheduled and fixed route (like conventional public transport).[5]

Conceptually, microtransport fits somewhere between private individual transport (private cars or taxis) and public mass transport (scheduled bus/train). It is often presented as a solution to the first/last mile problem in transport – but not necessarily from door-to-door, but rather from a transport stop close to home (or the origin) and to a destination like a transport hub, or to a big workplace or an industrial site.

Microtransport might have a double role related to public transport. On the one hand, the main role might be seen as *feeding* the public transport system, and improve the accessibility from underserved areas to high-capacity trains and buses. On the other hand, it might be foreseen also as substituting the scheduled public transport services.

Micromobility

'Micromobility' is another term or new kind of mobility practice that may be useful to see in relation to the introduction of automated vehicles. Micromobility refers to personal (sub 500 kg) vehicles that can carry one or two passengers. Bicycles are obviously the most common example. Today's most highlighted micro-mobility vehicles are pedelecs/EPACs [elsykler] and electric kick scooters [elektriske sparkesykler] usually running on charged batteries. It represents also a flexible and efficient door-to-door, a first/last mile, or a suitable urban solution. As it is has been put: "*How Micro Mobility Solves Multiple Problems in Congested Cities*"[6].

[5] https://www.enotrans.org/etl-material/uprouted-exploring-microtransit-united-states/

[6] https://maas-alliance.eu/how-micro-mobility-solves-multiple-problems-in-congested-cities/

2.2 Policy strategies for automated driving at European, national and regional levels

2.2.1 At EU level – On Automated driving in European transport

A recent (draft) report *"Motion for a European Parliament resolution, on autonomous driving in European transport"*, from the Committee on Transport and Tourism, 20.7.2018, highlights the following:

- There is a potential in connected and automated road vehicles to improve traffic flows, increase safety for all road users and reduce the environmental impacts of transport
- Passenger cars with automation functions beyond level 3 will enter European road transport very soon after 2020
- In need of regulatory framework, research and innovation, real-life testing of vehicles and road and communication infrastructure is important, and it is a key for Europe to stay at the forefront of this field
- Among the particular problems/challenges are:
    - technical standard of vehicles and infrastructure
    - the use, safety and privacy of data
    - responsibilities in vehicle operations
    - liability, ethics, societal acceptance and the co-existence of automated with human controlled vehicles
    - rules for access to in-vehicle data; data protection, vehicle and route data uses
    - cyber security
- The importance of addressing new (beyond level 3) user complacency – and guidelines on ethical issues
- And the potential of innovative automated public transport systems to tackle urban mobility and congestion challenges, and measures to promote and support projects addressing such issues.

Of particular interest for this project is the claim for more research efforts on the potential long-term effects of automated/driverless transport in terms of its societal implications.

2.2.2 From the Norwegian National Transport Plan (2018-2029)

The main objectives of regional transport and development can be derived in part from general goals for metropolitan, or large urban regions, in the Norwegian National Transport Plan (NTP), partly from regional plans and in particular from the recent urban traffic agreements and former urban environment agreements for the nine largest urban areas in Norway.

NTP 2018-2029 (launched in June 2017)[7] has notified that a gradual automation will have substantial impacts on the following overarching policy goals:

- To reach the set climate goals without reduced mobility
- To increase the safety of the transport system in line with the zero vision of a transport system without loss of life or permanent injury

[7] https://www.regjeringen.no/no/tema/transport-og-kommunikasjon/nasjonal-transportplan/id2475111/

- To focus on coordinated land and transport planning, public transport and bicycle express roads in the larger urban areas to reach the zero growth target (for reduced greenhouse gas emissions and better air quality)
- To ensure an optimal standard of operation and maintenance, which provides good accessibility and safety
- To get more people to walk and cycle on the basis of environmental and climate considerations, better transport capacity and public health.

2.2.3 Regional goals

Urban Growth Agreements [Byvekstavtalene] is a key tool for achieving the target of zero-growth for passengers car use (Ministry of Transport and Communications, 2017) in the largest urban regions. This tool offers investment support for "county municipal collective infrastructure of great national interest".

For the moment the two Urban Growth Agreements that have been launched (for the Bergen and Stavanger regions) are under renegotiations based on the National Transport Plan 2018-2029. For the Oslo region and for the Trondheim region there are Urban Environment Agreements that also will be renegotiated toward Urban Growht Agreements. Also for the other larger urban regions Urban Growth Agreements will be considered: the Tromsø region, the Kristiansand region, Grenland, the Buskerud city, and the Lower Glomma region.[8]

For the agreements/policy packages now under *re-negotiation* there is considerable disagreement between the state and the local authorities on e.g. the state funding, the downscaling of some projects, and, in particular, the toll ring financing, not least due to strong oppositions from local activists ["Bompengeopprøret"[9]].

[8] https://www.regjeringen.no/no/tema/kommuner-og-regioner/by--og-stedsutvikling/Byvekstavtaler/id2454599/

[9] "Bompengeopprøret sprer seg". TV2 25.5.19 https://www.tv2.no/a/10626606/

3 Literature review – state of the art

The following review provides an overview of the literature that focuses on the societal consequences of Automated Vehicle (AV) technology. This chapter has as main objective to systematically review the state of the art of the current international research about AVs as described in point 3.2 of the signed proposal.

The Norwegian National transport plan (NTP) identifies three main goals for 2018-2029: i) better accessibility for people and goods, ii) reducing transport accidents in line with vision zero, and iii) reduce greenhouse gases and other negative environmental impacts. Many claim that AVs will be the next disruptive innovation and for this reason they will have an important impact across all the three goals.

The societal implications of AVs are complex and involve several dynamic interactions. Through this review, we identify several main dimensions that are likely to stir the direction of such implications. The level of automation (especially), the level of cooperation (vehicle-to-vehicle and vehicle-to-infrastructure), and the organization and utilization of the vehicle (private or shared). In addition, important implications for the geographical differentiation and environment and health perspective are linked with the kind of fuel technology these vehicles will have (fossil-fuel versus electric).

The vast majority of recent literature on AVs focuses on technological development side[10]. In contrast, we have tried to summarize work that contributes to the understanding of what consequences AVs will have on people's life and to our society. Spanning from the most direct effect on mobility, urban planning and accessibility, to the effect on the environment, public health, safety and equity. We have investigated both academic research and more policy oriented canals.

3.1 Review methodology

This literature review is the result of searches on the databases "Web of Science", which contains a wide range of interdisciplinary journal databases such as ScienceDirect, Springer Link and Taylor & Francis. In addition, we used the search engines Google and Google Scholar. We used a series of key words and synonyms, such as: "Automated", "Autonomous", "self-driving", "driverless", and "cars", "vehicles", and "social", "societal", "policy", and "impact", "consequences", "evaluation", "assessment", "scenario". We selected articles starting from 2014 or newer.

Out of this first search, we selected relevant papers based on title and abstract. After this first selection we included relevant papers that were cited within the found articles. The current review is the result of insights gained from 29 academic articles, 4 reports, 3 books and several online articles found in blogs and online newspapers.

Most of the selected work uses a quantitative methodology such as experiment, surveys and agent based modelling or simulations. A few studies used instead qualitative methodology such as interviews, experience in driving simulators and quality-evaluation. Among those

[10] See for example the topic analysis carried out in Rosenzweig and Bartl (2015) literature review.

that were not included in the final list of papers we find purely technological studies and purely ethical or law-oriented articles. The list of included studies in table 3.1 is chronologically organized, with the most recent on top.

Table 3.1: Overview of the articles reviewed.

Article	Theme	Method	Level	Type AV
Harrow, Gheerawo, Phillips, and Ramster (2018)	Attitudes and acceptance	Test-bed	Neighborhood (London)	
Straub and Schaefer (2018)	Policy reccommendations	Case study	Campus level	
Fraedrich, Heinrichs, Bahamonde-Birke, and Cyganski (2018)	Effect on urban planning	Sistematic Review	National (Germany)	
Puylaert, Snelder, van Nes, and van Arem (2018)	Effect on mobility	Case study	National (The Netherlands)	Level 1-2-3
Freedman, Kim, and Muennig (2018)	How price and safety affect adoption	Cost-benefit	calculation for US	Taxis
Shabanpour, Golshani, Shamshiripour, and Mohammadian (2018)	How vehicle feature affect adoption	Survey		Fully Automated
Körber, Baseler, and Bengler (2018)	Trust and influence	Experiment	National (Germany)	Level 3
Nielsen and Haustein (2018)	Attitudes and expectations	Survey	National (Danmark)	
Mazur, Offer, Contestabile, and Brandon (2018)	Role of AVs for adoption of electric vehicles	Case study	UK	
Hulse, Xie, and Galea (2018)	Public perception of safety	Survey	National (UK)	
Anania et al. (2018)	Effect of information on perception	'Mechanical turk' experiment		
Nieuwenhuijsen, de Almeida Correia, Milakis, van Arem, and van Daalen (2018)	Innovation system and diffusion	Simulation	National (The Netherlands)	
Buckley, Kaye, and Pradhan (2018a)	Trust and attitudes	Simulation and survey		
Zhang, Guhathakurta, and Khalil (2018)	Effect on ownership and mobility behaviour	Survey		Private AV
Buckley, Kaye, and Pradhan (2018b)	Trust and attitudes	Driving simulator		Level 3
Sanbonmatsu, Strayer, Yu, Biondi, and Cooper (2018)	Attitudes, beliefs and trust	'Mechanical turk' survey		Fully Automated
Dimitris Milakis, Kroesen, and van Wee (2018)	Effect on accessibility and location	Conceptual framework		Fully Automated
Salonen (2018)	Perception of safety and security	Case study	National (Finland)	Self driving public buses
Holstein, Dodig-Crnkovic, and Pelliccione (2018)	Policy recommendation	Discussion		
Dimitris Milakis, Van Arem, and Van Wee (2017)	Effect of AVs on 3 levels	Review		
D Milakis, Snelder, Arem, Wee, and de Almeida Correia (2017)	Effect on traffic, transport behaviour & planning	Scenario analysis	National (The Netherlands)	

Article	Theme	Method	Level	Type AV
Clements and Kockelman (2017)	Effect on economy	Review	National (USA)	Connected AV
Madigan, Louw, Wilbrink, Schieben, and Merat (2017)	Perceptions and acceptance	Survey	National (Greece)	
Crayton and Meier (2017)	Effect on health (environment, land use, safety...)	Define a research agenda		Fully Automated
Harper, Hendrickson, Mangones, and Samaras (2016)	Effect on mobility for seniors and people with medical conditions	Survey	National (USA)	
Wadud, MacKenzie, and Leiby (2016)	Effect on emissions, energy use	Review		all levels
Kyriakidis, Happee, and de Winter (2015)	Attitudes, acceptance, and willingness to buy	Survey	109 countries	Level 1-2-3-4
Fagnant and Kockelman (2015)	Adoption and penetration	Discussion		
Fagnant and Kockelman (2014)	Effect on distance travelled, environment and ownership	Agent based model		Shared AV

3.2 Results from the literature: Approaches and Methods

A majority of the gathered studies use a quantitative approach such as microsimulations, agent based modelling, survey analysis, system dynamic models. A few articles use both quantitative and qualitative methods (Fraedrich et al., 2018; Harrow et al., 2018), while some use a purely qualitative approach (Buckley et al., 2018b).

Most data used in the reviewed articles are a result of computer simulations or come from collections through surveys, interviews or workshops. Nevertheless, some articles use real field testing of AVs, such as Straub and Schaefer (2018) and Salonen (2018), or Waymo data also previously known as Google Self-Driving Car Project (Freedman et al., 2018). A few papers make use of driving simulators to test theoretical models (Buckley et al., 2018a, 2018b) or the influence of trust promoting/lowering information on take-over performance (Körber et al., 2018).

Finally, some articles are written in form of discussion papers (Fagnant & Kockelman, 2015; Holstein et al., 2018), while others review parts of the literature (Clements & Kockelman, 2017; Fraedrich et al., 2018; Dimitris Milakis et al., 2017; Wadud et al., 2016).

3.3 Topics

Based on the results of our search, we ended up with a series of different studies that can be grouped in four main literature categories:

- Individual perception, attitudes and acceptance of AVs
- Policy recommendations aiming at creating the basis (necessary conditions) for the adoption of AVs, and to correct and regulate its market
- Innovation diffusion. Adoption, penetration and diffusion process (development or transportion process)
- Effect of AVs on two levels: Direct effects on mobility and transport, and more indirect effects on various societal aspects.

We conceptualize the relationship between these four categories in figure 3.1. This conceptualization is very simple and abstracts away from the complex relationships that characterize research topics in reality. Nevertheless, it can help to understand how the different research areas presented below complement and feed each other like a system dynamic.

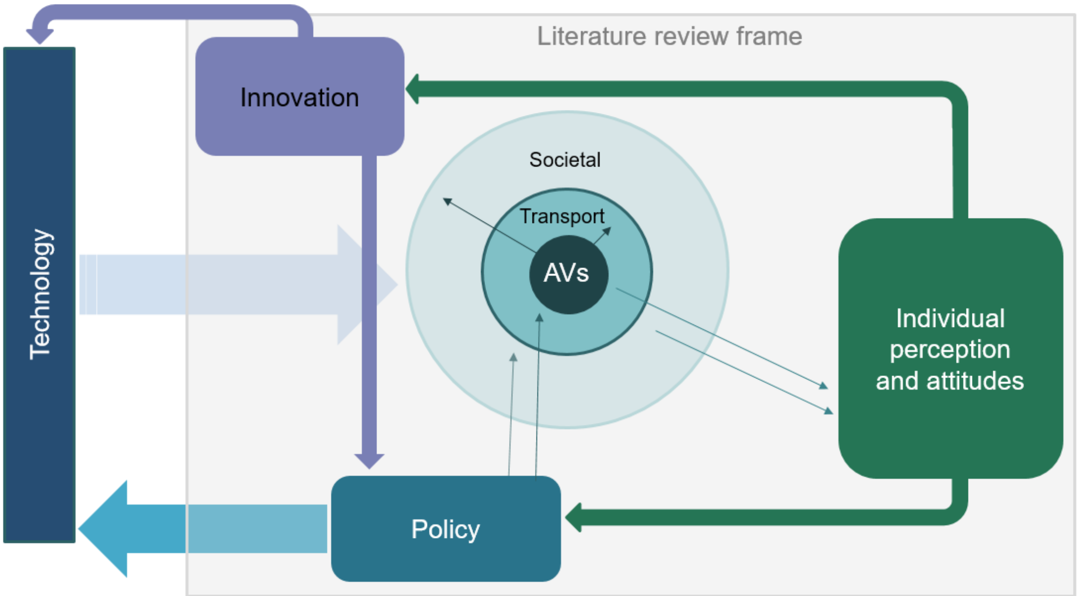


Figure 3.1: Conceptualization of the connections between different strands of literature.

Starting from the right side of figure 3.1, the first strand of literature we find is research on individual perception and attitudes toward AV, and how these impact acceptance and adoption. Understanding the user's perspective is fundamental to inform both policy makers and suppliers of the technology. Suppliers, such as manufacturers, can use the inputs from such research to develop vehicles with features that best fit expected demand.

Going clockwise, the second strand of literature is the one focusing on policy recommendation. Policy makers can use these results to create the right regulations and policies directed at manufacturers, transport and urban designers and users depending on the policy objectives to be achieved.

On top of figure 3.1 we find a third strand of research: Innovation (diffusion) theory, which focuses on identifying challenges and suggests path for adoption and penetration of the technology. Such literature feeds, among others, from the literature on individual perception, while its output is useful for suppliers and policy makers as it clarifies how best to tackle the diffusion problem.

Finally, the fourth strand of literature, that we find in the center of the picture, focuses on estimating or predicting the effect of AVs on both mobility and the society at large. We further divide this last part of the literature in more direct effects of AVs on transport and more indirect societal effects.

Once AVs will start entering the market, they will affect individual perception again. New research will then start feeding technology adjustments and new regulations and so on. In such a way these different strands of research feeds and complement each other in a dynamic way.

3.3.1 Individual perception and acceptance of AV

In this category we collected papers that focus on the impact or relevance of trust, information, beliefs and other attitudes, together with perceived safety, security and other possible concerns, on AV's acceptance and adoption.

These papers have research questions such as: What are the perception or attitudes toward AVs that will need to be considered in order to foster their acceptance and/or adoption? (Buckley et al., 2018a, 2018b; Harrow et al., 2018; Hulse et al., 2018; Kyriakidis et al., 2015; Madigan et al., 2017; Nielsen & Haustein, 2018; Salonen, 2018; Sanbonmatsu et al., 2018). In addition, some articles focus on the effect of trust promoting/lowering and positive/negative messages mimicking the effect of media coverage on perception, trust or acceptance (Anania et al., 2018; Körber et al., 2018). A few studies also look at identifying differences between countries (Kyriakidis et al., 2015), gender (Hulse et al., 2018; Salonen, 2018) and other relevant socio-economic characteristics (Nielsen & Haustein, 2018; Sanbonmatsu et al., 2018).

As a result, this research highlights a set of factors that are fundamental drivers of demand and will play a role for adoption and use of AVs. Mapping such results is fundamental to shape the right policy recommendations and can point in the direction to shape the legal and physical infrastructure needed to put AVs on the road.

3.3.2 Policy recommendations

In this category, we are placing papers whose main focus is to discuss or to give policy recommendations. However, many other articles found in this literature search also contain a dedicated section to policy recommendation.

The role for policy makers is almost ubiquitous. For example, policies and regulations will play an important role into AVs adoption. Starting from influencing purchase price through taxation or subsidies can have important impacts on adoption, but also on equity issues and accessibility (Shabanpour et al., 2018). Another important aspect that can foster adoption is removing or clarifying liability from the "driver" in the case of accidents. Shabanpour et al. (2018) shows that the increase in the adoption rate when the liability for crashes is removed from the driver, goes from 3.4% in a high price scenario (where purchase price is $60k) to 8% in a low price one ($40k).

Regulations are already playing a crucial role in the development of the technology itself. Holstein et al. (2018) take the engineering point of view to consider ethical and social challenges of AVs, discussing the ethical motivation behind choices of the hardware and software technology and the role of regulation when it comes to different social challenges.

Other papers focus on highlighting the most pressing issues for policy makers to consider during the process of AVs development and adoption. For instance, Straub and Schaefer (2018) focus especially on the interactions between users and non-users. The authors highlight the fact that policies will need to carefully consider non-user behavior in and around AVs to ensure smooth, safe integration. In addition, it is important to create dedicated external funding for research for instance private, federal or at the European level (Fagnant & Kockelman, 2015; Nieuwenhuijsen et al., 2018) and develop common guidelines for AV certification.

Finally, the last gathered recommendations is that it will be vital to invest in the "scenarios" that deliver the highest social benefit, for instance make use of connected vehicles (Puylaert et al., 2018) and to shift from privately owned/used vehicles to a shared-use system (Wadud et al., 2016)

3.3.3 Innovation

Challenges and directions for adoption, innovation diffusion and penetration of AVs are discussed in a few papers collected under this group. According to a 2015 report from the International Transport Forum, mainly two incremental paths toward full automation are envisioned. In the first one, automation will be gradually improved in conventional vehicles and human drivers will slowly allocate more and more control toward automated systems. This first path is the favorite of manufacturers since it involves a gradual business strategy shift for them too. The second path instead envisage deploying driverless vehicles in limited context and then gradually expanding the range and usage conditions (ITF, 2015a). Due to several safety and human factor problems, the second path has been favored recently and a few pilots with automated busses have taken place in small areas in Kongsberg and Stavanger, Norway.

Many factors play a role into facilitating versus hindering adoption of new technologies. When it comes to AVs, Shabanpour et al. (2018) show that people can be more sensitive to purchase prices and incentive policies, such as removing liability from the "driver" in case of accidents or dedication of lanes for AVs, compared to other factors such as fuel efficiency, safety, or environmental friendliness. The purchase price is mostly driven by R&D of very expensive technology of AV platforms. However the increase in purchase price may be partly offset by reductions in operating costs and insurance cost, estimated to be about 50% reduction for insurance and 13% for fuel costs (Fagnant & Kockelman, 2015). Other important factors are: The establishment of a common regulatory certification and standards, perception of safety, improvement in cyber security and regulations around data protection and privacy (Fagnant & Kockelman, 2015).

Freedman et al. (2018) focuses on understanding a reasonable time-to-adoption using cost-effectiveness simulation models. The authors show that it makes economic sense to start introducing AVs as taxis substitute and they try to estimate the point at which AVs become reasonably safe and affordable for widespread adoption. Mazur et al. (2018) discuss the role that AVs could have into bringing about electric vehicles.

Nieuwenhuijsen et al. (2018) focus on the complexity of the innovation diffusion process around AVs. The system is very uncertain and the market penetration varies greatly between different scenarios and policies adopted. The authors suggest that focusing on more knowledge transfer and creating an external fund (private or EU research) would be more effective for the diffusion process than subsidies. In fact, they would give only a short-term impulse to a higher market penetration, but would not create a higher market surplus for vehicle automation.

3.3.4 Impact of AVs

In this category, we have grouped all papers that estimate or predict effects of AVs on people’s mobility and transport behavior, ownership decisions, urban and transport planning, accessibility, economy, emissions and energy consumptions and public health. In this category we find mostly papers that are tailored to a specific city or state, or to a case study. Moreover, we find papers that focus on specific type of AVs, such as private AVs (PAV), connected AVs (CAV), shared AVs (SAV) or that estimates effects for vulnerable parts of the populations and study accessibility and equity problems. Finally, a few papers are very comprehensive looking at effects on the whole economy, while others are literature reviews.

In this study we separate implication of AVs in two categories. We define societal or indirect impacts of AVs, in contrast to the more direct and immediate effects on urban transport and mobility. An alternative conceptualization is the one found in Dimitris

Milakis et al. (2017) where the authors group the implications of AVs in three orders through a "ripple effect" diagram. The authors describe the sequential effects of AVs technology on: i) traffic (congestion and vehicle use), travel costs, and choices for public transport and vulnerable users; ii) as a consequence of such changes, vehicle ownership and sharing as well as location choices and land use, and transport infrastructure will be affected; iii) finally, AVs will impact energy consumption, air pollution, safety, social equity, economy, and public health.

Transport and mobility effects

Travel cost and road capacity

Automated and connected vehicles with high levels of automation and penetration, have a big potential for improving road capacity, reducing congestion and general travel costs. The higher the automation level, cooperation and penetration rate, the higher the positive impact on road capacity. For example, Level 3 or higher AVs and connected automated vehicles (CAVs) in a 100% penetration scenario will have the capability to optimize vehicle distribution across lanes and stabilize traffic flow by controlling time gaps, speed and lane changes, smoothly and automatically. Such enhanced free flow capacity will increase road capacity and reduce congestion. However, such positive benefits will likely be counterbalanced by increased travel demand. Whether the net effect will be positive or negative is still unclear and it depends on multiple factors such as modelling assumptions, type of simulation, penetration rate, level of automation, level of connectivity, deployment path, human factors and type of infrastructure (Dimitris Milakis et al., 2017). Another positive impact for congestion will come from the reduced total number of vehicles on the road. The International Transport ITF (2015b) finds that Ride-Sharing AVs combined with high capacity public transport could remove 9 out of 10 cars maintaining the same level of mobility in a mid-size European city.[11]

AVs will have a higher production costs then non-automated vehicles because of the high level of technology required. However, mass production and high adoption rates may bring production costs down. While high penetration rates can lead to substantial travel time savings because of reduced congestion and fewer accidents. Moreover, thanks to smoother driving styles, lower fuel consumption can be achieved. These findings are dependent on the level of automation, connectivity, deployment path, penetration rate and human factors (see Dimitris Milakis et al. (2017) and Fagnant and Kockelman (2015) for more details).

Demand and travel choice

As a consequence of reduced congestion and travel cost, travel demand is predicted to increase and may offset these positive results. Moreover, if empty cruising for relocation is not regulated the increase in Vehicle Kilometre Travelled (VKT) may increase substantially. Estimations for possible increase in VKT ranged between 3% and 27% when using a scenario analysis based on expert opinions for the Netherlands[12] (Milakis et al., 2017), between 2% and 9% when assumed 10 and 90% penetration rate of AVs (Fagnant & Kockelman, 2015), 17% after replacing all private conventional cars by AVs (PAVs) in a simulation for the city of Delft (de Almeida Correia & van Arem, 2016) and 10% when considering shared AVs (SAV) (Fagnant & Kockelman, 2014). When looking at early stages of automation (level 1-2-3) in the Netherlands, Puylaert et al. (2018) show that traffic,

[11] In peak hours this rate would be lower bringing substitution rates around 65%, in a scenario with high capacity public transport and ride-sharing AVs.

[12] These numbers are referred to the "AV in bloom" scenario which is the one with highest technological development and most supporting policies.

congestion and VKT are likely to increase especially in motorways and if automated vehicles do not communicate with each other.[13] However the degree of uncertainty is very large.

Reduced congestion and costs are not the only motives behind the increase of VKT. For instance, changes in destination choices are likely to occur given the reduced cost of travelling. Hence, people may choose further-away destinations to live, work or shop, and subsequently increase the amount of travel. Harper et al. (2016) estimate an increase in VKT of about 10-14% when non-driving users will start using AVs (see more about this in the *Easier Access* section below.

To summarize, important factors that will affect travel demand identified in the literature are: shift in mode choice from public transport, and active transport to car due to lower generalized travel costs and reduced congestion; increase in the number and length of trips, especially from people with travel restrictions (elderly or disabled) and because of relocation trips for shared vehicles between users (Milakis et al., 2017).[14]

Ownership

Assuming that the introduction of AVs implies an increase in shared mobility, results from the gathered literature point toward a reduction of vehicle ownership. The International Transport ITF (2015b) showed that Shared Automated Vehicles (SAV) could deliver today's mobility with only 10-16% of the current number of vehicles (depending on rideshared or not), in a scenario with 100% penetration rate and high capacity public transport.[15] In a scenario where 50% of the vehicles were used for private use, the total number of vehicles are predicted to be around 80% of the current fleet.[16] Such results change quite drastically if we do not assume that a high capacity public transport is in place. Interestingly, in a transportation scenario without public transport and 50% SAV penetration rate, the number of vehicles required to cover the same demand will be higher than today, implying the crucial role of public transport.

Fagnant and Kockelman (2014) suggest that, in a fully automated reality, each SAV could replace between 9 and 11 conventional cars depending on (peak or off-peak) demand. SAVs may also bring important changes to urban mobility, as travelling by car could be completely transformed into a subscription/pay-on-demand service hence substituting public transport or active modes, at least in situations where it is economically viable. On top of such impacts on short commutes AVs may have important impact on long trips. For example, it may become more convenient or cheaper to sleep or work in a car for a 6-10 hour drive than to take the plane (Clements & Kockelman, 2017).

Emerging from several surveys, not everyone is willing to give up private car ownership. Zhang et al. (2018) studies the impact that Private Automated Vehicles (PAVs) will have on ownership decisions. Their results show that about 18% of the households have the potential to reduce the number of vehicles owned maintaining current travel schedule

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[13]Such vehicles are generally called connected or cooperative because they will have ability to communicate between vehicle (V2V) and with the infrastructure (V2I).

[14] Nevertheless, the VKT increases expected to be lower for dynamic ride-sharing systems.

[15] The range depend on whether it is considered ride-sharing or car-sharing system in a simulation made for the city of Lisbon based on a 24h weekday. "Ride sharing" are trips where the same self-driving car is shared simultaneously by several passengers, while "car sharing" is a sequential use of one vehicle by single passengers.

[16] These numbers are the results of simulations made for the city of Lisbon.

constant. However, this estimate could increase with re-scheduling daily trips, especially for suburban households with frequent and short trip rates.

Transport infrastructure

Many scholars have studied the possible impact that AVs will have on our transport and city infrastructure, for example changes in the road space and infrastructures (right-of-ways, lanes and signage), effects on the location, amount of parking, and changes in land-use and residential relocation (Fraedrich et al., 2018). Fully automated and connected vehicles might not need a series of infrastructures dedicated to safety, such as extra-wide lanes, wide shoulders, guardrails, and stop signs, while increased capacity might reduce requirements for road expansion. Urban planning will also have an important impact for penetration and development of AVs (D Milakis et al., 2017). The potential effect on road infrastructure are thus contrasting. On the one hand, increased road capacity would reduce needs for more roads. On the other hand, induced travel demand may reduce or even offset such benefits. In the last case (more than offset), additional road capacity may be required to accommodate new travel demand (Dimitris Milakis et al., 2017).

In urban areas, parking needs will greatly decrease with the penetration of SAVs and the decline of privately owned vehicles. Moreover, when AVs will be able to fully drive themselves to a parking spot or to pick up a person, it is likely that parking areas will be moved outside the most densely populated areas, unless empty cruising is to be regulated or banned (Zhang, Guhathakurta, Fang, & Zhang, 2015). Less parking space means additional urban area available for residential or commercial development, green public spaces, but also the possibility to expand bus lanes or cycle lanes.

Societal impacts

Easier access

As Dimitris Milakis et al. (2018) point out, accessibility can be thought as made of four components: transport, individual, temporal and land use. AVs will affect the transport component by, for instance, reducing travel effort, costs of driving while increasing time savings and VKT. AVs will allow individuals, who cannot drive for different reasons, to reach further away places and perform new activities. Fully AVs may affect the temporal component as the vehicles themselves will be able to accomplish certain activities that are today impossible because of closing times and working hours. Finally, the land use component could be impacted by relocation of residence, businesses and services further away from urban areas compensating for lower travel costs. AVs may allow people to relocate living, working or leisure activities further away from urban areas.

Assuming that taking an AV becomes easier, cheaper and more enjoyable, Childress, Nichols, Charlton, and Coe (2015) shows that the perceived accessibility would be enhanced especially for households in remote rural areas causing an increase of 20% in VKT. At the same time expert opinions gathered by Dimitris Milakis et al. (2018) suggest also an opposite trend of densification of existing city centers taking advantage of self-parking capability of AVs. Accessibility benefits are deemed uncertain and experts expect unequal distribution between social groups (Milakis et al 2018).

Safety and security

Most road accidents can be attributed to human errors, such as distraction, aggressive driving, mistakes in judgement, or impaired driving. Hence, if AVs can reduce or even eliminate such errors, the safety improvements can be great, such as reducing crashes by 90%. However, this is an uncertain and untested hypothesis that need more research (ITF, 2018). At the moment, safety test for AVs are performed on how well they can replicate crash-free driving without human control. Even though early results are promising, new types of crashes can become common (ITF, 2015a). For instance, when the automated car has to hand back control to the driver in level 3 automation, the driver may not be fast enough to take over. High safety benefits may then not be realized until fully automated vehicles penetration rate is high enough. This creates a need for regulators to ensure that safety performance will not be part of a competitive strategy, but that safety performance is uniform across automated systems and suppliers.

In addition to road safety, also cyber security plays a central role for traffic safety, as software can become vulnerable and the entire system of CAVs is at risk of cyberattacks. Hence, it is critical to ensure that connectivity does not compromise cybersecurity and safety. Similarly to airplanes and metro system, some core safety-critical components need to be isolated both on hardware and software level (ITF, 2018).

Environmental effects

Most of the studies looking at the impact of AVs on the emissions and energy use point toward a reduction as a result of less congestion and less idling, higher fuel efficiency due to more eco-driving styles, lighter and less powerful vehicles and reduced production (assumed that the number of AVs will be lower than today's fleet). Nevertheless, the majority of studies also predict an increase in VKT, because of lower associated costs and higher demand, but also due to empty cruising for relocation or self-parking. In addition, possibly larger vehicles will be produced to accommodate sleeping or other in-vehicle activities.

Even when only conventional fuel vehicles are taken into account[17], Fagnant and Kockelman (2014) simulations show substantial environmental benefits of SAVs in terms of a wide range of pollutants thanks to significantly less times a vehicle starts. The authors assume similar production rate for new vehicles: on the one hand there will be fewer vehicles produced, on the other hand SAVs would need to be substituted at a faster rate because of their increased use. Hence, their environmental impact could be counterbalanced by faster fleet updates in terms of engine technology, bringing potentially greener vehicles on the streets.

When focusing on battery electric SAVs, Greenblatt and Saxena (2015) estimated a reduction of GHG emissions per mile by 87–94% compared to the emissions of internal combustion conventional vehicles. The authors also argued that thanks to a significant increase in travel demand for autonomous taxis, battery electric vehicle technology will become more cost-efficient compared to conventional cars or hybrid-electric vehicles. In addition, Wadud et al. (2016) points out that one of the user-perceived barriers to the further adoption of alternative fueled vehicles lies in the high cost and inconvenience (limited availability and long recharge times) of alternative fueling infrastructure. AVs will be able to solve this problem as they could drive themselves to refuel or recharge.

Wadud et al. (2016) also find that many energy intensity savings could be reached at relatively low level of automation as they are associated more with vehicle connectivity than automation. In contrast, the risks of increased emissions and energy consumption is associated with higher level of automation. In lights of the gathered results, the total net effect of AVs on energy consumption and emissions remains uncertain (Wadud et al., 2016) and (Dimitris Milakis et al., 2017).

[17]The authors assume same trip pattern/demand schedule is maintained and that all vehicles are replaced with conventionally fueled (shared and automated) Sedans. Hence their results do not include potential improvements brought about from electric, hybrid, or other alternative fuels cars.

Social equity

AVs could have a positive impact for social equity, as they could offer mobility to social groups that are currently unable to drive, especially if the prices are low enough possibly due to regulations. Most studies on the effect of AVs on travel demand indicate that VKT is likely to increase for multiple reasons, but that a large part of this increase will come from new user groups, such as seniors, young people, and people with travel restrictive conditions. Wadud et al. (2016) estimate an increase of VKT of about 10% when assuming that people older than 62 years old will travel as much as those at 62. It is important to notice that the population of elderly people is forecasted to grow in the near future. Harper et al. (2016) consider three wedges that could make VKT increase with the introduction of AVs. First they assume that non-drivers will travel as much as drivers, for all age groups and gender. In the second wedge, they assume that people older than 65 will travel as much as younger people, and finally that adults between 19–64 with medical conditions will travel as much as working adults without medical conditions within each gender, and that elderly will travel as much as the younger ones. Combining these demand wedges, the authors estimate an upper bound of 14% increase in VKT for the US population. In more details, Harper et al. (2016) show that uptake of driving by people with medical condition make up for 2.6% of the VKT increase, while female are the biggest drivers of such increase as they are now the gender group with the sharpest decline in driving after a certain age (assuming that this is a cohort and not an age effect).

In contrast with this literature, other authors point out that such benefits may not be realized or at least not in the short term. For instance, the first types of AVs are probably going to be expensive, limiting these benefits to the richest.

Public health

There are few studies on this topic and there seems to be a lack of any systematic study on the effect of AVs on public health. Nevertheless, compared to traditional vehicles, the potential positive impacts of AVs on public health are large. Especially because AVs are predicted to greatly reduce traffic incidents and with them fatalities and injuries.

All direct effects described in the previous section have indirect implications on the public health dimension. On top of accident rate, reduced emissions, both for fossil fuel and electric vehicles are derived, may play an important role for public health. Improved mobility and accessibility for elderly and other vulnerable user groups is estimated. Furthermore, freed up space derived by reduction of urban parking, may be transformed into additional bike or pedestrian infrastructures (Dimitris Milakis et al., 2017). In the presence of SAVs and the consequent reduction in vehicle ownership, additional income may also benefit household life style and health (Rojas-Rueda, Nieuwenhuijsen, & Khreis, 2017).

On the negative side, the presence of private AVs may lead to an increased travel demand, congestion, trip length, amount of roadway infrastructure encouraging dependency on private vehicles and community sprawl. This over-stimulation of car use has the potential to greatly reduce the use of more active means of transport such as walking and cycling.

Nevertheless, most of the reported results are highly uncertain and they strongly depend on the technology used and on the type of regulations implemented.

Industries and Employment

A few articles have considered the effect of AVs on different industries and the related job market. According to the very comprehensive review from Clements and Kockelman (2017), most industries will be affected. The automotive industry will have the most direct effects: on the one hand private ownership may fall dramatically with the introduction of SAVs, but on the other hand heavier use of SAVs will mean faster retirement or scrappage. Software technology firms as well as content providers and social network will have a lot to gain from AVs adoption in terms of vehicle-production process and in-vehicle entertainment. Freight transport may also face a huge increase in productivity thanks to the reduced costs of driverless trucks, reduced congestion and reduced crashes. As a consequence of reduced accidents, industries such as car repair, medical, legal, and insurances may face losses as high as 60% depending on its adaptation.

3.4 Research gaps

From the reviewed literature, we find that most research gaps comes from the fact that we do not have (enough) real data, since AVs are not yet on the roads. Hence, most of the studies are based on hypothetical surveys or at best carried out using driving simulators, with some exceptions such as Salonen (2018). For instance, research on the potential effects of AV uptake on the value of time are still inconclusive, especially when incorporating motion sickness and apparent safety into the definition of comfort (Dimitris Milakis et al., 2017). Hence, whether people will actually use travel time for more productive activities is still an open question. Moreover, Anania et al. (2018) shows that information and media coverage have a large impact on people's willingness to ride, and therefore public opinion may have a strong effect on adoption of AVs.

Even if AVs were technologically ready, an important issue discussed through the papers is the lack of standards and regulations that will legally allow such vehicles to drive in the streets. Fagnant and Kockelman (2015) highlight the need for a more comprehensive market penetration evaluation. For instance, one that would be able to attach dates and percentages shares to different levels of AV-adoption scenarios and then would be able to inform policy makers on needed regulations and infrastructure investments.

4 Scenario analysis – steps and criteria

4.1 The scenario methodology – definition and development

Scenarios are used in policy, business and research as a way of thinking systematically and creatively on plausible alternative futures. Most simply, a 'scenario' is a description of a possible future situation, and a scenario-analysis is seen as a *"powerful tool for integrating knowledge*" and *"scanning the future in an organized way*" (Swart, Raskin, & Robinson, 2004). A common and widespread definition (e.g. from Wikipedia) is that *"…scenario analysis is a process of analyzing possible future events by considering alternative possible outcomes*". [18]

Scenario analysis – or scenario planning (these terms are often used interchangeably) – is increasingly used as a tool or methodology in policy research and policymaking. Scenario analysis was not however, initially elaborated within the social sciences. Future thinking and studies were at first, peculiarly enough, developed in fields for large strategic operations, such as in the military and in the oil business. In particular, scenario planning evolved in military strategies in and after Second World War. Thus, scenario analysis was for long of no particular interest in the social sciences. One reason claims to be that the social sciences for long prioritised more academic endeavours (Tyfield, 2018). Scenario planning was for long seen only as a practical tool in thinking about the future, of little theoretical interest (Derbyshire, 2017). However, at least since the 1980s, scenario analysis has been highly popular also in societal future studies, across different scales and types of problems and challenges (Alcamo 2008). In Norway, an early well-known example is the cross-institutional public-private research project, "Scenarier 2000" (Hompland, 1987). Since then there have been social scientific journals for future research in general and scenario analysis in particular.

The aim of scenario analysis is not to present an exact or a full description of the future, but rather "...*to highlight central elements of a possible future and to draw attention to the key factors that will drive future developments*" (Kosow & Gassner, 2008). Most often several alternative (frequently three to five) scenarios are presented, including important distinguishing elements in the path of development leading to the situation. MacKay & Stoyanova (2017) point to three primary purposes for scenario planning. They are seen as challenging conventional thinking by

i) Changing mind-sets and reframe perceptions within organisations;
ii) Improving decision-making within strategy development processes; and
iii) Enhancing understandings of connections, causal processes and logical sequences of events that may shape the future. (ibid.).

Scenario analyses are thus useful for highlighting, prolonging and extrapolating current trends while taking different uncertainties into consideration. They are said to use

[18] The term 'scenario' is Italian and etymologically derived from the stage, 'la scena', used for the outline of the plot, the very story line, in the Commedia dell' Arte tradition from the Italian renaissance.

plausibility rather than probability, and to focus on potential extreme outcomes in order to shape and highlight distinct different, alternative images of the future (Derbyshire, 2017).

4.2 Scenario development methods: Steps and tools

Scenario building usually follows a stepwise procedure, from problem definition to the evaluation of alternative strategies where the main steps often involves the following:[19]

1. **Problem definition** and analysis
2. Identifying the **drivers**, distinguish main certainties and uncertainties
3. Selecting the **scenario logics**, the main scenario dimensions or criteria
4. Developing the **scenarios** and assessing the **impacts**
5. Evaluating **alternative strategies** and actions, using the scenarios in further planning.

Underlying a stepwise scenario development syntax is a DPSIR model (developed by OECD in the early 1990s) discerning the Drivers from the Pressure, the State, the Impact and the (policy) Responses. For the further identification of different drivers, impacts and policy responses a PESTEL-scheme is very useful, specifying and discerning the key Political, Economic, Social, Technological, Ecological, and Legislative issues – drivers and impacts – to be at stake. Both the DPSIR and the PESTEL-scheme provide a systematic analysis, or at least as a heuristic check list, when the most relevant scenarios are to be developed. Also SWOT-analysis – identifying the main Strength, Weaknesses, Opportunities or Threats - of a specific societal phenomenon is a useful analytical tool for the scenario development.

A much used tool for scenario presentations is the scenario funnel or the 'the futures cone'[20] spanning a space where the '*possible*' future is larger than the '*plausible*' which in turn is larger than the '*probable*' - and that what might be the '*preferable*' future. The development of various scenarios will most reasonably be found and presented within the plausibility range.

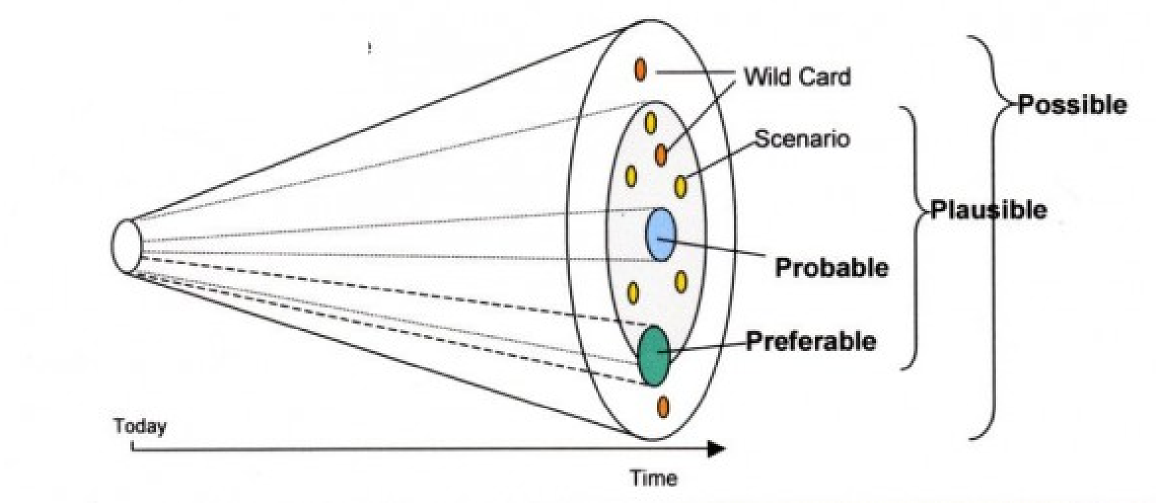

Figure 4.1: The Cone of Plausibility, ccoined by Chareles Taylor (1988)

[19] Millennium Ecosystem Assessment 2003: https://www.millenniumassessment.org/en/Scenarios.html

[20] https://prescient2050.com/the-cone-of-plausibility-can-assist-your-strategic-planning-process/

A scenario funnel might also be presented by three basis scenarios: A *trend*, the BAU (business as usual) scenario, describing the continuation of the current state into the future. Then the funnes is spanned by the two extremes: a *best case* scenario, and a *worst* (Kaulfuss, 2011).

Scenario development might be built on quantitative modelling or predictions or a qualitative approach - or a method mix among the two. Due to the complexity and ambiguities when it comes to the scenario development for the societal consequences of automated vehicles, quantitative modelling along a few, and in this case highly uncertain, variables, would hardly be applicable.

4.3 Scenario analyses for future transport

The transport sector is undergoing and preparing for rapid changes. Scenario analyses have thus proven to be a fruitful approach to understand what is going on. Most forecasts for future transport have references to contemporary **mega-trends** as a point of departure. Three recent Scandinavian reports on the future mobility stress mega- or macro-trends like: *urbanisation; globalisation; digitalisation; a growing and ageing population; climate change, resource scarcity and increased environmental awareness;, economic growth and increased work mobility; improved transport system* (FRI 2018; Kristensen 2018; Aarhaug et al 2018). Some of these trends are more influential than others to the development pace of AVs and their transport and societal consequences. These are, in turn, dependent on general development trends in traffic volumes and the modal split.

As a preparation for the selection of the main scenario criteria, a short review of some of more renowned scenario analyses for the future transport might be fruitful.

"After the Car" – scenarios (2009)

A decade ago a sociological study from the 'mobilities research group' at the Lancaster University presented the renowned scenario analysis (and best seller): "*After the car*" (Dennis & Urry, 2009). They present the contemporary transport system characterised by four dominating development trends: the *climate crisis*; the soon-to-come '*peak oil*'; the *digitalisation* of services; and the *population growth in the cities*. The book ends with presenting three 'post-car' scenarios for a low-carbon mobility pattern — the scenarios was also used in the British public policy foresight programme (Nenseth, 2011):

The three 'post-car' scenarios:

1. **Local sustainability,** a post-oil localism, due to e.g. increased geo-social conflicts, in which all travels (particularly car use and air travels) is reduced and mostly local, with people living in compact, walkable urban neighbourhoods
2. **Regional war-lordism**, based on the fight for post-peak oil and a breakdown in energy and ICT infrastructure and a backlash to a sort of feudal resource management, more or less gated communities and regions
3. **Digital control networks** filled with smart transport solutions, a ***hypermobility,*** based on monitoring, surveillance, and thus a huge challenge to human and democratic rights (or GDPR[21] as we would say today).

All in all the foresighted *low-carbon mobility scenarios* are in different ways three rather worrisome scenarios, even if it is based on the same mega-trends as mostly used today. The

[21] 'General Directive Protection Regulation'

automatization of transport is dealt with in the *digital control* scenario, however, without dealing directly with the coming of automated vehicles.

In his latest book *"What is the Future?"* (2016), John Urry suggested that social futures thinking should consider and discern between '*the possible, the probable and the preferable'* – obviously a heuristic guidance for all scenario thinking. Or as it is put elsewhere: "*Futurists seek to know: What can or could be (the possible), what is likely to be (the probable), and what ought to be (the preferable)"* (Bell, 2003).

Three transport revolutions: Sharing, electrification and automation (2017)

Sharing, electrification and automation have been coined as three ongoing and, to a certain extent, converging revolutions in transport, for example by the National Centre for Sustainable Transport, University of California, Davis. From this '3 revolution' concept as a point of departure, scenarios have been put forward, taken into account various combinations of the "three revolutions", e.g. from the Institute for Transportation & Development Policies, University of California, Davis[22].

A business-as-usual, the **BAU-scenario** with the same (small) rates of sharing, electrification and automation as of today

- A **2R-scenario**, where **electrification and automation** are combined, providing numerous single-occupancy electric automated vehicles
- A **3R-scenario**, where the electric, automated vehicles are shared, where there is a dominant ridesharing, an on-demand mobility service and increased public transport performance.

In a recent book, edited by the founding director of the Institute of Transportation Studies at the University of California, Davis (ITS-Davis), Dan Sperling and colleagues state that we for the first time in half a century is experiencing a real transformative mobility innovation, particularly targeting passenger transport: The convergence of new shared mobility services with automated and electric vehicles promises to significantly reshape our lives and communities for the better—or for the worse. Thus the book puts forward: *"The dream scenario could bring huge public and private benefits, including more transportation choices, greater affordability and accessibility, and healthier, more liveable cities, along with reduced greenhouse gas emissions. The nightmare scenario could bring more urban sprawl, energy use, greenhouse gas emissions, and unhealthy cities and individuals".* The authors state further that a new transport paradigm toward the public interest might be based on the innovative ideas and partnerships related to the three transport revolutions, and the dream scenario of *social equity, environmental sustainability, traffic safety* and *urban liveability* might come true (Sperling, 2018).

4.4 Review of previous scenario analyses of automated vehicles

The literature on the societal impact of automated vehicles in general and scenario analysis of automated vehicles in particular, is rapidly growing. Due to the lack of empirical results yet for the fully automated vehicles, research on the effects is to a large part based on *simulations* (e.g. ITF 2015b).

As for the use of the analytical tool of a 'the scenario funnel', many scenario analyses for the investigation of the consequences of automated driving simply discern between some

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[22] https://www.itdp.org/publication/3rs-in-urban-transport/

'best' or 'worst' scenarios. Some point out that a certain *hype* for automated vehicles the last decade, seems to be diminishing and that the "peak of inflated expectations" now has been followed by "a trough of disillusionment" (Roberts 2018).

The optimistic 'best' scenarios stress for example:

- The economic and time savings without a driver
- The safety issue when the faults and the distractions of the human driver are eliminated
- The improved traffic flow due to platooning and tight distances between the vehicles
- The increased mobility for underserved populations or underserved geographical areas.

As it is simply stated by EU in the recent factsheet for "Europe on the Move" (2018)[23]: *"Cooperative, automated and connected driving could shape mobility in the years to come, the way motor vehicles did in the last century. It will make mobility safer, cleaner, more accessible and more efficient".*

Whereas the 'worst' scenarios are also manifold and accompanied by titles like "the nightmare scenario for self-driving cars"[24] or "Self-driving cars: The Hell Scenario"[25]. They tend to emphasise the overuse of the vehicles due to the tremendously higher convenience and the easy access for any trip and errand and the consequential clogging of the streets and cities[20], or a "robot-powered grid-lock" (avfutures.org). Also emphasised are the negative distributional effects and social inequalities when it comes to who will have (the best) access to the automated vehicles. Easily thinkable, are also some 'vicious circles' of increased automobile dependency with increased vehicle kilometres travelled (VKT) resulting in urban sprawl and regional enhancement, in turn leading to a feedback effect of even more VKTs.

In addition, there are important worries about general data protection considerations with the increased automation and connectivity of transport. To many, hacking is seen as the biggest threat with the future AVs. With the further AV development the considerations of cybersecurity and countermeasures against hacking will inevitably be an integral part (see e.g. (Bowles, 2018)[26].

Not so frequently stressed, some have put forward the threats of the overload of increased advertising with the utilisation of the free time by spared attention from drivers when using the self-driving vehicles, as a parallel in how most of the web platforms and social media networks we use today are financed. Much of the advertising is inevitable while net surfing. Social media platforms are overwhelmingly based on commercials hunting for catching the attention of the users. To put it shortly: *"transportation is going to become more like an app, and we know how most apps are funded"* [19].

In the growing literature on societal impacts of automated vehicles scenario analyses have proven to be a much utilised and useful research design (cf. chapter 3). Future problems and potentials and probabilities with the development of automated transport are presented in a systematic manner.

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[23] https://ec.europa.eu/transport/modes/road/news/2018-05-17-europe-on-the-move-3_en

[24] https://www.vox.com/energy-and-environment/2018/3/27/17163264/autonomous-car-self-driving-advertising-business

[25] https://www.euractiv.com/section/future-of-mobility/opinion/we-have-five-years-to-choose-between-transport-heaven-or-hell/

[26] https://www.cpomagazine.com/cyber-security/autonomous-vehicles-and-the-threat-of-hacking/

For many scenario analyses it is difficult to reveal the underlying logic the scenarios are based on. Nice narratives for the future development with automated vehicles might be presented, some key factors are highlighted, however, with no explicit or specific systematic in the selection of the key variables and main scenario criteria.

More systematic are the many scenario presentations based on *scenario crosses*, two of some main selected key factors, where the outcomes are spanned by two dimensions, making up four quadrants. As we will see, many of the key dimensions, the scenario criteria, are the same or quite similar in different scenario analyses. This is of course a strong indication that these in fact also are the most important dimensions to take into considerations. These are, for instance:

- The technological development/the level of automation
- The organisational or operational principle of the AV fleet: Individually owned AVs or a collectively or shared AV fleet
- The use of the AVs – private use (personally or own household) or shared use, i.e. shared rides.

The scenario crosses provide a systematic presentation of various outcomes, however, with only two dimensions, or criteria, substantial input might be lacking. Different divergent development trends may be merged without necessarily occurring simultaneously.

In this short review we present the most relevant scenario analyses from 2015 onward.

2015: Carsharing or ridesharing, PT availability and AV penetration rate

OECD's International Transport Forum (ITF) launched a report in 2015 called *"Urban Mobility System Upgrade. How shared self-driving cars could change city traffic",* examining a large-scale uptake of a shared and self-driving fleet of vehicles, based on simulations, from the city of Lisbon. (ITF 2015b).

The study was based on modelling the future mobility pattern from Lisbon, a city of more than 500 000 inhabitants, with a relatively low car ownership per capita, 217/1000, a scarcity of parking space in the (historic) city centre and a well-established underground metro system. The *private car* had a share of 36 percent in the city of Lisbon and 60 percent in the surrounding metropolitan area; while the shares for *public transport* was 48 percent in the city and 32 percent outside. The modelling aimed at presenting a hypothetical shared mobility system for Lisbon based on the premises that the model should deliver the same mobility, the same trips as of today, and that all the car and bus trips were replaced by shared mobility, either by so-called self-driving *single-passenger AutoVots* or by self-driving *rideshared TaxiBots*, shared with other passengers in the same trip.

The report suggests **scenarios** based on three dimensions:

- The mode of shared or self-driving operation, either **carsharing** or **ridesharing**
- The availability of a high-capacity **public transport**
- The **penetration rate** of the shared and self-driving fleet – 100 or 50 %.

Key findings from the study are:

- Nearly the same mobility can be delivered with 10 percent of the cars
- The overall volume of car travel will likely increase
- Impacts on congestion depend on time of the day (rush hour or not) and the combination with a high-capacity public transport system
- Reduced parking needs will free up significant public and private space
- Ridesharing with so-called 'TaxiBots' replaces more vehicles than carsharing with single-occupancy so-called 'AutoVots'.

The size of the self-driving fleet needed is influenced by the availability of public transport and obviously, but importantly: "*Managing the transportation will be challenging"* (ITF, 2015b)

The study also puts forward the following **policy recommendations** (italicised here):

- Self-driving vehicles could *change public transport* as we currently know it
- The potential impact of self-driving shared fleets on urban mobility is significant, it will be *shaped by policy choices* and *user options*
- *Active management* is needed to lock in the benefits of freed space
- Improvements in *road safety* are almost certain, *environmental benefits* depend on vehicle technology
- *New vehicle types* and *business models* are required
- *Public transport, taxi operations* and *urban transport governance* will have to adapt
- *Mixing fleets* of shared self-driving vehicles and privately-owned cars will not deliver the same benefits as a full (rideshared) TaxiBots or full (private rides) AutoVotsfleet – but will still remain attractive for the users/passengers.

2016: Scenario cross based on Travels and Energy/Carbon Impacts

In a study on potential mechanisms through which vehicle automation may affect transportation energy use and emissions, scenarios are developed spanned by the extent of energy use versus the driven distances (VKT) (Wadud et al., 2016).

The impacts are examined based on the degree to which

- Energy-saving is implemented
- The automation actually leads to system-wide changes, e.g. shared vehicles
- Reduced driver burden lead private travellers to more VKT
- There are policy responses at the federal, state, or local levels

Four scenarios are presented, spanned by the dimensions of energy savings and VKT:

- The optimistic "**Have our cake and eat it too**" providing energy benefits and only a small increase in travel demand
- The **"Stuck in the middle"** with energy intensity benefits, but more travel demand
- "**Strong responses**" when transport energy is unchanged with maximal benefits and burden, but cancelling each other out
- The «**Dystopian nightmare**» - with both higher energy use and increased travel demands.

Main conclusions from this study are e.g. that:

- Vehicle automation offers the potential for substantial reductions in energy consumption and emissions
- These reductions are not assured, since they generally are not direct
- Some of these reductions may be enabled by greater connectivity in vehicles, even without full automation
- Total automobile travel and fuel consumption could increase significantly, if automation sharply reduces the cost of drivers' time and sufficient energy intensity benefits are not realised.

2017: Scenario Cross by Automation versus Policies

In a scenario analysis for the plausible future paths of AVs in the Netherlands, Milakis et al (2017) operate with two dimensions discerning between a high and low technological development on the one axis and a restrictive versus a supportive AV policies on the other.

The four quadrants spanned by these dimensions are called and have the main characteristics as follows (see figure 4.2 below):

AV – in bloom: High automation level and supportive policies
Fully automated and cooperative vehicles in 2025; laws allowing AV traffic; public investment in AV research and infrastructure; positive consumer response
AV – in standby: High automation level, but restrictive policies
Fully automated and cooperative vehicles in 2030; inflexible legislation for AVs; restrained passive consumer response
AV - in demand: Low automation level, but supportive policies
Fully automated and cooperative vehicles in 2040; progressive legislation and policies; low demand for AV
AV - in doubt: Low automation level and restricted policies
Fully automated vehicles in 2045; limited legislation; negative consumer response.

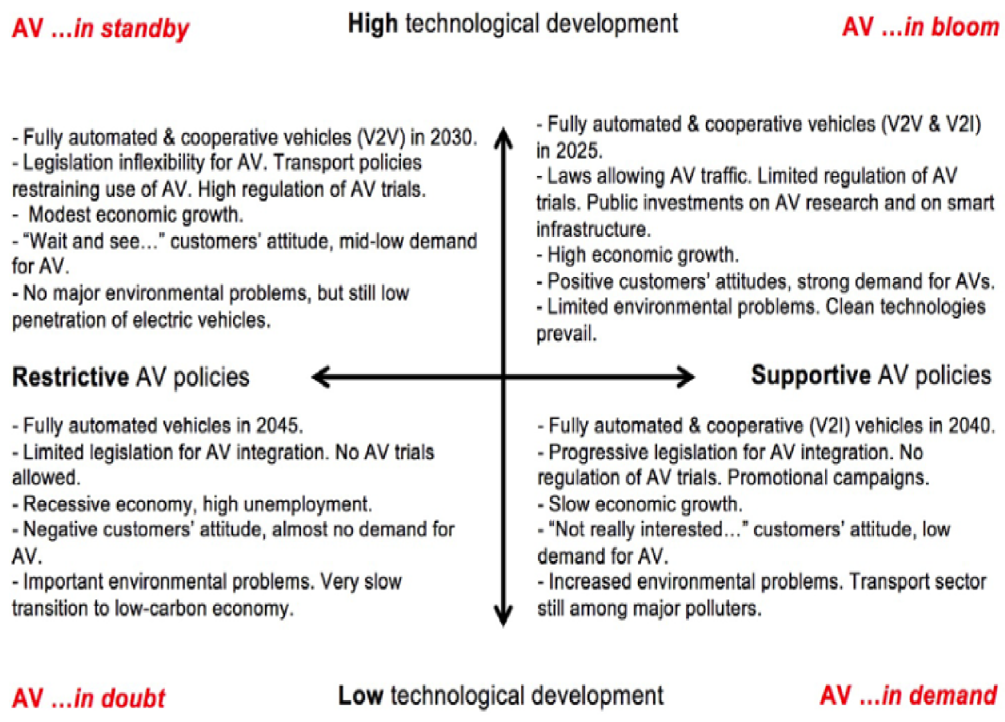

Figure 4.2: Scenario cross by Automation development and AV Policies, Milakis et al 2017.

The scenario analysis here provides lots of interesting insights and the selected dimensions seem crucial for the further development, with findings and observations also very applicable in the Norwegian context. However, it is not clear why some of the related characteristics necessarily follow the particular development traits; for instance, the expectations on economic growth or recession and expectations of clean or electric vehicles. In the Norwegian case, a further pervasive implementation of electric vehicles is probable quite independent of the AV technology or policy (D. Milakis, Snelder, Van Arem, Van Wee, & De Almeida Correia, 2017).

2017: Scenario cross by extent of Public transport and Shared vehicles

On behalf of the public transport company in the Oslo region, Ruter, a consultant collaboration has explored "how to utilise the potential of self-driving vehicles", based on "*scenario analyses of self-driving vehicles impacts on mobility in Oslo and Akershus*" (Jordbakke, Salte, & Mehammer, 2017).

Four scenarios are developed spanned by the two dimensions: the extent of scheduled public transport (train, metro, tram/light rail, bus on the one axis and the extent of shared mobility (shared rides or shared cars) versus individually private car use on the other.

- High supply of scheduled public transport and high amount of sharing
- High amount of sharing, less supply of public transport
- Little extent of sharing, public transport, i.e. mostly private car/vehicle use
- Good supply of public transport, little extent of sharing.

Each of the four scenarios are presented with expected **impacts**, such as: effects on the **transport system** (specified as the vehicle fleet, car traffic (congestion), public expenses); consequences for the **transport users/the passengers** (user utility, public health and distributional effects); and consequences for **land use**, road infrastructure, parking and urban development). See table 4.1. (Jordbakke et al., 2017).

Table 4.1: Impacts from the scenarios spanned by the extent of sharing and extent of public transport. (+ means positive, 0 means neutral, - means negative impacts).

		High level of Sharing		Low level of Sharing	
Impacts		**Shared & PT**	**Shared**	**Private AVs**	**Public transport**
passengers	Passenger utility	+	+	-	0
	Public health	0	-	-	0
	Distributional effect	+	+	-	-
transport system	Vehicle fleet	+	+	-	0
	Congestion	+	0	-	0
	Delays	+	+	-	0
	Public costs	-	+	+	-
land use	Road infrastructure	+	0	-	+
	Parking	+	+	-	0
	Urban development	+	-	-	+

2018: Individual/Collective Mobility versus Public/Private Mobility

The autumn 2018 the Danish engineer association [Foreningen af Rådgivende Ingeniører] (FRI, 2018) launched a report with a scenario analysis on the future mobility based on a scenario cross with one dimension for behaviour and lifestyle spanning from *collective mobility* solutions on the one end to *individual mobility* solutions on the other; and a scale for the financing actors from *privately financed* transport solutions versus a *publicly financed* solutions on the other axis.

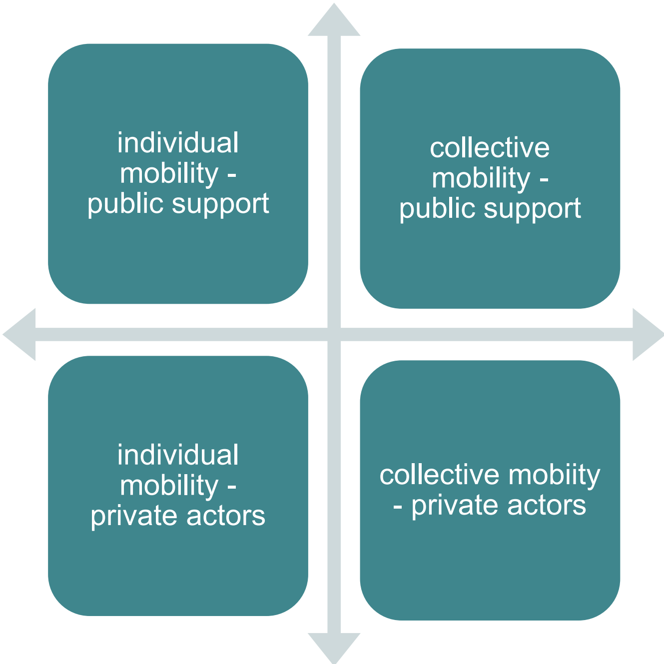

Figure 4.3: Scenario cross spanned by dimensions Individual/Collective and Private/Public Mobility solutions.

Impacts are derived according to the following factors: Traffic, Possibilities, Risks, need of Regulation, and need of Investments, see table 4.2 under. (FRI, 2018).

Table 4.2: Impacts from scenarios spanned by Individual/Collective and Public/Private mobility.

		Public support/actors		**Private actors**	
		Individual mobility	**Collective mobility**	**Individual mobility**	**Collective mobility**
Impacts	Traffic	congestion	reduced traffic	congestion	reduced traffic, congestion in hubs
	Possibilities	environment, equity	accessible multimodality, environment, equity	effective digitalised mobility	high intra-/interurban mobility private pt solutions
	Risks	more driving and parking	less innovative, private solutions	unequal accessibility socially and geographically	unequal accessibility,
	Regulation	data protection, road pricing	MaaS integration requirements, private vehicles taxes	standardisation, data protection	social conern requirements to private actors
	Investments	new road infrastructure	high-speed trains, BRT, metro, e.g.	subsidied social transport (para-transport)	support to local shared mobility, e.g.

2018: "Four stories how to shape future cities"

Some scenario analyses for automated vehicles provide important insights even if the selection criteria for discerning between the different scenarios are not saliently presented.

An example is the American National League of Cities' (NLC) presentation of the "futures of automated vehicles" presenting four, all beneficial, scenarios: [27]

1. **Mobility: Tap taxis to tackle isolation:** emphasising how AVs might be beneficial for the underserved, as an innovation of the 'para-transport' for disadvantageous niches, those with special mobility needs or serving off-transport grid neighbourhoods; the idea is that the financing of these usually high-cost services would be by a widespread automated, dynamic *road pricing*.
2. **Sustainability: Weaving a micro-transport mesh**: an open, interconnected system of driverless shuttles as part of a regulated larger mobility-as-a-service platform (based on city-sponsored data sharing to resist a coming chaos of driver-less vehicles), i.e. small shuttle buses, "practical people-movers", that are simple to design and running programmed routes - and probably the first AVs most people experience (as they already have done, in e.g. Norwegian pilots).

Figure 4.4: Four stories how to shape future cities, by the future automated transport (avfutures.org).

[27] https://avfutures.nlc.org

3. **Jobs and the economy: A human touch on robot delivery:** This scenario combines the challenge of urban robot commodity distribution and reduced jobs, by providing the automated robot distribution by a human touch, by shifting the human role in logistics from a driver to a curbside porter, in collaboration with delivery AVs, and thus reducing the hassle with pick-up points, being there in time, etc. To shape a smooth and orderly city logistics, some local municipal-commercial collaboration is likely to finance such a human touch at the last metres of delivery.
4. **Urban transformation: Reprogramming buses, bikes and barriers:** This scenario combines an automated bus rapid transport (BRT) concept with a huge *micromobility* transport, through the rise of urban electric bikes/bikesharing, scooters, hoverboards, e.g. coping claim for door-to-door-mobility, i.e. the first/last mile to the mass transport hub/stop. This combination of an automated mass transport core and electric, some automated, micro-mobility might be seen as a solution to serve people with affordable housing, unclog public transport, and free urban streets from private cars. (ibid.)

4.5 The scenario criteria selected

For the scenario development in this project we have had a qualitative approach based on research synthesis, policy document analysis, systematic literature reviews, and expert knowledge. The monthly participatory workshops with mutual and iterative feedback among the policy officials in Rogaland Regional County (and the regional public transport company in some meetings) and the TØI research team have been used for the selection of the scenario criteria. The methodology in the literature reviews is specified in the presentation of the state-of-the-art (chapter 3).

The literature review and the presented scenarios have revealed some of the key factors determining the societal impact of automated vehicles. Some of the key factors are replicated in several of the studies, which substantiates that these are the most important selection criteria for the further assessment. There are, however, differences among the key factors. Some are more outer given, whereas others are more contingent of local action.

Crucial factors determining the future of automated driving are the *automation level* and the *geographical differentiation*. Automation level depends, obviously, on the technological development, whereas the geographical localisation - whether in a city centre, in the suburbs, or in rural areas - is a variable more physically given. Thus both the technology and the geography may be considered like exogenous conditions when assessing the further development. Instead of selecting these variables as scenario criteria to which policies might be heavily influential, we see them more as consequensial for the societal impacts. These will very much differ depending on the automation level of the AVs and not least where they will drive – in city centres, on motorways, in suburban areas, or in rural areas.

4.5.1 Ownership: Personally or shared automated vehicle fleet

The ownership[28] structure of the forthcoming automated vehicles is expectedly one of the huge changes in the passenger transport system that may occur. Some of the AV enthusiasts see a huge potential for mostly *shared* fleets eliminating the demand for personally owned vehicles. While others are more sceptical and do not foresee a rapid

[28] The precise term would be 'possession', since ownership is really not what matters (e.g. car leasing, car rental, etc.) for the sake of simplicity we use "ownership".

decrease in personal car ownership in the developed countries – not least since personal car ownership is so massive and numbers per capita still increases. Nearly 90 percent of Norwegians have access to their privately owned car and among half of the households have two cars (Hjorthol et al 2014).

However, there are significant ongoing trends pointing in new directions. The rapid rise in the sharing economy globally the last decade in general and the growth of shared mobility in particular represent considerable social changes. In Norway nearly five percent of the driving license holders, and more than 200.000 people, have already used or have at least registered (in terms of having provided their credentials and downloaded an app) for carsharing, an immense growth in interest only since 2015 (Nenseth, 2019). However, many of these "interested" carsharers have not even tried the service yet.

The crucial question will be whether shared cars take over as the primary form of car use somewhere, and to what extent shared cars will also play a significant role where parking space is abundant, i.e. for inhabitants outside the major cities and city centres.

4.5.2 Use: Private single-occupancy or Rideshared AVs

Another dimension discerning among future expectations for the implementation of AVs is the extent to which the AV will be *used* privately by individuals or by households, or for shared rides – together with strangers. Or put differently: whether the sharing is asynchronous (carsharing) or synchronous (ridesharing).

Private use of shared AVs

Regular taxis and carsharing today is an example of shared ownership, whether by a taxi company, a cooperative member-based car club or a commercial company (so-called B2C, business-to-consumer) or owned by another private person lending or hiring out his/her car for carsharing (so-called P2P, peer-to-peer). There are also many public agencies, city authorities or transport companies, owning a shared car fleet and offering carsharing. The new launching of 250 'NSBs bybiler' in Oslo is a recent example, based on a similar scheme of 'shared urban cars' in Copenhagen. Internationally, in e.g. US and Germany, also car manufacturers have launched carsharing companies.

In either case, the very use of the car, the single trip, is individually and privately initiated and of single-(or single family) occupancy. The model is like shared taxies on a commercial basis.

The very trip or ride is private, not organised and shared by others. AV carsharing will certainly free up parking space, but does not necessarily alleviate congestion - even if it is rather probable. Corroborated findings from carsharing research is that one shared car might substitute (approx.) every 10th car in the roads (9-13 to be more accurate, e.g. (Martin & Shaheen, 2011).

Interestingly, it is the same ratio as was found in the ITF-simulations study (2015b) from Lisbon, that shared AVs could offer the same level of mobility with only 10 percent of today's vehicle fleet (see page 27).

Shared rides of shared AVs

Shared rides, however, with at least 2+-occupancy in a shared vehicle (and not a joint trip by several household members), will reduce traffic and congestion if the additional occupant(s) would alternatively have used an additional car. There are – or will be - two different notions of such ridesharing:

i) One more individualised and flexible collective transport with smaller vehicles based on, often ***on-demand shared rides,*** probably in small mini-buses, up to 10-14 passengers, i.e. the phenomenon of **'microtransport'** (cf. earlier definition)

ii) Traditional and regular **scheduled public transport** with fixed frequencies along fixed routes. Even if the notion 'ridesharing' is not regularly used, public transport is also essentially about '**ridesharin**g' – shared rides.

As a high-frequent public transport (PT) grid is best applicable in densely populated areas, the more flexible microtransport might be appropriate in various geographical settings: Both in ***urban*** centres – to reduce the amount of underutilised PT vehicles disturbing urban liveability, or in ***suburbs*** feeding into the scheduled PT system – and even in rather sparsely densed, ***rural*** areas as a convenient on-demand public transport service.

4.5.3 Policy implementation for automated vehicles

The political dimension is of utmost importance for the future development of the use and implementation of AVs in the Norwegian context. Indirectly policymakers influence the implementation of AVs by organising pilot projects, research and development. However, political support - or restrictions - will also directly heavily influence the size of an AV fleet, the individual accessibility and not least the numbers of the AVs in the streets and cities. Different policy incentives provide distinct outcomes, whether

- *Economic* measures (taxes, fees, road pricing, e.g.)
- *Regulation* (driving and parking restrictions for private AVs or specific priorities, for shared AVs or AVs according to social policy concern for disadvantageous niches, regions or selected groups (remote, underserved areas; elderly, disabled, schoolchildren, i.e. what is called para-transport (particularly in US)
- *Communicative* measures (launching of integrated mobility services to ease seamless mobility; mobility-as-a-service apps and easily accessible, real-time information).

5 Five possible scenarios and their societal impacts

Main scenario criteria, general presuppositions and impacts

Based on the review of literature and scenarios for the potential impacts of future AVs and our familiarity with the Norwegian transport system, we have selected three main scenario criteria. The selected dimensions span the space of some potential and distinct different scenarios – with features and characteristics that may occur, depending not least of the policies targeting the various challenges.

As laid out, the main scenario criteria or dimensions are first and foremost the exogenous technological factors – the level of *automation*. However, combined with *context-conditional* factors, like for instance, the *regional or geographical differentiation,* policymakers may decide a gradually try-out, in different campuses, specific streets/roads, or urban zones, - as has been already experienced. When assessing the societal impacts of the various scenarios – the potential consequences across different regional areas and depending on the automation level, will be further explored.

The three dimensions spanning our suggested scenarios are:

- Whether the AVs will be personally owned or possessed, or belong to a shared (public, cooperative or commercial) fleet
- Whether the very use of the AV will be private or shared
- What kind of policies that are introduced to influence the use of the AVs.

These three dimensions span a space of eight future (2x2x2) scenarios. As we will see, some of the policies to support or restrict the use of AVs will be quite similar, therefore some of the scenarios might overlap and might be merged. That is the case, for instance, for the policies supporting different types of carshared AVs, i.e. the renting of AVs for private use from a shared fleet.

There are also some essential presuppositions in all the scenarios:

1. All AVs will be *electric*, not fossil-fuelled. That should not be seen as unrealistic with the Norwegian national policy goal of solely electric new cars from 2025
2. The penetration rate of *automated vehicles* are expected to be up to 10 percent in 2030 of conditionally automated vehicles (level 4), and up to 60 percent of fully automated vehicles (level 5) in 2050 (Milakis et al 2017).

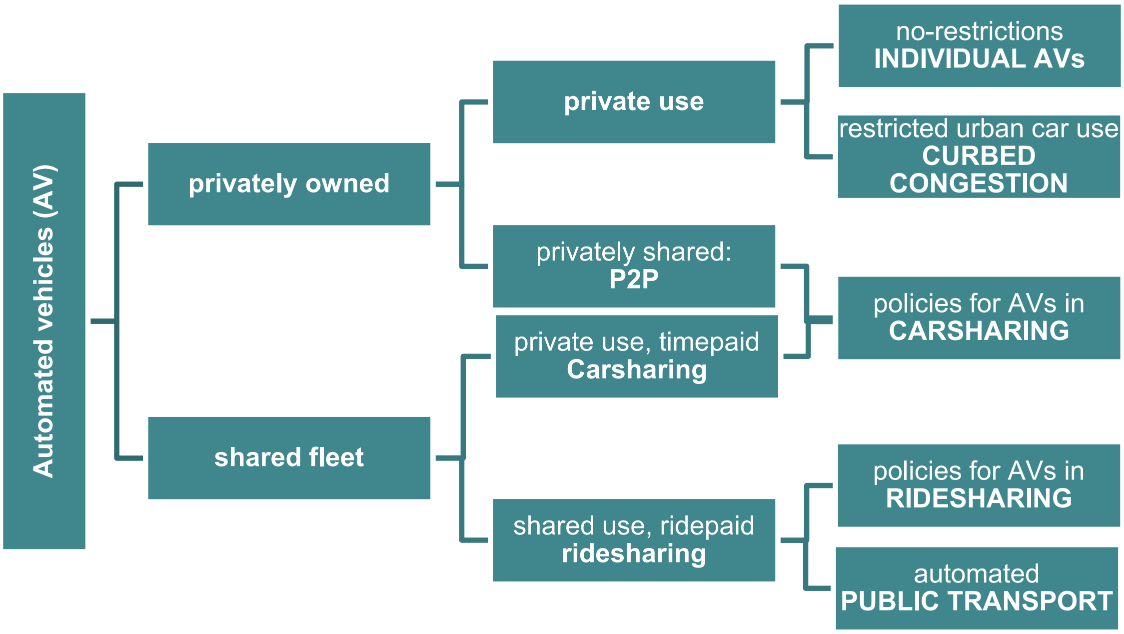

Figure 5.1: Scenarios suggested. Based on private/shared Ownership; private/shared Use; and Policies implemented.

The scenarios are interpreted with today's situation as a baseline. In short, the five scenarios may be characterised by:

1. **Individual AVs for all**: Unrestricted individual mobility by driverless cars
2. **Curbed congestion**: Restricted urban car use, i.e. few private AVs in cities
3. **AVs in Carsharing:** Optimised use of urban space by giving up the private car
4. **AVs in Ridesharing:** Seamless, individualised flexible microtransport by MaaS
5. **Automated public transport:** Prioritised scheduled high-frequent AV public transport.

The five scenarios are presented below according to their main characteristics, the scenario criteria and followed by their probable impacts (the impacts as specified from the *Rogaland County Council's* point of view): the *social* impacts for the users or passengers; the *environmental* impacts for the urban environment and urban sprawl, and the *consequences for particularly the public transport system.*

5.1 Individual AVs for all: Unrestricted individual mobility

This scenario is characterised by individually personally or **privately owned** small AVs for single-occupancy **private usage**. It takes for granted that small car-like AVs will be object for ***mass manufacturing*** and low prices. Everyone, owning a car today, will be able to have an affordable AV on his/her own. Evidently, with cheap AVs available for all, the individual mobility by car will increase. AVs will be available also for the approx. one tenth of the Norwegian adult population who does not have a driving licence, and it will be possible for all to use their own AV in all situations.

This scenario is mainly characterised by ***no policy intervention*** neither of purchasing nor on the use of the forthcoming AVs. It means a liberal market driven *laissez-faire* policy — i.e. *a policy of minimum governmental interference in the economic affairs of individual and society"* [29].

Increasing wealth and cheap self-driving AVs will make private car use available for all, thus increasing individual motorised mobility for everybody and reducing the public service obligation argument for public transport provision. Thus, individual AVs will cover most of ***the mobility demand***. Since almost two of three trips nationally are with a car today, more individual AVs will increase this share and probably reduce even more today's 10 percent share of public transport.

Driverless car transport will offer unprecedented opportunities for new ways of using the car which will increase demand for car travel. In combination with empty vehicles driving around for relocation or remote parking this will lead to a massive increase in vehicle km travelled (VKT).

Capacity effects from more smooth driving and fewer accident events might compensate somewhat for increased individual car travel on arterial roads. But these will most likely be much more complex to achieve in urban streets with many frequent intersections and will therefore at best occur far into the future.

Increasing congestion, primarily in big and to some extent medium sized cities, which will in practice lead to slow travel speed and, hence, less mobility by car in these areas. The access to an AV for people outside congested city centres will significantly increase mobility for people not able to drive a car. Fully automated vehicles might function well in less "complicated" zones like sparsely densed areas with uncongested traffic and in separate motorway lanes.

Impacts of the 'Individual AVs for All' scenario

Social impacts for the road users

An easy access to a private AV for all – will in general increase mobility which will give individual welfare benefit, however, with possibly unintended personal welfare consequences. Easy access to motorised mobility may imply less active mobility (walking and cycling) with detrimental health effects.

However, expected significant increases in traffic volumes will exacerbate problems with congestion in and around the city centres, on the arterial roads into the city centres – particularly in peak hours in the morning and afternoon.

However, for people living in remote rural areas, and for local transport outside the city centres with no road capacity problem, a privately owned, electric AV will give increased mobility and flexibility without impairing others or other societal goals.

Consequences for the urban environment and land use

When private AVs are generally affordable for all, the person kilometre travelled (PKT) are supposed to increase largely and in particular also vehicle kilometre travelled (VKT) because of the added driving of empty vehicles repositioning themselves. Thus inevitably, there will be problems with congestion, in particular in and around the city centres and on the arterial roads towards and between cities.

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[29] Encyclepædia Brittanica: https://www.britannica.com/topic/laissez-faire

In the rather distant future where this scenario can be realised, the higher energy consumption will be less of a problem to the extent that propulsion is electric, and more power generated by renewable energy (hydrogen, solar, wind, geothermal, e.g.).

Consequences of private AVs for public transport

The ease in commuting long-distances and increase in travelled distances might imply that people want to move further from urban centres. Private AVs may lead to 'regional enhancement' with larger housing and labour market regions, and inferring increased urban sprawl.

Larger, detached houses in sprawled surroundings make it difficult to provide efficient public transport and thereby reinforce the effect towards modal shift towards private car.

Hence, the role of public transport is expected to be reduced significantly compared to today. PT may be restricted to a minimum determined by the politically determined level of public service obligation to serve specific groups (people with disabilities, school children, e.g.).

When 'everyone' has their own AV, a strong public transport system is unlikely, also because public transport is expensive per passenger km and increasingly under financial pressure, and electrification will reduce the environmental argument for public transport.

With further electrification of private cars there will be strong need for charge stations, however, hardly not publicly financed. In this private AV scenario it is also unlikely with public financing of the future connected automated vehicles (vehicles-to-vehicles, V2V) or the connection of the vehicles to the infrastructure (V2I).

To sum up, the main impacts on key features are put in table 5.1 below, differentiated in the various types of regional settings. The +sign indicates a positive development, the –sign a negative, and both a mixed or an uncertain development.

Table 5.1: Impacts for the ***individual-automated-vehicles-for-all*** *scenario. By regional differentiation.*

Impacts:	Individual AVs for all	Urban	Suburban	Rural
Social	individual mobility and accessibility	+/-	+	+
	reduced travel exchanges/user compliance	+	+	+
	societal equity	+/-	+	+
	Safety	+	+	+
	public health (more car use, less active mobility)	-	-	-
	cyber-security	-	-	-
Environment	reduced environmental burden	+/-	+/-	+
	reduced urban sprawl, densification	+	-	-
	land use (no freed up parking space)	-	-	-
Transport	no reduced single car use	-	-	-
	no reduced car ownership	-	-	-
	traffic volumes (VKT)	-	-	-
	public investment infrastructure (less nead)	+	+	+
	public operational costs for PT (less PT)	+	+	+

5.2 Curbed congestion: Restricted urban car use

This scenario can be interpreted as a *regulation response* to the negative urban traffic and further societal consequences of the unrestricted private AV use.

It is different from the first 'individual AVs for all' scenario in that there will be **policy restrictions on car use**, both AVs and traditional cars, first and foremost to reduce and manage the congestions within cities and on arterial roads around them.

Experience from cities with restrictions on urban car use reveals that toll rings are effective in curbing private car use. However, only recently, there have been significant reduction in private cars into the city centres, and a salient increase in public transport share, particularly in Oslo. There have been toll rings in the Norwegian large cities for decades (the world's first toll ring was set up in Bergen in 1986, and soon after in Oslo). The reduction of private car use is a result of the huge improvement of the public transport service in the Oslo region.

Also, *regionally* 'disadvantageous transport niches' might be prioritised in their access to city or suburban centres, such as, for instance, people living in remote districts not well served with on-demand transport services (like taxis) or regular public transport.

Also the *freeing up public space* for creating liveable towns and cities will be a driver for this scenario, irrespectively of the degrees of AV penetration. Restrictions in terms of regulations or pricing on cars in city and demand based prices on parking in public space will limit access by car.

Thus this is a scenario mainly relevant for larger urban regions experiencing *pressure on public space* in dense urban structures and *congestion* within the city centres and in surrounding arterial roads in peak hours. In the Norwegian context, the nine largest urban regions for which there have been the 'urban growth agreements', might indicate where this scenario with policy restrictions to curb private car use will be most relevant.

Impacts of the 'Curbed Congestion' scenario

Social impacts for the road users

With the private car use restrictions, reduced congestion by private motorised transport may lead to an improved urban liveability in the city and suburban centres for all. However, it will also imply that private AVs will only be available for a minority.

This scenario will serve very well the advantageous or selected groups, either those *who can afford* the increased costs with the purchase and use of private AVs, but also for people in disadvantageous transport niches who will be best served by a privately owned AV: groups who cannot easily use shared or public transport, or people living in *remote regional districts* in need of easy access to regional, suburban or city centres.

However, the restrictions on private car use might also lead to *increasing social inequalities* in individualised mobility as people with less affordability in general will be more demand responsive to pricing mechanisms. AVs might be privately owned by 'the wealthy' - by those who can afford the pricing - or by those who are eligible for what is called (mainly in the American context) *'paratransport'*, i.e. users of personalised public local community transport services (elderly or people with disabilities or others who cannot use public transport easily). Policies like access regulations and pricing might be less restrictive for these user groups to ensure their mobility.

Consequences for the urban environment and land use

With electric cars and vehicles there will be *no greenhouse gas emissions* from the driving (only from the production of the vehicles). However, the emissions of *particular matters* (from the wheels) will still be harmful for the local air quality. *Less land take* by driven or parked cars in urban areas frees up urban space in streets and roads and parking spots, and there will be *more urban land available* to increase the attractiveness of urban life and liveability.

High prices on private AVs may lead to increased *urban sprawl*, if wealthy people who can afford a private AV choose to move and live in remote rural areas because their private AV easily bring them back and forth to regional or city centres and freeing their time for doing other things while driving. Their value of time spent in traffic is reduced, that may lead to travel longer distances and thus urban sprawl.[30] If this group of people who can afford a private AV, turns into a majority, this scenario resembles the first: private individual AVs for all.

Consequences for public transport

This 'curbed urban congestion' will be influential for urban regional centres, particularly in peak hours (given congestion charges) which will increase the demand for public transport services. As experiences from Oslo reveal, the policies for 'car-free cities' with the increased implementation of toll stations together with restricted car use and parking within the city-centres, have saliently increased the public transport share of daily transport in recent years. The stronger demand for public transport will of course also increase both the operation and investments cost for public transport.

Table 5.2 sums up the main impacts for this Curbed-urban-congestion scenario, where the main difference from the first scenario will be in densed urban areas.

Table 5.2: Impacts for the **Curbed urban congestion** *scenario. By regional differentiation.*

Impacts:	Curbed congestion: restricted urban car use	Urban	Suburban	Rural
Social	Individual mobility and accessibility	-	+/-	+
	reduced car ownership	+	-	-
	reduced travel exchanges/user compliance	-	+	+
	societal equity	-	+/-	+
	Safety	+	+	+
	public health	+/-	-	-
	cyber-security	-	-	-
Environment	reduced environmental burden	+	+	+
	reduced urban sprawl, densification	+	-	-
	land use (freed up parking space)	+	+/-	-
Transport	reduced car ownership	+	+/-	-
	reduced single car use	+	-	-
	traffic volumes (VKT)	+	-	-
	public investment infrastructure	+/-	+	+
	public operational costs for PT	+	+	+

[30] www.mind-sets.eu/future-mobility-trends-car-sharing-automated-mobility/

5.3 The 'AVs in Carsharing' scenario

While the 'Curbed congestion' scenario provides only limited access to private cars as a consequence of AVs generating increasing VKT, this next scenario with shared AVs might be seen as a solution to offer the benefits of AVs to more people. AVs in carsharing schemes mean that AVs from a shared fleet organised by a transport network company (TNC) are available for private use.

The **business or organisational model** in these TNCs might be private (whether commercial or cooperative) or public, and can be offered in two different ways:

- Either as a classical carsharing service, ***pay-per-time*,** where the AV is possessed for a certain timeslot, ranging from hours to days or weeks, typically a weekend or a holiday. This service might be like today's on-demand carsharing
- Or as shared AVs from one TNC, i.e. a ***pay-per-ride*,** an on-demand platform-based and automated fleet management, similar to a ***driverless taxi***, service, defined as " …*a self-driving taxi or a driverless taxi is an autonomous car (SAE Level 4 or 5) operated for an e-hailing (on-demand mobility) service"*[31]

Experiences from carsharing reveal that it is a preferred option for infrequent trips and people who are in need of a car solely now and then. In general, carsharing is found to replace among 9-13 private cars and reduce private car use by approx. one third.(Shaheen 2013). The rapid Norwegian growth in recent years, particularly in Oslo, is also seen on the basis of increased awareness of the hassle of holding, parking and maintaining a private car in dense urban settings. This is in turn, related to the increased tolls and parking restrictions in the city centre of Oslo.

Even if carsharing has existed in Norway since 1995 it was not until the peer-to-peer carsharing among private persons (Nabobil) was established in 2015, there was a huge acceleration in carsharing. There are now nearly 30 000 members of (cooperative or commercial) stationbased carsharing (B2C) providers, while there are nearly 200 000 people that have registered at the P2P platforms. Several new carsharing platforms (transport network companies (TNCs)) have popped up recently, of which several with noticeable interest also in providing shared AVs in the future.

Private use of AVs from a shared fleet will be like a *driverless pay-per-ride taxi*. It is likely that they will be highly visible and available in urban/suburban centres and station-based at transport hubs. Thus they will be mostly accessible, and most likely used, in urban areas. A challenge might be to reduce the amount of available shared AVs, to not get urban centres overloaded with these kind of AVs.

A *pay-per-time shared AV* will be more like the carsharing service today, used mostly for infrequent leisure trips, and for particular purchasing (buying big things). This kind of service are less limited to short trips in urban areas, but used also for the week-end and vacation travels. Thus it is a service that might be applicable in all kinds of urban, suburban and rural districts. Using shared AVs for private, individual occasional trips at first seems most applicable in urban areas. There can hardly be station-based shared AVs "everywhere". However, a P2P sharing (a renting) of a private AV shared with other might be quite suitable also in less urban regions, in suburbs or sparsely densed rural areas.

So far carsharing has been brought on without any direct policy measure. Just recently urban policy in Oslo has reserved particular public parking spots for shared cars within the established carsharing schemes. However, with shared AVs ai urban settings lots of parking

[31] https://en.wikipedia.org/wiki/Self-driving_car

spot will hardly be necessary, since the AVs assumingly will be used and drive around more or less all the time.

Even if there is around five percent of the Norwegian driving licence holders who are enrolled as potential carsharers today, carsharing is still just a niche phenomenon. For carsharing of AVs to pave the way for fundamental changes in the modal split in general and for private car use in particular, *carsharing has to be complimentary, not competitive* to the alternatives to private car or AV use: Public transport and active transport (walking and cycling).

If the shared AV fleet will be a *free-floating* service, the vehicle can be picked up (and set back) any place within a specific urban zone. (For instance, similar to the recent new service provided by NSB bybiler in Oslo). This is most likely, and increased convenience and ease to pick up an AV for a private, single-occupancy trip, will probably be more likely than using other alternatives to private vehicle use.

Impacts for 'AV Carsharing' scenario

Social impacts for the road users

Easily accessible and available shared AVs might serve the population well, given that there are enough shared AVs available, available in time and in the right distance from people's origin destination. They will be like a driverless taxi , but much cheaper. The cost of the driver usually counts for around 70 % of the cost of a taxi trip (Kristensen 2018). However, they will not be as cheap as public transport (in turn depending on level of the public subsidies).

If the shared AVs will be accessible within short distances, whether station-based in urban centres or available as a P2P solution in rural neighbourhoods, this kind of service might serve the population well. From the user's point of view, a free-floating shared AV service will probably be seen as a very *convenient solution*, within an urban region.

Consequences for urban environment and land use

With an excessive amount of *shared AVs in urban areas and in peak hours* it will obviously be harmful for the urban environment – but most likely not in the same scale as in the first scenario, private individual AVs for all. Moreover, when the AVs belong to a shared fleet from one provider, it should be much easier to regulate the size of the fleet compared to a huge amount of different individuals with privately owned AVs.

In particular, the free-floating shared AV solution needs to be carefully surveyed to avoid urban centres packed with an excessive amount of free-floating AVs driving around.

Consequences for public transport

Even if the main findings from carsharing research are that private car use is reduced, shared AVs might easily cannibalize the other transport modes supported by overarching policy goals: public transport, walking and cycling.

If the shared AVs are integrated in a MaaS solution, regular scheduled public transport might have an important role in reducing congestion. Most probably will the pricing mechanism support and ease the choice between different modes, for instance like in the Whim[32] system in Helsinki or merely road pricing.

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[32] Whim offers public transport, taxies, bike and carsharing in one app, having with three prices for mobility services, one pay per ride, one 'whim urban' with unlimited public transport and reduced taxi prices as a

Table 5.3: Impacts for the Shared AVs for all scenario.

Impacts:	Shared AVs for all	Urban	Suburban	Rural
Social	Individual mobility and accessibility	+	+	-
	reduced car ownership	+	+	+
	reduced travel exchanges/user compliance	-	+	+
	societal equity	+	+	+
	Safety	+	+	+
	public health	+/-	-	-
	cyber-security	-	-	-
Environment	reduced environmental burden	+	+	+
	reduced urban sprawl, densification	+	+	-
	land use (freed up parking space)	+	+	+
Transport	reduced car ownership	+	+	+/-
	reduced single car use	+	+	+
	traffic volumes (VKT)	-	-	-
	public investment infrastructure	+	+	+
	public operational costs for PT	+	+	+

5.4 The 'AVs in the Ridesharing' scenario

AVs in a ridesharing system means that a fleet of AVs are provided to users for an organised *on-demand ridesharing with others*. It is not for individual private transport the vehicle is shared.

The ***microtransport*** concept, ranging from shared taxi-sized vehicles to minibuses (10-14 passengers), currently with low speed over short distances is illustrative for this development. The fleet of microtransport AVs meant for ridesharing might be object for different kinds of business or *organisational models*: whether privately owned (commercial or cooperative) transport network company (TNC) – or also highly plausible in the Norwegian context, publicly funded and operated.

Also in this scenario the service will most likely be integrated in a *MaaS solution*. The main difference from the former (car)shared AVs is that *the rides are shared*. An elaborated on-demand service of shared rides, integrated in a MaaS solution, implies the possibility of booking or picking up an AV from home or a nearby pick-up zone, similar to today's public transport stop, and bringing the passengers to a local transport hub, or to another destination or drop-off zone close to the destination of several passengers, for instance an urban or regional centre, an industrial site or another common workplace. Users may actively seek for a ride through an app that guides users to the same waiting spot or along the same route. The advantage of this ridesharing is that it does not require scheduled routes or commitments from users in advance, whereas the drawback is that the service's functioning in the long run requires a certain amount of users.[33] Shared on-demand services might substitute costly scheduled routes with low ridership.

monthly subscription, and one with unlimited access to all mobility services within the urban area (approx.. the same price as holding a privately owned car) https://whimapp.com/

[33] www.mind-set.eu/Future_Trends_in_Mobility_The_rise_of_the_sharing_economy_and_automated_transport

This ridesharing solution might work well in various regions, both urban and rural. In urban settings it can underpin more conventional public transport along main arterial corridors to/from the suburban outskirts, and also within city centres, depending on how the curbside management is solved.

The on-demand service implies flexibility. Many stops and very flexible routing hampers the effectiveness of the transport service, whereas direct routes provide higher frequencies and fewer stops. This is a solution suitable in many different regions and urban areas. A crucial challenge in city centres will be the curbside management. It will require new solutions with optimal design for pickup/drop-off zones (- as has already been tried out with the small automated minibuses that have been piloted at Forus, in Kongsberg, at Fornebu, and soon to come, in Oslo).

Table 5.4 sums up the main impacts for the rideshared-AVs-for-all scenario.

Table 5.4: Impacts for the rideshared-AV-for-all scenario. By regional differentiation.

Impacts:	Rideshared AVs for all	Urban	Suburban	Rural
Social	individual accessibility	+	+/-	-
	reduced car ownership	+	+	+
	reduced travel exchanges/user compliance	-	-	-
	societal equity	+	+	+
	safety	+	+	+
	public health	+	+/-	+/-
	cyber-security	-	-	-
Environment	reduced environmental burden	+	+	+
	reduced urban sprawl, densification	+	+	-
	land use (freed up parking space)	+	+	+
Transport	reduced car ownership			
	reduced single car use	+	+	+
	traffic volumes (VKT)	-	-	-
	public investment infrastructure	+	+	+
	public operational costs for PT	+	+/-	-

Impacts of the 'AVs in Ridesharing' scenario

Socal impacts for the road users

For the users this organised rideshared solution will be less flexible and convenient than for the private use of an AV. However, depending on how the service (e.g. the ridesharing app) is organised, the convenience will of course be decided of where and when to be picked up.

Even if users in urban settings more easily might be served by this kind of organised rideshared solution, it may function well also in the regionally 'disadvantageous transport niches', e.g. for instance for those who live in underserved areas for regular public transport.

Ridesharing might be socially disturbing for some users that are not acquainted or comfortable with sharing a ride (within the same carriage) with strangers. People who rideshare are thus found to prefer people they are familiar with or are similar to themselves.

So far the small AV minibuses that have been in operation in the pilots different places, have hardly been very impressive to any users, considering the low speed and inconvenience as an effective transport mode. It has, so far, perhaps been considered more like a transport toy than a promising future transport solution. However, it must be seen as an experiment in a stepwise progression to the future concept.

Consequences for urban environment and land use

Rideshared AVs might be beneficial for the urban environment (in reducing the number of private vehicles), and will probably not have any particular importance when it comes to urban sprawl. The challenges already observed today with TNCs in dense urban settings indicate that curbside capacity might turn out as a severe problem that requires development of more efficient, perhaps dynamic, concepts for pick-up and drop-off if rideshared AVs become a dominant mode.

Consequences for public transport

With the introduction of rideshared minibus AVs they may further develop in two versions: One is the *microtransport* service with on-demand shared (pick-up/drop-off) rides, between (close to) home and transport hubs. The other might be an AV minibus service replacing larger buses in urban areas. When automation opens up for saving the driver costs, it creates opportunities for offering users same capacity with higher frequencies and where suitable services by smaller buses and/or a more fine-meshed scheduled route network.

5.5 The intensified 'public transport' scenario

This is the scenario for the *shared AVs* used for *shared rides*, publicly funded. A further development of a strong public transport (PT) system would possibly increase the modal share from its 10 percent share today[34]. An intensified PT system might aim at what the transport authorities in Helsinki puts forward: "*Public transport of the future is so smooth and flexible that you might never need to buy a car of your own".*[35]

Public transport, as we know it today, obviously is about *ridesharing*, however, not on-demand, but organised and scheduled in advance and with *fixed time-table* and *fixed routes*. PT for road users include buses, trains and trams, providing urban transport and affordable mobility for all. In urban areas the inflexibility of scheduled PT might be compensated by frequency, i.e. when the buses or trams are so frequent that no time-table is necessary.[36] Apart from these hyper-frequent PT solutions, an automated PT system might in principle have the same characteristics as a conventional PT system, time-scheduled and along fixed routes.

In urban and regional planning PT is seen as an important driving force for *efficient land use*, e.g. by what is called TOD, '*transit oriented development*'. Or it may also be seen as the other way round: urban concentration of dwellings and workplaces is a prerequisite for efficient and attractive PT. That is land use planning based on *compact multi-modal* neighbourhoods based on the vicinity to transport hubs, places that are or might be less (private) car dependent than the more sprawled suburbs in the surroundings. In a 'transit oriented

[34] 10 percent PT share at the national level, 10 percent in the city of Stavanger, and even less in the rest of the region

[35] Notat «*Bestillingstransport/kollektivtransport med små enheter – hvor og hvordan*», Rogaland fylkeskommune, Samferdselsavdelingen, 15.2.19

[36] Some trams and bused in Oslo are scheduled every 5th minute, thus being called "rolling sidewalk"

development' the development of housing and workplace localisation will follow the main PT corridors and axes.

An automated driverless PT system could lean heavily on the experiences and expectations from advanced BRT (*bus-rapid-transit*) solutions, where the buses have segregated, separate lanes. BRT is significantly less costly and complicated to plan and develop than fixed rail investments, however, with somewhat less capacity per occupied space.

Impacts for the 'intensified public transport' scenario

Social impacts for the road users – the passengers

The supply of *efficient and affordable mobility* for all will be the main social impact of automated PT, as it has been for conventional PT.

However, driverless PT will have some further social implications that might be difficult to compensate: The fact that a PT driver often is a *service provider*, supporting the passengers for a various of services during the travel (seating, luggage, wheelchairs, baby strollers, etc.) needs to be solved. A suggested solution is to introduce automated PT with some dedicated *PT hosts* to ease particular user worry and provide this kind of user-service. This is also the case with the ongoing Norwegian pilots of driverless minibuses, they are piloted with dedicated AV host on-board. However, if not the driver cost is saved, to many the whole point of launching automated PT will be missed.

As automated PT will not be able to provide highly individualised on-demand service (as for the AV carsharing and the AV on-demand ridesharing scenarios), the transport flexibility might be achieved by combining a high-frequency, fine-meshed strong scheduled public transport system with a well-developed *micro-mobility services* – e.g. city bikes, electric scooters, mainly for the first/last mile service: to/from the PT stops and the home or the final destination.

A societal impact from the 'transit oriented development' is the probable disruption of the earlier less mobility advantageous, low-income neighbourhoods, e.g. that gentrification might occur when the PT system is improved or renewed and new *high-profiled urban transport hubs* are built.

Consequences for the urban environment and land use

The important environmental impact from automated PT is the reduced '*ecological footprint*' compared to private AVs, mostly from the reduced land take, and the local PM emissions (given as presumed before, with no combustion emissions of greenhouse gases or other pollutants while driving).

Moreover, the 'transit oriented development' (TOD) indirectly implies more compact, less energy-consuming places where people live and work compared to a more sprawled urban development without such a TOD.

Consequences for the public transport

It goes without saying that an intensified PT scenario will provide a higher PT service level. If a 'bus service host' is introduced to compensate for the possibly lower *quality* (less safeguarding) of bus services when the driver is not around, the cost by automation will not be reduced so much as expected.

There might also be internal changes within the PT system that could possibly change the system significantly. The definition of public transport becomes more blurred when the range from private cars to mass transit becomes gradual over the concepts: taxies → shared taxies → on-demand door-to-door minibuses.

For instance, several *hybrid PT solutions* might be foreseen:

i) When automation opens up for saving the driver costs, it creates opportunities for offering the users same capacity with more and smaller buses (*microtransport)* and/or a more fine-meshed route network. Saving the driver costs will also give significant room for providing new more individualised concepts (e.g. carshared AVs or rideshared AVs) integrated in public transport with conventional high capacity routed solutions (such as buses, trams and metro)

ii) Or the automated small-scale *microtransport* AVs (single-cars, minibuses or small 'pod vehicles') and the automated large-scale public transport vehicles (trains or buses, possibly BRT) might be merged, e.g. when the smaller pods or AVs are *platooned* into longer, larger AVs along main roads within and between cities and towns. Small AV pods might be platooned like this in intraurban or high-speed intercity motorways – and the AV single pods might be detached in less populated regions, for instance for infrequent business or leisure long-travels.

Table 5.5: Impacts of the intensified public transport by AVs scenario. By regional differentiation.

Impacts:	Intensified public transport by AVs	Urban	Suburban	Rural
Social	individual mobility and accessibility	+	+/-	-
	reduced car ownership	+	+	+
	reduced travel exchanges/user compliance	-	-	-
	societal equity	+	+	+
	safety	+	+	+
	public health	+	+	+
	cyber-security	-	-	-
Environment	reduced environmental burden	+	+	+
	reduced urban sprawl, densification	+	+	+
	land use (freed up parking space)	+	+	+
Transport	reduced car ownership	+	+	+
	reduced single car use	+	+	+
	less traffic volumes (VKT)	-	-	-
	public investment infrastructure	-	-	-
	public operational costs for PT	-	+/-	+/-

5.6 The scenarios seen together

The five scenarios are deliberately formulated in a stylized, ideal-typical, manner to pinpoint their differing characteristics and hence facilitate to sharpening the different perspectives for the policy implications. The scenarios from 1 to 5 might be seen as a response to each other, as on a scale from the least (no) policy intervention to the most heavy policy investments for primarily public transport, see figure 5.2. We will, however, see the three intermediate scenarios between these two "extremes" as the most plausible and probable – and perhaps also preferable - in the Norwegian context. Thus the scale does not work as a time scale since the no-policy scenario with individual AVs accessible for all will hardly be the first situation.

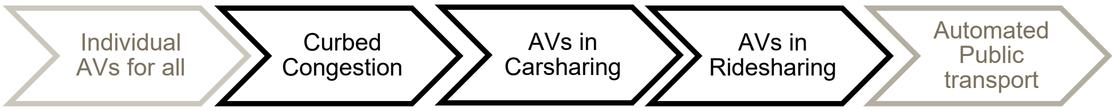

Figure 5.2: The scenarios seen on a policy scale from the least to the most heavy policy intervention (with the two extremes as the least possible scenarios, indicated by grey contours)

First, as individual AVs, automated cars, will be cheap and available for all, there will be more individual car driving and thus congestion. *Second*, the 'Curbing traffic' scenario is a response of the congested cities with too many private AVs driving around; thus the induced traffic generated by the new opportunities of AVs, requires policy instruments curbing private car and AV use. However, only economic instruments (toll roads, road pricing, etc.) will favour those who can afford it. Yet, private AVs might also be reserved by policy regulation for some priority groups, e.g. people in transport disadvantageous niches, socially or geographically. Also communicative policy instruments such as 'nudging' for livable towns and appealing mobility alternatives to private cars and AVs might play a role.

Third, with the need for regulating the amount of single AVs, more AVs for all will be available by fleets of *shared AVs*, by private or public carsharing providers that offer AVs for people who is in demand of an individual, single-(family) occupancy only infrequently, e.g. for special big-thing transport or weekend or holiday trips.

Finally, the two *ridesharing* scenarios, represent the solution with innovative (automated) mobility solutions increasing capacity utilisation of both the cars/vehicles, and more importantly, of the infrastructure by avoiding too many single-occupancy AVs driving around. The development of ridesharing services is twofold – either a further advancement of conventional scheduled public transport (PT), or a development of *flexible on-demand micro-transport*, either for feeding into the public transport grid, or as small minibus shuttle AVs bringing people from (close to) home and to their destination, like larger transport hubs, urban or work place centres e.g.. A strong PT system with scheduled automated buses/trains with fixed routes will still be needed of capacity reasons in city and urban areas. The service from conventional route-scheduled services would probably benefit from new supplementary flexible mobility solutions, i.e. all the other innovative mobility solutions, known as the *micro-mobility* (el-bikes, electric scooters, e.g.). Both the rideshared minibuses in micro-transport and the micro-mobility equipment will be particularly suitable for the first/last mile solutions.

The table 5.6 below sums up the five scenarios' main impacts with the important regional differentiation: whether in city or urban centres; in suburban areas at the outskirts of urban centres, and in the rural areas.

Table 5.6: Overall impact of AVs. The 5 scenarios by Regional differentiation (colours indicate positive (green) and negative (red) development and strength (darker))

		SCENARIOS				
		privately owned AVs			*shared AVs*	
		private use of AVs			*shared use of AVs*	
		INDIVIDUAL AVs FOR ALL	**CURBED CONGESTION**	**AVs in Carsharing**	**AVs in RIDESHARING**	**AUTOMATED PUBLIC TRANSPORT**
REGION	Urban	congestion		congested if empty cruising	feeding PT	
	Suburban	queues on arterial roads	AVs for the few		(on-demand)	
	Rural		irrelevant	P2P	on-demand	costly

5.7 Time expectations: Introduction and further implementation

In our review of literature and presentation of scenarios we have touched upon various and to some extent diverging time expectations. The timing for the *first introduction* of the automated vehicles at different automation level depend mostly on the technological development. The further market penetration or diffusion in different cities and regions are, however, highly dependent on policies and also influenced by the evolving of user acceptance.

Time expectations thus differ strongly whether it is about the first introduction of a vehicle or it concerns the major implementation or penetration in the market. Milakis *et al* 2017, suggest that fully automated vehicles (level 5) are expected to be *commercially available* within a time window of twenty years (between 2025 and 2045), while the respective time window for conditional (level 3) or high (level 4) automation is smaller (ten years) and more immediate (between 2018 and 2028). The penetration rate of AVs is expected to be up to 10 percent in 2030 of conditionally automated vehicles (level 4), and up to 60 percent of fully automated vehicles (level 5) in 2050. (ibid.).

As we have noticed earlier (chapter 2), the time expectation for the introduction of *self-driving vehicles on motorways* are around 2025 and *in urban traffic* only two-three years later (ITF 2015b).

The table 5.7 below shows the time span from now to 2045 depending on the automation level (conditionally automated or fully automated) or whether the policies have been supportive or restrictive (based on Milakis *et al*, 2017). Supportive policies means appropriate legislation allowing AV trials and AVs in real traffic and public investmenst on AV research, while restrictive policies indicate the lack of the same. Thus we would consider the Norwegian situation already in accordance with the 'supportive policies' as presented by Milakis and colleagues.

Table 5.7: First AV introduced. By technological and policy development, based on Milakis et al 2017.

		First vehicle on the market	
		Conditionally automated (level 3&4)	Fully automated (level 5)
Supportive AV policy	high technological development	2018	2025
	low technological development	2020	2030
Restrictive AV policy	high technological development	2025	2040
	low technological development	2028	2045

A survey among self-identified experts in vehicle automation found a median estimate of 2019 as the initial date at which vehicles would be capable of driving themselves on specific motorway lanes, with drivers available to take over, if required (i.e. level 3). The same group predicted that vehicles would be capable of *driving themselves* (level 4&5) on urban and rural roads and motorway by approx. 2025, and doing so in a completely safe manner (without a human driver backup) by 2030. (Underwood, 2017).

Figure 5.3 shows the experts' forecasts (in a US survey from 2014) on when AVs at different automation levels will be implemented, in different contexts (from Underwood, 2017). The size of the blocks indicate where most of the responses are.

As we see, the assumption on **low-speed shuttle AVs in pedestrian zones** in 2018, fits perfectly well with the Norwegian situation (i.e. the small shuttle AVs at Forus, Fornebu and Kongsberg). Furthermore, motorway driving (with limited access) is expected in 2019/2020, while the first full driver replacement, for instance as a robo-taxi, in urban driving is not expected by most of the respondents before after 2025. Interestingly, around 2030 most of the respondents believe that a driverless AV might bring children to school. (Underwood, 2017).

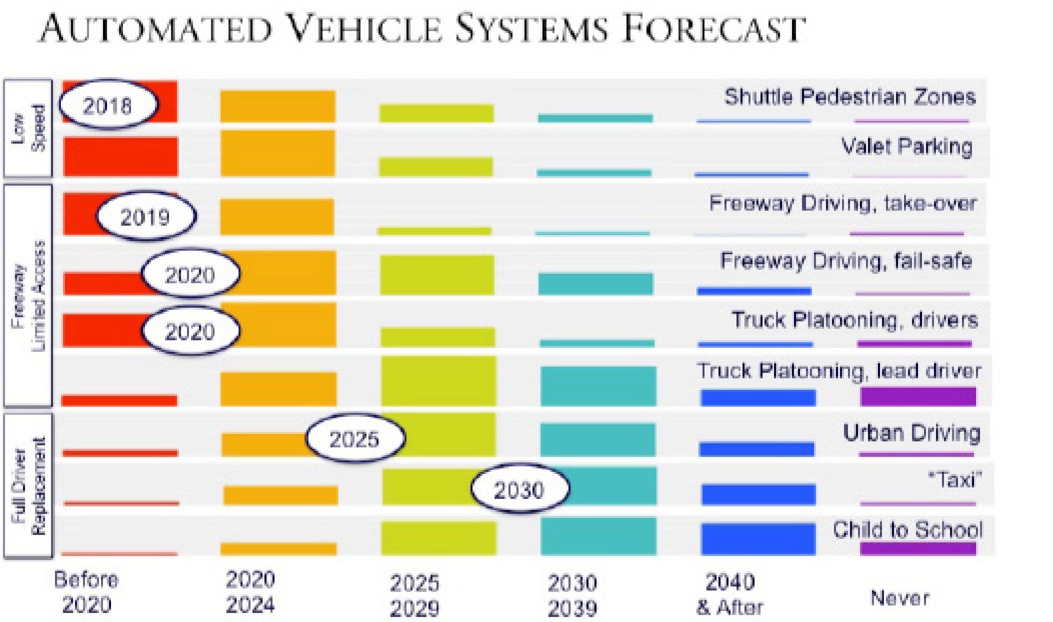

Figure 5.3: Forecast of the introduction of AVs under different conditions. Expert survey (Underwood, 2017).

Some of the more optimistic timelines – for instance, from car manufacturers, suggest that there will be a significant number of cars with some self-driving capacity on the road by the early 2020's, with the first vehicles being luxury cars or part of a commercial fleet. However, also from this market or technological point of view here is a strong belief that the further adoption timeline will depend heavily on the regulatory development in the years to come. But also optimistic expectations such as: *"…if you live in a major city you will be able to hail some form of automatic car ride in less than a decade"* [37].

5.8 Policy implications

The final scenario criteria for the five scenarios is based on the degree and kind of policy intervention: from one end of a scale where there is *no policy intervention* with market driven implementation of private AVs to the other end of the scale where the AVs will mainly be a part of the *public transport* supply. Fully implemented might both these scenarios be seen as possible but unlikely in terms of their consequences – the former due to the unrestricted amount of driving and number of vehicles and the latter due to the high increase in public investments and costs.

For the Norwegian context the three intermediate scenarios are seen as the more **plausible** – both the one emphasising *policies for curbing urban congestion* and the two sharing scenarios, The last ITF report outlook[38] states that "*A massive uptake of shared mobility could halve vehicle-kilometres travelled in cities and reduce urban transport CO_2 by 30% by 2050"* (regardless the degree of automation). The scenario with **shared AVs for private trips** will certainly free up urban (parking) space but might unregulated lead to increased driving,. The critical parameter is the *occupancy rate* within the vehicle. Thus, the **scenario with use of AVs for shared rides** could be a probable solution for the further policy development of facililating the introduction of selfdriving and driverless minibuses, *microtransport.*

When considering the Norwegian first pilots with selfdriving vehicles is precicely it is interesting that it is precicely this scenario of small **rideshared AVs** the policies and endeavours for first pilots with automated vehicles have been directed to. That means that the regional transport policymaking entities, the county authorities and their public transport companies, already have taken a pro-active and leading role for further introduction of automated vehicles in Norway. Also the (temporal) legislation for the pilots are now in place – no other companies or firms have been given any permission for try-outs of selfdriving vehicles in Norway. Also further pilots with larger **rideshared AVs** – i.e. regular **public transport** – are highly probable, for instance in railways or driverless buses on specific motorway lanes (in the international literature expected already by the mid 2020s). As we have seen, the policies will probably be tailored regionally differentiated – whether in city or urban centres, in suburbs or in rural areas.

Most political uncertainty for the moment (spring 2019) is related to the continuation of the Norwegian curbed urban congestion policies – connected to the Urban Growth Agreements in the nine larger urban regions in Norway. If these politically vulnerable agreements that now are under reconsideration will be renegotiated, also the policies for further implementation of AVs in the Norwegian context might be affected. That is particularly the case since the regional transport policy authorities so far have been in charge for the first AV pilots.

In general, the potential for reduced costs, smaller environmental burden and increased traffic safety makes it probable that the further introduction and implementation of AVs in the Norwegian context will (still) be high on the urban and transport policy agenda. The ways to avoid the future negative consequences of the development strongly depend on the political will – as always.

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[37] https://emerj.com/ai-adoption-timelines/self-driving-car-timeline-themselves-top-11-automakers/

[38] https://www.itf-oecd.org/transport-demand-set-triple-sector-faces-potential-disruptions

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