

# **Niche management of Autonomous Vehicles for positive environmental outcomes in Copenhagen**

Evaluating the feasibility of purposive measures through scenario analysis

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## **Abstract**

Cities around the world are leading the race toward an environmentally sustainable future, but one of their major obstacles have been the personal automobile. The movement of people using public transportation often has a far lower impact than the personal automobile, but these systems are often rigid and expensive to build and operator. Now, with the emergence of intelligent transport systems – and soon self-driving (or autonomous) vehicles – cities will become increasingly capable of offering affordable, convenient, and potentially sustainable transport. Whether autonomous vehicles (AVs) will contribute to sustainable mobility is, however, far from guaranteed. With competing motivations behind the technology's development, it will be up to city authorities to steer the integration of this technology down an environmentally sustainable path. This entails finding purposive measures to prevent congestion, lower vehicle kilometres travelled, and limit the cannibalisation of their public transport systems.

Copenhagen is one city that has recently taken the first step in adopting autonomous vehicles, initiating a preliminary test-phase in a confined area of the city. Though the technology is primed to offer a host of opportunities in Copenhagen, the city will eventually need to consider concrete measures that ensure AV contribute to positive environmental outcomes. The cutting-edge of literature and experts in the field reveals a number of potential measures, from which four scenarios could be described. However, based on an evaluation by Copenhagen's technical and environmental administration, i.e. the city's strategic unit, responsible for the integration of AVs in the city, it was impossible to determine which scenario the city is likely to undergo. Lack of knowledge, and the technology's uncertain interaction with the city's existing agendas were the main obstacles for the lack of clarity.

**Keywords:** Autonomous vehicles, sustainable urban mobility, strategic niche management, scenario analysis

## **Executive Summary**

Often referred to as the most significant advancement in automotive transport in over a century, autonomous vehicles are soon going to be a common facet of urban life. The impacts of this technology are by many believed to be revolutionary; destined to change the fabric of cityscapes. These expectations, while grand and enticing, leave a glaring question mark on how this technology will adjust to cities' existing agendas, specifically in relation to making mobility less environmentally harmful.

This paper explores the advent of this novel technology, which; while still in its infancy, is giving substance to extensive speculation. Among its many purported attributes and benefits, is the notion that the technology can contribute to sustainable urban mobility. This paper questions this sentiment, drawing on contemporary issues of urban mobility, which are likely to be replicated and amplified by the self-driving capability. While this paper will not question the technology's capacity to live up to these claims, it investigates how cities' integration can ensure their fruition. Over the past 100 years, our integration of the personal automobile have left cities dependent on road-based transportation, and on-going trends – particularly in the world of mobility service provision – suggest that AVs may induce a similar reality.

This paper is founded on the assumptions that cities cannot afford to leave this technology unmanaged, despite its alleged superiority to the conventional automobile. If cities want to derive the technology's ability to provide sustainable mobility, they must engage in purposive action, and be willing to make compromises. This research set out to identify the potential environmental benefit of this technology, as well as the environmental issues likely to arise from its integration. In so doing, it found congestion, vehicle kilometres travelled, and public transport cannibalisation to be the predominant environmental problems. Building upon these issues, and through review of literature and expert interviews, the research identified 20 potential measures that cities could deploy in order to tackle these issues. These measures were categorised across two dimensions: The degree to the facilitative of AVs sustainable attributes, or restrict AVs' propensity to cause the aforementioned environmental issues.

Drawing on these measures, a scenario analysis was conducted, which constructed four generic scenarios: Asleep at the wheel; The Green Miles; Speed-limiting progress; and A U-Turn in Automotive Impacts. The baseline, i.e. 'Asleep at the Wheel' describes a situation in which AV integration is unmanaged, leading to the technology drastically increasing the distances travelled within the city, and loss of ridership in public transport. The Green Miles describes a sharp growth in mobility service provision, albeit with a much greater degree of electrified mobility. Speed-limiting progress, outlines how all core issues are essentially addressed, but at the significant expense of other benefits. Finally, A U-Turn in Automotive Impacts, describes how the city manages to largely address most issues, whilst still keeping the city as an attractive business proposition to AV mobility service providers.

Furthermore, the research used an evaluation of these measures, by Copenhagen's technical and environmental administration to determine which scenario the city is trending towards. Though this exercise proved inconclusive, the main obstacles for the eventual deployment of these measures were identified as lack of knowledge, and uncertainty around the technology's integration with the city's existing goals and objectives.

The concept of strategic niche management posits that all technologies must eventually face the selection pressures of the market. It teaches us that mere restriction and direct competition with existing technologies are likely to shape novel innovations that mirror their predecessors, and to realise its unique capabilities, active facilitation of its desirable attributes must occur.

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## Abbreviations (if required)

AV – Autonomous Vehicle	PT – Public Transport
EV – Electric Vehicle	SNM – Strategic Niche Management
MaaS – Mobility as a Service	TNC – Transport Network Company
MSP – Mobility Service Provider	V2G – Vehicle-to-Grid
OEM – Original Equipment Manufacturer	V2I – Vehicle-to-Infrastructure



# 1 Introduction

The story of the self-driving car is one that has been told for nearly a century, and potential benefits of this technology have long been a source of much imagination. With the earliest documented case dating back to the 1920s (Lafrance, 2016), it now appears that we will get to observe the effects of this technology materialise within the coming decade. It is anticipated that this technology will have sweeping implications across society, and the city is one domain that is likely to undergo profound change (KPMG, 2017; Rodoulis, 2014; Zakharenko, 2016).

The cutting-edge research on AVs is predominantly technical, and conducted within managed test spaces. Research on the technology's potential implications is often categorised speculative; comprised of historical accounts of technological developments, simulations, and models (Hörl, Ciari, & Axhausen, 2016). This has allowed the technology to permeate the discourse of influential societal groups, mostly in the form of consultancy reports, mobility plans (Arbib & Seba, 2017; Schaller Consulting, 2017; Viegas & Martinez, 2017; WEF & BCG, 2015), and urban mobility schemes (BCG, 2016; Københavns Kommune, 2016b). These are all based on various assumptions, producing a range of different narratives, which combine to form likely scenarios of future developments. One emergent topic on AV is whether this radical technology will result in greater environmental harm, or be a catalyst to a surge in sustainable mobility (Arbib & Seba, 2017; Litman, 2014; Wadud, MacKenzie, & Leiby, 2016).

A novel technology is only as interesting as its functions, i.e. the benefits it brings, the problems it promises to solve. Among a myriad of purported benefits, AVs stand to contribute to positive gains in sustainable mobility (Arbib & Seba, 2017; Fagnant & Kockelman, 2014; Viegas, Martinez, Crist, & Masterson, 2016). To fully realise AVs contributions to sustainable mobility, a number of elements at both international, national, and local levels must align, and it is assumed that municipal administrators will have a significant role to play (Lang et al., 2016; Milakis, Snelder, Van Arem, Van Wee, & De Almeida Correia, 2015). The two primary factors that will result in AVs contributing to sustainable urban mobility, are their abilities to synergise with electric vehicles<sup>1</sup> (EVs), and provide a platform for mobility service provision (Fulton, Mason, & Meroux, 2017; Viegas et al., 2016). The narratives drawing on these two factors highlight that this would lead to road-based transport emitting no CO<sub>2</sub> during use, and that the overall number of vehicles on the road could be drastically reduced (Fagnant & Kockelman, 2016; Viegas et al., 2016). However, one consistent belief is that AVs will accelerate the growth of so-called mobility service providers (MSPs) (T. D. Chen, 2015; Fagnant & Kockelman, 2014; Wadud et al., 2016; Wilson, Pearson, Roberts, & Thompson, 2015).

The relevance of investigating the sustainable mobility of AVs in cities is twofold. Firstly, urban domain is likely to be one of the first to adopt this technology (Dokic, Müller, & Meyer, 2015; ERTRAC, 2015), and second is the host of problems cities are currently facing that could be – to some extent – addressed by this technology. Air pollution, congestion, and land scarcity are but some of the problems that AVs have been speculated to alleviate (Fagnant & Kockelman, 2015; Litman, 2014; Meyer, Becker, Bösch, & Axhausen, 2017).

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<sup>1</sup> Will also be referred to as electromobility, or e-mobility

## 1.1 Problem definition

Cities around the world are coming to terms with the numerous threats posed by climate change, and are coming to the realisation that they may need to spearhead efforts to develop more sustainable systems (Kousky & Schneider, 2003; Pancost, 2016; Rosenzweig, Solecki, Hammer, & Mehrotra, 2010). A substantial part of this task will be to overhaul existing transport systems, and devise new modes of sustainable urban mobility. These include efforts such as Sustainable Urban Mobility Plans, which has become part of the European Commission's agenda. With a growing focus on the use of intelligent transport systems to strengthen public transport (PT) (CIVITAS, 2012), AVs may constitute a key enabler, as they have the form, function, and flexibility to directly compete with the conventional automobiles on the open road. It is expected that these vehicles will not only be predominantly electric, but also shared and integrated such that they support existing PT systems (Fulton et al., 2017; Viegas & Martinez, 2017; Wadud et al., 2016).

Expectations from influential actors and commentators is only one component in the development of niche technology (Geels, 2005; Schot & Geels, 2008) (Twomey & Gaziulusoy, 2014). As AVs are currently confined to experimental test-zones, it is difficult to empirically gauge the ways in which this technology will develop once it matures, and its potential environmental impacts.

A study conducted in 2015, found that experts rank 'environment' as one of the weakest drivers for AV development<sup>2</sup> (Milakis et al., 2015), while other studies indicate that AVs may result in higher rates of congestion, vehicle kilometres travelled (VKT), and lead to a cannibalisation of public transport (Lang et al., 2016; Milakis et al., 2015; Schaller Consulting, 2017; Wadud et al., 2016). For these reasons, further examination into the extent to which cities can act to ensure this technology is steered toward electrification, sharing, and PT integration is required, and city authorities will need to decide their role in this process (Bulkeley & Kern, 2006). There is currently sparse knowledge on what measures need to be taken, how feasible these are, and what futures cities face in the absence on proactive management. If this matter is left untouched, there is a very real possibility that the advent of AVs will create a similar level of dependence as our current reliance on the automobile (Schaller Consulting, 2017; Wadud et al., 2016). This would resemble previous developments, where our cities have become disproportionately designed around the automobile (Newman & Kenworthy, 2006), wherein the city is both defined by, and dependent on the AV.

This paper assumes that that the emergent narratives around AVs and sustainable mobility collectively point toward likely futures. In drawing on these narratives and relevant trends, it will thus be able to produce a list of probable scenarios, likely to occur from the actions taken by cities, to either facilitate or restrict the technology to reach environmentally positive outcomes.

## 1.2 Research purpose

Against this background, the purpose of this research is to take stock of potential measures cities can pursue to promote environmentally sustainable integration of AVs. Despite the nascent state of AVs, the paper is founded on the belief that pre-emptive preparation and purposive intervention are two critical prerequisites that can help ensure that AVs realise their potential as a sustainable form of urban mobility. In building on this assumption, the paper will test the feasibility of the compiled measures through an evaluation by Copenhagen's technical and environmental administration, i.e. the department responsible for the integration of AVs. The author recognises that this purpose can be perceived as premature, however, historical accounts teach us that misguided action, or inaction, can lead to undesirable lock-ins that can be difficult to escape

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<sup>2</sup> The four other drivers in this study were: technology, policies, customers' attitudes, and economy.

(Arthur, 1989; Newman & Kenworthy, 2006; Unruh, 2000), such as the exacerbation of shopping, living, recreation, and work is dispersed and only reachable by car (Newman & Kenworthy, 2006).

### **1.3 Research aim**

The aim of this research is to understand, from both literature and actors at the cutting-edge of AV testing, deployment, and implementation, what measures can determine the extent to which AVs constitute a sustainable form of urban transportation. In so doing, the paper will explore the prevailing narratives, and the various expectations held by central actors in AV integration into urban settings.

As the purpose of this paper is to begin bridging the gap between literature and purposive action, with the objective to pre-empt and create a sustainable transport system using AVs, the paper will draw on the use of scenarios to capture possible pathways and investigate the feasibility of various measures to achieve desired outcomes. The paper will generate four generic scenarios, constructed from various measures that can be categorised as either facilitative of AVs environmentally positive attributes, or restrictive of their environmentally negative uses.

The final task of this paper will be to contextualise the measures to Copenhagen. The aim of this task is to validate and evaluate the compiled measures, and to provide insight into the case of Copenhagen, based on knowledge of the Strategic Niche Management (SNM) framework. These measures will be contextualised based on feasibility, in hopes of arriving at a score, and comments from the administration responsible for AV integration. This score should highlight which generic scenario Copenhagen is trending towards, and provide a basis for advice on how Copenhagen could proceed in order to steer the development towards other scenarios – if the current likely scenario is deemed undesirable.

The hope is that this work will help critical areas of concern, and allow Copenhagen's technical and environmental administration to build on the work, by working towards making measures currently believed to be unfeasible, feasible.

### **1.4 Research questions**

- What are the possible measures cities need to consider when integrating autonomous vehicles for the purpose of achieving sustainable mobility?
  - What generic scenarios can be extrapolated from these measures?
- How feasible are these measures in the context of Copenhagen?
  - What obstacles are Copenhagen likely face in the application these measures?

### **1.5 Scope and limitations**

#### **Scope**

Automation will eventually extend to most, if not all, forms of transportation. However, this paper will focus predominantly on autonomous<sup>3</sup> road-based transportation of people in cities, both through private and public modes. The rationale behind this focus is the stark differences between the transport of people and the transport of goods; with the former having far more real-time decision-makers, i.e. daily commuters.

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<sup>3</sup> Distinction between autonomy and automation will be made clearer in the background

The informants selected for this paper will be actors responsible for – or involved with – the implementation and functioning of AV systems. The information the paper will use is the narratives of these actors; their expectations and what knowledge will be required. The actors will consist of municipal transport administrators, actors within municipal transport companies, and actors actively testing and researching the technology.

## Limitations

- The current state of the technology is the largest limitation of the research, as real-world empirical research being conducted on the topic is predominantly technical (Hörl et al., 2016), or concerned with the legal aspects of implementation (Anderson et al., 2014).
- Due to the current narrow focus on AV development, it can be expected that environmental concerns will only become more concrete in the narratives of political actors once the impacts of the technology become tangible.
- Access to certain key actors, notably original equipment manufacturers (OEMs) and transport network companies (TNCs)<sup>4</sup>, however, most of the key information pertaining to the cutting-edge of AV research is predominantly within research simulations and models.
  - Only one *indirect* actor could be accessed from the Volvo DriveMe project, and to make this informant's information more generalisable, a review of Volvo's and other OEMs' sustainability reports was conducted.

## 1.6 Concepts and definitions

### *Sustainable mobility*

In the context of this paper, sustainable mobility refers to the environmental sustainability of transport. The use of the terms 'sustainable' or 'sustainability' refers exclusively to harmful effects human actions and technologies are having on the environment, based on aspects such as emissions of damaging gases, and energy use. The term therefore does not reference social or economic sustainability.

### *Mobility service providers*

Mobility service providers, or MSPs, will be used to describe actors that engage in mobility provision. The term encapsulates anything from taxi companies, PT providers, TNCs, and OEMs. In relation to sustainable mobility, the act of mobility provision is largely accepted to have significant environmental benefit (Arbib & Seba, 2017; Holmberg, Collado, Sarasini, & Williander, 2016; Lund, 2016; Viegas et al., 2016), compared to users owning a vehicle themselves.

### *Transition theory*

Transition theory was created on the platform of multiple concepts such as path dependence, coevolution, and lock-in. These have been synthesised to produce what transition scholars refer to as the multi-level perspective. These concepts all underpin the framework of Strategic Niche Management used in this paper. Rather than going into depth on this topic in the paper, elaborations on each of these concepts can be found in the appendix.

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<sup>4</sup> TNC and OEMs will commonly be referred to as mobility service providers (MPSs) throughout the paper

## List of key assumptions<sup>5</sup>

Autonomous vehicles are inevitable, and will become a highly attractive mode of urban transport due to relatively low cost, and high level of convenience.

Autonomous vehicles are not environmentally sustainable by default, despite having inherent properties to allow for a better environmental performance relative to conventional vehicles.

Active management from cities will be required to ensure AVs contribute to sustainable mobility.

Incumbent OEMs (Mercedes, Volvo, GM, etc.) will gravitate towards becoming MSPs due to growing demand for mobility service, and the low operation costs enabled by AVs.

AVs will more likely be electric due to the lower costs of operation and maintenance, which is further amplified in AVs operated on a fleet-basis, i.e. owned and operated by organisations.

## Disposition

Having established the critical concepts for understanding this paper, as well as the key underlying assumptions pertaining to AVs, the paper will proceed as follows.

Chapter 2: As theory runs throughout the course of this paper, the theoretical framework will be presented in this section. It will describe the three expected stages radical innovations undergo to reach maturity, and which policy areas must be considered.

Chapter 3: Scenario analysis is described in this chapter, how they will be used to produce four generic scenarios, and the scoring system that will be used to determine which scenario Copenhagen is trending towards.

Chapter 4: The background will introduce AVs, when they can be expected on city streets, their expected benefits, and background information on the city of Copenhagen.

Chapter 5: The review of literature will initially cover the life-cycle impacts of EVs, followed by how they can potentially synergise with AVs, and how AVs can help overcome problems with shared mobility. The chapter will highlight the core issues surrounding the environmental sustainability of AVs, and the AV-narrative put forth by OEMs.

Chapter 6: The findings section will consist of three parts; expert expectations for potential measures, the explanation of four generic scenarios, and the final scoreboard used to determine the scenario Copenhagen is gravitating towards.

Chapter 7: This section will cover the discussion on what scenario Copenhagen appears to be trending towards, and how the SNM framework can be utilised to understand this development.

Chapter 8: The conclusion finalises the paper by summarising the identified measures, possible scenarios, what can be learnt from the application of the measures in the context of Copenhagen, recommendations for Copenhagen, and suggestions for further research.

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<sup>5</sup> This list of explicit assumptions serve as a reference point for the reader with regard to the key assumptions the underpin the research and its scenarios. The underlying justifications behind these assumptions will, however, be described in greater detail throughout the paper.

## 2 Theoretical Framework

### 2.1 Strategic Niche Management

Strategic Niche Management (SNM) is designed to facilitate the growth and diffusion of path-breaking innovations that can lead to more sustainable societies (Smith & Raven, 2012). This approach offers a set of broad steps on how to purposely integrate technologies into society. As such, the framework is often used to analyse technologies deemed ‘environmentally superior’. This approach poses a problem for this research, as a core assumption of this paper is that AVs do not need facilitation to become a reality, rather; they need to be steered toward sustainable outcomes. Therefore, the SNM framework will not be used for the purpose of explaining how AVs *ought* to be implemented, but rather a source of knowledge as to how it will *likely* integrate itself. The framework should be able to offer the necessary insight, as the framework was constructed based on the accounts of prior technological developments.

In broad terms, SNM has three generic phases: shielding, nurturing, and empowerment. Shielding refers to the phase in which a particular innovation is protected from the selective pressures of society. These selective pressures include, among others (Smith & Raven, 2012)

- **Industry structures**, i.e. how existing business models function, and industry capabilities
- **Technologies and infrastructures**, i.e. standards imposed on new technologies, infrastructural incompatibilities
- **Knowledge base**, i.e. the preference toward incremental and certainties of research
- **User relations and markets**, i.e. user preferences and poor pricing mechanisms
- **Public policies and political power**, i.e. political agendas and political networks, favouring, for example, jobs over new technologies
- **Cultural significance and association with regime**, i.e. a mismatch between existing values and new innovation

The experimental space provided by niches effectively decouples the technology’s development from these forces. Moreover, this ‘**shielding**’ is not always highly active endeavour, whereby funds or resources need to be secured to sustain the shield. Innovative technologies can be protected passively (Smith & Raven, 2012) by introducing it into unusual contexts that have favourable characteristics, such as solar PV in remote regions or on smaller islands.

The **nurturing** can occur once a shield has been established for a particular innovation, and is defined as ‘processes and mechanisms that support the development of the path-breaking innovation’ (Smith & Raven, 2012: 8). Nurturing can be broken into three general processes: articulating expectations, assisting learning processes, and helping network processes. To succeed Schot and Geels (2008) found that, expectations need to be robust, meaning that they are shared by many actors, are specific, and substantiated by on-going projects. Network building succeeds when they have plural perspectives, and strong resource commitments by stakeholders. Finally, learning processes must cover issues across the socio-technical dimensions, and rather than focusing on specific facts, it is critical that actors find alternative ways to support and value the niche (Schot & Geels, 2008; Smith & Raven, 2012).

**Empowerment** of an innovative technology is the final phase, wherein the protective shield is removed, meaning that the technology must now compete in the mainstream selection environment (Smith & Raven, 2012). Research on this stage has found that there are two distinct types of empowerment: fit and conform, and stretch and transform (Hoogma, 2002). Fit and conform refers to the prevailing regime, essentially adapting itself and become nothing but a new



element in an otherwise unchanged system. By contrast, stretch and transform refers to the institutionalisation of practices developed in the niche, effectively establishing a new criteria for the rest of the socio-technical regime to fulfil (Smith & Raven, 2012).

While any integration of a new more sustainable innovation can be considered positive, fit and conform empowerment does not modify the existing practices and values in the regime, meaning that empowerment only manages to fit and conform the new technology, leaving it prone to failures such as the rebound effect (van den Bergh, 2011). It is for this reason that stretch and transform empowerment is required to actively undermine the existing regime, which likely has protection institutionalised for a number of key industries, such as subsidies for the fossil fuel industry (Smith & Raven, 2012). Stretch and transform empowerment must therefore push for policies and institutional reforms that actively favour the path-breaking innovation, preferably at the expense of the existing measures that benefit the regime (Smith & Raven, 2012).

What is important to understand from this framework is that it delineates the likely development of technologies based on historical accounts, and that regardless of purposive measures, radical technologies will follow a trend of shielding, nurturing, and empowerment. The framework draws on this understanding to highlight what measures involved actors – especially policy-makers – can undertake to both accelerate the process and favour desirable technologies. In short, any radically disruptive technology, i.e. technologies that are not incremental iterations on existing variants, will follow the steps of SNM, which means that the lens it provides serves as an analytical tool. Furthermore, the articulation of expectations constitute the step preceding the experimental projects that develop and dictate a technology's role in society. According to Schlipzand, Raven, and Van Est (2011), the articulation of expectations serves to reduce uncertainty in the process of innovation, by allowing the technology to be accepted within both public and private agendas, and thus facilitate resource mobilisation.

A study by Schot and Geels (2008) identified specific policy areas, their respective guidelines from SNM, and potential dilemmas. Their list includes expectations, learning, upscaling, network, protection, and niche-regime interaction. **Expectations**, they argue, must be both flexible and iterative, but must also have a level of persistency, i.e. a general set of objectives and targets must be used to guide its development. **Learning** must be varied, and inclusive of multiple perspectives, but learning efforts cannot be too broad, as it will dilute the resources, and subsequently delay commitments from consumers and policy makers. **Upscaling** must be balanced between the stepwise, incremental developments, and breakthrough strategies that allow the technology to achieve rapid success, but at a higher risk of failure, due to misalignments with the selection environment. **Networks** must include both incumbents and radical outsiders, the former of whom will likely have the resources to facilitate the technology, but too many vested interests in the existing system. **Protection** is required to give the technology time to become relevant to various stakeholders, but too much protection could prevent the technology from adapting to selection pressures it will face once the protection is removed. Finally, **niche-regime interaction** refers to the process of waiting for windows of opportunity in the existing regime, and the process of actively promoting the niche technology during such 'cracks' in the existing regime.

### 3 Background

The purpose of this background is to introduce the reader to AVs; their likely timeline for adoption, developers involved, and expected benefits. The chapter will finalise with background information on the city of Copenhagen.

#### 3.1 Autonomous vehicles

Autonomous Vehicles – also commonly referred to as Self-Driving Vehicles or Driverless Vehicles – are vehicles that equipped with technologies that allow vehicles to drive themselves (SAE, 2016). This ability is possible through the use of various sensors, transmitters, and computing-technologies (ERTRAC, 2015).

The capabilities of autonomous technologies have been divided into five separate stages, which each decrease the responsibility of the driver, and the final stage of ‘full-autonomy’ being defined as “the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver” (SAE, 2016). A simplified explanation of these stages, and the driver’s responsibility at each respective stage has been provided by BMW (BMW Group, 2016b):

- Level 1: Feet off
  - Driver responsible for steering and supervising acceleration and braking
- Level 2: Hands temporarily off
  - Supervising vehicle control; eyes on the road
- Level 3: Eyes off
  - Always prepared to take over; eyes on the dashboard
- Level 4: Mind off
  - Required to only drive on certain roads
- Level 5: Passenger
  - Driver no longer has any responsibilities, and is effectively a passenger

As can be seen, while each step is underpinned by significant improvements in technology, the levels signify more a ‘statement of confidence’ on behalf of the OEM, as they assume an increasing level responsibility from the driver.

#### 3.2 Difference between autonomous and automated vehicles

Automated vehicles and autonomous vehicles, despite often used interchangeably, are not the same. Automated vehicles refer to the vehicles that are capable of driving themselves, but rely extensively on ‘artificial hints’ in the environment (Antsaklis et al., 1990). These external inputs are often referred to as vehicle-to-infrastructure (V2I) (Washburn, 2014). Autonomous vehicles, on the other hand, refer to vehicles capable of handling uncertainty, and compensate for system failure without external intervention (Antsaklis et al., 1990). Although the term ‘autonomous vehicle’ is frequently used, no vehicle exists as of yet that fulfils the criteria of a fully autonomous vehicle. Moreover, the V2I technologies that are being installed to support automated vehicles will likely remain once the technology reaches full - or level 5 -autonomy V2I will likely remain as a safety- and control-measure (Washburn, 2014). It therefore makes sense to conceptualise autonomous vehicles and automated vehicles on a spectrum, rather than two binary technologies.

This paper will focus on autonomous vehicles – not automated vehicles. For the purpose of this paper, these vehicles will be defined as vehicles of any size i.e. resembling coaches, mini-buses, personal automobiles etc., capable of driving on open roads, without the need for external assistance. As these vehicles do not yet exist, some overlap between autonomous and automated

are inevitable. The most important distinction is that the former can be owned and used by a wide spectrum of actors, i.e. private owners, taxi-companies, and PT actors, whereas the latter is largely constrained to large, organised operators such as private companies.

### 3.3 Timeframe of adoption

A report conducted by the Boston Consulting Group (2015) found that cities are expecting these vehicles by 2025, while other studies assume that vehicles will reach full-autonomy before this time (Viegas & Martinez, 2017). In terms of when these vehicles will become available to consumers, the general feeling among policymakers, urban planners (WEF & BCG, 2015), and Original Equipment Manufacturers (OEMs) the coming decade is often referenced (BMW Group, 2016a; Daimler AG, 2016; Volkswagen Group, 2016a). Roadmaps outlining the various technological obstacles similarly conclude that 2025 is when most technologies will have passed their R&D and demonstration stages, and begin entering the market (Dokic et. al., 2015). Beyond this point, adoption forecasts begin to differ, depending largely on how the ‘adoption rate’ is defined. In a symposium on AVs, experts agreed that 2025 will be a significant year for both urban and highway automation, while 2030 is the likely year where full-autonomy is achieved, and widespread use and adoption can be expected (Volpe, 2014).

There are two general ways to define the adoption rate: proportion of AVs ‘on the road’, and proportion of kilometres driven by AVs. The former will tell you how many vehicles have been sold, which is applicable to the existing model of individual ownership, but the latter is likely a more accurate representation of AV adoption. Once the initial technical and legal hurdles have been overcome, OEMs are expected to deploy their offerings en masse in order to capture the growing mobility service market (Arbib & Seba, 2017). As a consequence of this rush, estimates show that by 2045, up to 87% of vehicles on roads in the United States could be fully autonomous (Bansal & Kockelman, 2017). Another estimates that 95% of passenger vehicle kilometres travelled (VKT) in the U.S. will be autonomous by 2027 (Arbib & Seba, 2017).

### 3.4 The Vienna Convention

One major hurdle towards the eventual diffusion of AVs is outdated legislation (Anderson et al., 2014). The most significant legislation in relation to AV implementation is the Vienna Convention on Road Traffic, which entered into force in 1977, and was designed to facilitate international (i.e. cross-border) traffic, safety rules, and standard traffic rules (United Nations Conference on Road and Motor Transport, 1968). Recent amendments to this treaty has been included to facilitate the advent of AVs, notably:

- Article 8, paragraph 5: “Every driver shall at all times **be able to** control his vehicle”
- Article 13, paragraph 8: “Every driver of a vehicle shall at all times have his vehicle under control so as to **be able to** exercise due and proper care and to be at all times be in a position to perform all the manoeuvres required of him”

In the wording ‘be able to’, is a clear reference to the possibility of self-driving capabilities. However, depending on how member states choose to interpret these statements will determine whether further amendments to the convention will be required in order to permit AVs. If interpreted as ‘driver must always be in control’, further amendments will be required, whereas if interpreted as ‘driver must be **capable** of being in control’ no amendments are required (Eugensson, n.d.). At present, Sweden appears to be the only country that loosely adheres to the latter definition, with companies like Volvo willing to assume responsibility in case of accidents while the vehicle is driving autonomously.

## 3.5 Developers of autonomous vehicles

### Original Equipment Manufacturers

OEMs have been working their way – consciously or otherwise – towards full autonomy for a number of years. As autonomy is achieved through the combination of various technologies, each undergoing continuous improvement (ERTRAC, 2015), then relatively simple features such as cruise control and lane-keeping can be considered constituents of full-autonomy by the Society of Automotive Engineers' (SAE, 2016) definition. The drive towards autonomy, at least in the case of OEMs, can therefore be interpreted as response to consumer demand for added value and legislative pressure for greater safety (Anderson et al., 2014).

However, as we are now approaching full-autonomy, questions are being raised about which OEMs are going to emerge as winners (Giffi, Vitale, Robinson, & Pingitore, 2017), and even if OEMs are going to win in this mobility-provision market (Wilson et al., 2015). Among the OEMs there are destined to be laggards and leaders, but with only a few companies such as Tesla and Google overtly showcasing their achievements, it can be difficult to gauge who will be first to market. Moreover, the reason that a company, whose success is founded on an internet search engine, is interested in AV is another matter entirely. The likely explanation is that AVs open up an entirely new in-vehicle market that companies with different expertise can exploit (Wilson et al., 2015), tapping into the new 'connected consumer'.

### Innovative pioneers

A significant group of entrants, which will be referred to as 'innovative and radical pioneers', constitute very early adopters. For years, these actors have been testing automated mobility solutions, while other have entered by virtue of technical expertise in other areas, such as mapping or data processing. These include recognisable actors, namely Google, Intel, NVidia, and even Apple has been speculated to be working on AVs (Mercer, 2017). Whether these companies intend to become MSPs, or suppliers of components and in-vehicle entertainment remains to be seen. Other entrants whose objectives are to provide mobility include 2getthere, Easymile, Navya, Localmotors, and CityMobil, have emerged due to their previous experience with automated transport systems.

## 3.6 Expected benefits of Autonomous Vehicles

The most often highlighted benefit of AVs is safety (Anderson et al., 2014; Litman, 2014; Meyer et al., 2017). As AVs will be both untiring and not prone to distractions, crashes and injury rates are expected to improve drastically. Depending on the level of penetration, one study expects to see high returns on safety at penetrations rates of just 10%, while near full penetration 90% of all vehicle accidents and crashes can be avoided (Bertoncello & Wee, 2015; Fagnant & Kockelman, 2015).

The economic gains from this technology are profound, and will be felt across society, by individuals, businesses, and governments alike. For businesses alone, a multi-trillion dollar market is expected to emerge from AVs, due to improvements in productivity, reduction in accident costs, fuel saving costs (Shanker et al., 2013). A new in-vehicle entertainment market for the 'connected consumer' is similarly expected to produce significant opportunities for new revenue streams (McKinsey, 2016). This in-vehicle experience is expected to drastically improve the quality of travel, and consequently to have significant appeal, all while reducing the price of mobility to a fraction of conventional taxis (Keeney, 2017). At a much lower operation cost, government expect to reduce their expenditures on PT (Bösch, Becker, Becker, & Axhausen, 2017), and while the loss of jobs is often an area of concern, a new range of jobs are expected to emerge (Lutz, 2016).

In terms of accessibility, i.e. how well a given place connects the opportunities of work, leisure, and shopping, is another expected benefit (Meyer et al., 2017). The clear benefit of the increased mobility of AVs is the inclusion of new demographics otherwise unable to access door-to-door at an affordable price, such as disabled, elderly, or youth (Childress et al., 2015; Meyer et al., 2017). Moreover, once high numbers of shared AVs become common on city streets the wait-times for mobility are expected to drastically decrease (Burns et al., 2013; Viegas et al., 2016). Whether this door-to-door is the most desirable model is another concern, and as will be highlighted later, the use of AVs as a first/last-mile service is likely a superior option from an environmental standpoint.

Improvements to land utilisation is another benefit, as AVs have been estimated to increase road capacities between 30-80%, as they will be able to drive in closer proximities, accelerate and decelerate simultaneously, and bypass the need come to a stop at intersections (Brownell, 2013; Childress et al., 2015; Friedrich, 2015). Coupled with the reduced need for parking lots, these spaces can be repurposed with urban infill. (Litman, 2014; Rodoulis, 2014; Schaller Consulting, 2017).

In light of the aforementioned benefits, whether sustainability will become prioritised is clearly uncertain. As can be discerned from the economic benefits in particular, the use of road-based passenger transport could increase dramatically. Although the general discourse appears to agree that shared, electric AVs offer more sustainable mobility than conventional, human-operated, ICEVs (Burns et al., 2013; Fulton et al., 2017; Viegas & Martinez, 2017), it can be difficult to identify any “natural” limits to the use and subsequent market-growth of this technology. While sharing is touted as a means to reduce the number of vehicles on the road (Burns et al., 2013; Fagnant & Kockelman, 2016); at a sharp reduction in price, it can be difficult to identify what would make people share. Electrification may be more likely to occur, as it would likely lower operating costs of fleet-based AVs (Arbib & Seba, 2017; Burns et al., 2013; Viegas et al., 2016), but their environmental impacts would vary depending on the context, and electricity mix. It is clear that when trying to identify potential drivers that could ensure AVs contribute to sustainable mobility, there are notable conflicts with other benefits. It can thus be difficult to argue that AVs and MSPs, if left unmanaged and run entirely by industry that the optimal environmental outcomes would naturally manifest.

### **3.7 Case of Copenhagen**

Copenhagen will soon be part of a list of cities actively exploring and experimenting with AVs (Tækker, 2017). As with any of the current test cities, some of Copenhagen’s overarching objectives will include an understanding of the technology’s technical prerequisites, its potential implications on employment, necessary policy amendments, the technology’s possible benefits for safety and sustainability (Københavns Kommune, 2017).

To assess the current state of Copenhagen, there are a number of developments that must be understood. To frame the existing mobility plans of Copenhagen, the SNM guidelines for policy action and dilemmas will be used. This section will proceed to cover trends that will become increasingly relevant as AVs become a reality.

#### **Existing sustainable urban mobility plans and legislation**

##### *Expectations*

Copenhagen’s current climate plan, KBH2025 has set a list of mobility objectives for a 2025 deadline. These include reducing personal car trips from 33% of total trips taken down to 25%. Moreover, all PT must be CO<sub>2</sub> neutral, and 20-30% of light-duty vehicles and 30-40% of heavy duty vehicles must use alternative fuels (Københavns Kommune, 2016b). Overall, Copenhagen

plans to reduce roughly 58% of the transport related emissions with efforts to improve PT, and provide an integrated Mobility as a Service (MaaS) to help travellers seamlessly travel between modes of transport (Københavns Kommune, 2016b). In comparison, focus on carsharing, eco-driving, and signal-optimisation makes up around 6.5%, and bicycle infrastructure is expected to account for 26% of the CO<sub>2</sub> reductions (Københavns Kommune, 2016b).

### *Learning*

As of 2017, the city's action plan for green mobility (Københavns Kommune, 2012) has been updated to include the implementation of self-driving vehicles. Although brief, the new plan recognises the potential for substantial benefit that can be derived from AVs, but also that numerous challenges will come along with the technology (Københavns Kommune, 2017). The plan emphasises the need to create an interplay between the technology and the city's extensive PT system and bike-oriented infrastructure. Moreover, the purpose of including AVs into the plan at this stage, is to "clarify the self-driving solutions in the city's traffic... understand the consequences on the layout of street-spaces, urban-planning, and other long-term effects" (Københavns Kommune, 2017: 29). In order to do this, the city intends to conduct at least two trials to elucidate the technical and city-relevant issues.

### *Protection*

At the beginning of 2017, Denmark passed legislation allowing for testing of these vehicles on Danish roads (Transport- Bygnings- og Boligministeriet, 2017). Copenhagen is one city that is already planning to deploy a test-zone, on the north-eastern peninsula of Nordhavn (Northern Harbour). In addition, a company known as Autonomous Mobility, an extension of the largest automobile import company in Denmark called Semler Group, is currently testing the Olli autonomous minibus produced by LocalMotors (Autonomous Mobility, n.d.). Testing of these vehicles have been constrained to a limited area on campus at the Danish Technical University, where students and researchers are looking into areas of bus-route optimisation, on-demand transportation, machine-learning and image recognition (Tækker, 2017).

### *Network*

The central node of the emergent network for AV implementation is Copenhagen's technical and environmental administration, which is overseen by the municipality's committee for technical and environmental matters. It is responsible for the implementation of strategic plans, management and operation of roads, parking, and sanitation (Københavns Kommune, n.d.). By extension, the Copenhagen's technical and environmental administration is overseeing the implementation of the city's green mobility and 2025 climate plans (Københavns Kommune, n.d., Københavns Kommune 2016b).

### *Upscaling and niche-regime interaction*

These two areas remain unclear, but below are a number of important trends and elements in Copenhagen that will become relevant once AVs are implemented. With that said, concerns with regards to the niche-regime interaction were apparent across literature and the findings, and can thus be found in these sections.

## Rising personal car ownership

One of the main objectives for AVs is to reduce personal car ownership, which remains a growing problem in Copenhagen. Since the year 2010, the population within the capital region<sup>6</sup> has grown from 1.680.271 to 1.811.809 inhabitants (Statistikbanken, n.d.-b); an increase of 7.8%. As is to be expected, a rising population means a rise in the demand for urban mobility. While Copenhagen does have a range of public mobility services, personal car ownership has, in this same period, seen an increase from 573.890 registered personal automobiles to 683.413 (Statistikbanken, n.d.-a), growing at a higher rate than population, at 19.1%.

## Emissions from road transport

According to the Copenhagen's emission account for 2015, personal automobile use accounts for roughly 16% of the city's total emissions<sup>8</sup> (Københavns Kommune, 2015). More recent data is not available, and in the period from 2015 to 2017, the number of registered personal automobiles rose from 633794 to 683413, an increase of 7.8% (Statistikbanken, n.d.-a). Of the total emissions from road transport, personal automobiles account for 68%, while trucks account for 25% (Københavns Kommune, 2016b).

Emission source	Emissions (CO <sub>2</sub> tons/yr)
Personal automobile	234.014 (16%)
Road-based transport <sup>7</sup>	344.688 (24%)
Total	1.551.898
Total (adjusted for wind-energy)	1.450.358

Table 1. Road-based emission in CPH

In this table, total emissions from the city has been included, as well as the total when adjusting for the presence of carbon neutral wind-energy, which becomes relevant as road transport becomes electrified. Moreover, from this data, it can be inferred that the personal automobile ownership is not solely a consequence of rising population, but that other factors are contributing to this increase.

## Legislation for electric vehicles

Automobiles in Denmark is subject to a significant registration tax, which was instituted back in 1925, and has meant that vehicles could cost up to 280% of their original value (Retsinformation, n.d.). Between 1984-2016, however, electric vehicles were exempt from this charge, only for it to be reintroduced at the beginning of 2016, starting at 20% of the tax of internal combustion engine vehicles (ICEVs), but increasing to 100% by 2020 (Praëm, 2015). The effects of amendment has been immediately clear (Dansk Elbil Alliance, n.d.), as can be seen in Fig. 1, where sales of EVs plummeted from 4523 in 2015, to 1262 in 2016.

<sup>6</sup> This figure, albeit three times larger than the population of the city itself, was chosen as the city is connected to a network of cities, across which PT services operate

<sup>7</sup> This figure includes busses, motorcycles, and trucks (Københavns Kommune, 2016a)

<sup>8</sup> This figure is currently undergoing revision, suggesting the emissions from road based transport may be up to 70% greater than was has previously been reported (Jyllands Posten, 2017)

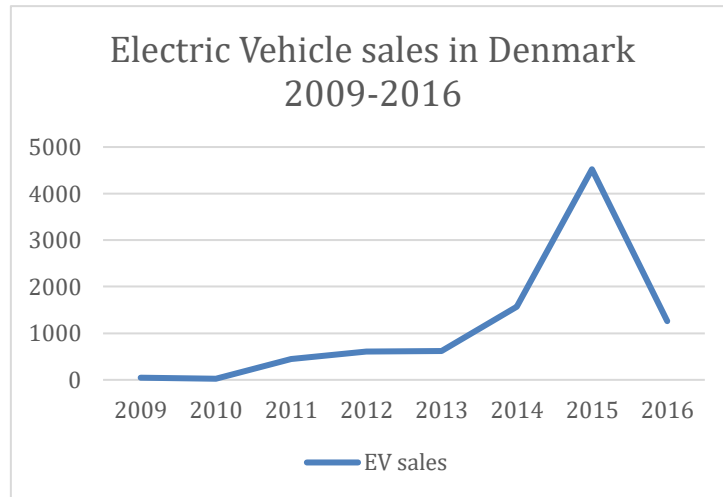


Figure 1. EV sales in Denmark

### Electricity mix

According to a report by the Danish Energy Agency, in 2014 renewable electricity accounted for 53.4% of the Danish energy consumption. Of this total, 38.8% came from wind-power, 11.4% from biomass, and solar, hydro, biogas made up the remaining 3.2% (DEA, 2016). For Copenhagen specifically, wind power has begun to grow rapidly, while other sources of renewable electricity has seen a decline (Københavns Kommune, 2016a). Further investments into wind energy will see 360MW renewable energy capacity be added between 2017 and 2025 (Københavns Kommune, 2016b).

Electricity source	Amount MWh/yr (2014)	Amount MWh/yr (2015)
Wind	178.992	233.854
Solar	751	736
Waste	118.024	94.203
Biomass	176.480	142.695
Total	474.247	471.487

Table 2. Growth of renewables in CPH

Based on these numbers, the paper will assume that Copenhagen is trending towards a future of high renewable energy production, and that the electricity mix will not be a critical point for electrified mobility. The more likely issues will be the rate of electric vehicle adoption (DEA Basis fremskrivning, 2017), and if adoption rates do begin improving significantly, whether the supply can sufficiently meet the additional demand from EVs.



## Public transport

In Copenhagen PT is comprised of a network of busses, trains, and metros, run by Movia, DSB and Metroselskabet, respectively. These three operators have been unified by the customer service DOT (Din Offentlige Transport; ‘Your Public Transport’). In addition, the city has bike rentals (Bycyklen), as well as the carsharing services DriveNow, and LetsGo, with the former being a free-floating system, while the latter requires to you pick up and return the vehicle at fixed locations (Lund, 2016).

In 2015, 21% of all trips in Copenhagen were made using PT, compared to 17% by walk, 29% by bike, and 33% by personal car (Københavns Kommune, 2016b). Movia is the traffic company responsible for all public bus transport in Copenhagen, and is collectively owned by 45 municipalities on the island of Zealand (Movia, n.d.-c). The company contracts its public bus routes for 14 operators (Movia, n.d.-b), and in Copenhagen the company transported a total of 184,634,130 passengers (Movia, n.d.-c).

On top of scheduled PT services, Movia also provides something called ‘Flextraffic’, a bookable taxi-like service. Movia emphasises that this is no taxi-service. While the service can be used by anyone, it requires customers book the trip two hours in advance; and may also arrive up to 15 minutes before, or 45 minutes after the trip has been booked (Movia, n.d.-a). The service does not operate throughout the day; only from 6:00 to 23:00, and it often requires you to share your ride. In other words, while the service does provide the same level of ‘transport precision’ as conventional taxis, the service has a number of conditions, which effectively precludes it from offering the same timely convenience as taxis.

Movia is currently investigating, together with the City of Copenhagen, how to test a Mobility as a Service (MaaS) system to integrate the various mobility services in the city. Currently, a prototype is planned for testing throughout 2018, and finalised with an evaluation. However, this plan is not yet confirmed. Shown below is an iteration of a working concept of MaaS.

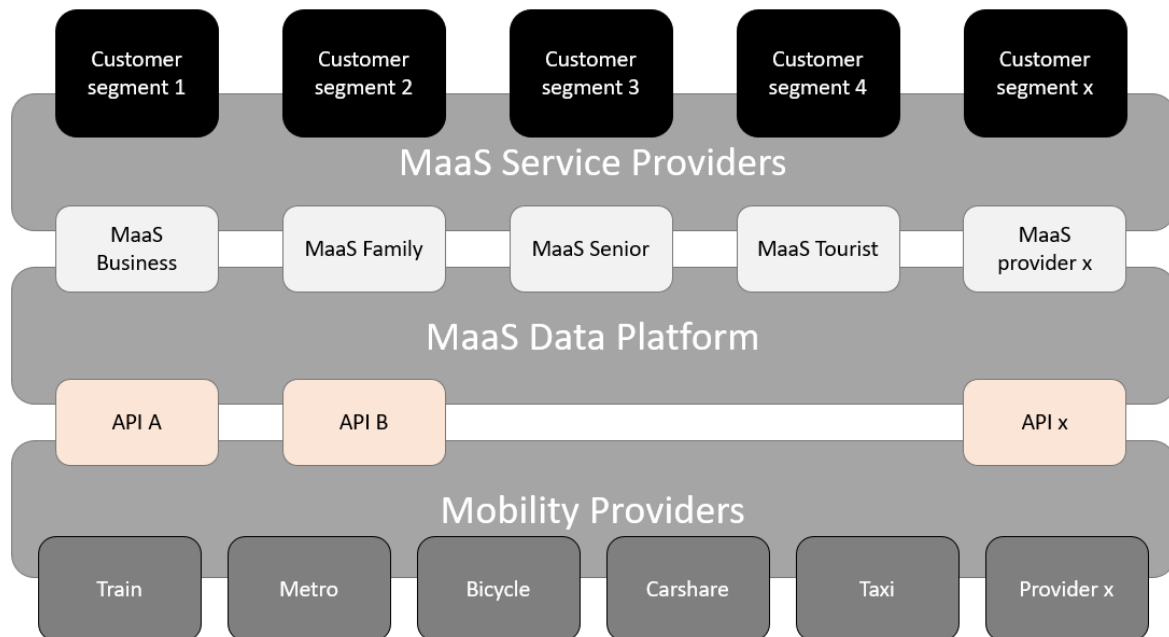


Figure 2. Movia MaaS Concept

## **MSPs in Denmark**

In April of 2017, Denmark enacted legislation that forced TNCs such as Uber, to comply with similar safety and training standards as taxis (Mathiasen, 2017). This ended 2.5 year strife between the Danish taxi companies and Uber, where it was argued that Uber had an unfair advantage, since they were not obliged to comply with these same standards<sup>9</sup>. After the legislation was passed, Uber left the Danish market.

The controversy of Uber is not only felt in Denmark, but across the globe (Rhodes, 2017), and in Denmark the fight was fought across lines of ideology, economics, and safety (Clement, 2017; Mathiasen, 2017). At its core, the controversy surrounding the company is largely due to the lower costs of the drivers, and their disruption of existing mobility providers, as the company managed to capture 300.000 Danish users over this 2.5 year period (Mathiasen, 2017). Not only does this indicate that a strong backlash toward MSPs using AVs is likely, once AVs become a reality, they will allow an even greater number of entrants into this space. It also suggests that the service will be highly attractive to the Danish consumer, and that the use of this technology will likely reflect this.

In short, the dominant business model that the majority of MSPs will utilize for AVs is as attractive in Denmark, as in most other countries that they have been deployed. This assumption will be key to the upcoming discussion, and as will become apparent in the literature review, sharp increases in MSP use can have detrimental effects on cities' PT systems.

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<sup>9</sup> Requires that Uber drivers have taxi-meters and weight scales in the seats of the vehicle (Mathiasen, 2017)

## 4 Method

### Data collection

#### *Literature review*

Sources used for this review include academic papers, as well as grey literature (i.e. scientific and consulting reports). Given the novelty of the technology in question, the literature review will encompass simulation-based, and speculative research, as well other scenario analyses that have attempted to understand the possible impacts of AVs in urban contexts.

To access articles, Google Scholar, SCOPUS, and Lubsearch (library service connected to Research Gate, ScienceDirect, Elsevier, etc.) was used. Keywords used in the initial search included autonomous vehicles, sustainable mobility, urban sustainability. Upon finding an initial group of papers, the research snow-balled using the citations of these works. This search led to growing number of papers highlighting the potential benefits of the technology, as well as its likely shortcomings and harmful effects. The search also pointed to a number of pre-existing concepts and measures that are in use today that could potentially be used to constrain the negative impacts of AVs, or be enhanced by the technology.

In addition to investigating the literature on sustainable mobility concepts in relation to AVs, the narratives of OEMs were analysed (Section 5.3.1). The method used to investigate this changing narrative, a counting of paragraphs with relevant keywords was conducted. If multiple keywords were mentioned in the same paragraph, it would only be counted once. Moreover, summarised 'lists' typically found in the concluding sections were excluded, as the purpose of this task is to highlight emphasis within the reports. In line with this, however, repeated statements that were clearly emphasised in the report were double-counted, these include statements typically in larger font sizes and different colours, often stated by executives within the company.

The keywords used for electric were: electric, electricity, electrification, electromobility, e-mobility, electric drivetrain, battery-electric, plug-in hybrid electric. Keywords, and the paragraph they were found, were only counted if the topic pertained to the vehicle technology. For example, if electricity was mentioned in relation to 'renewable' electricity for 'production facilities' they were omitted. For comparison, other forms of sustainable energy sources, notably biofuels and hydrogen will be included, based on the keywords 'bio-methane/ethanol/gas/fuel' and hydrogen.

Keywords used for autonomy were: autonomy, autonomous, driverless, self-driving, and vehicle-2-x. Once again, these terms, particularly autonomy were used to describe other processes, such as production, and thus were not counted.

Finally, the mobility service offerings of each OEM were included to demonstrate that these companies are exploring and building expertise in markets beyond their core business, i.e. moving from providing the *service* of mobility, rather than selling the *product* of the automobile.

In selecting the two years: 2012 and 2016, the latter was chosen simply due to it being the most recent iteration. The former, however, was chosen due to 2012 being the year where Uber, Lyft, and Tesla began to establish themselves. The relevance of these companies are that they have demonstrated a proof and viability of concept, Tesla with their Model S, and Uber and Lyft with their Smartphone-based, ridesharing service. Therefore these years were chosen based on the assumption that Tesla demonstrated that EVs can sufficiently serve the daily mobility needs of their owners, while Uber and Lyft demonstrated that a large market exists for Transport Network Companies.

*Expert interviews*

The informants for this paper included city administrators and researchers currently engaged in AV research and implementation. These cities included Amsterdam, Berlin, and Gothenburg. On top of these were actors involved in the deployment of these vehicles in their current test-zones, namely CityMobil2, 2getthere, Project Gateway, and Volvo’s DriveMe.

Moreover, a slightly broader range of actors were interviewed in Copenhagen. These included Movia; Copenhagen’s public transport company, Metroselskabet; Copenhagen’s metro company, and Økologisk Råd; the ‘ecological council’, a political organisation promoting sustainable development.

Experts were encouraged to answer with regard to their expectations on what measures would be required to ensure that AVs contribute to sustainable urban mobility. This naturally constitutes ‘speculation’, but granted their knowledge and future roles in this transition, these speculations were assumed to be highly likely, to the extent that they would shape and affect the discourse and subsequent policies.

The theoretical underpinning for this line of questioning is found within transition theory and SNM, in that expectations typically make up the initial stage in which a technology is shaped by society. As can be seen in the figure below by Raven and Geels (Raven & Geels, 2010). Granted the budding state of the technology, expectations were deemed the most telling indicator of likely future policies and developments.

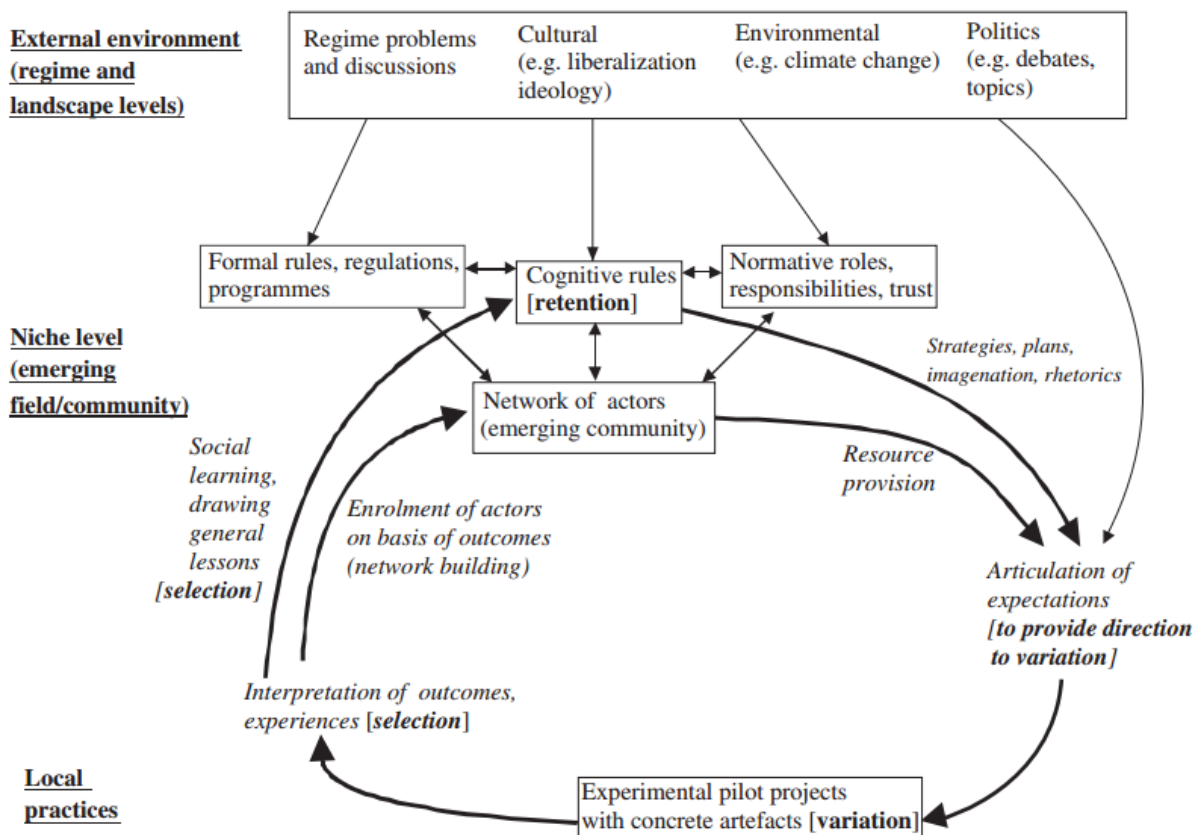


Figure 3. Dynamics in socio-cognitive technology evolution; articulation of expectations (Raven & Geels, 2010)

## 4.1 Scenario analysis

Scenarios are defined as the description of a possible future developments, and the paths that may lead to said futures (Kosow & Gaßner, 2008). It does not provide a comprehensive description of the future, only ‘segments of reality’ (Kahn & Wiener, 2000), and adds value to research through “the observation of certain relevant key factors” (Kosow & Gaßner, 2008: 11).

### Function of scenarios

There are four generic functions for scenarios; explorative, communication, goal-setting, and strategy formation (Kosow & Gaßner, 2008: 18-20). The latter of these has been selected for the research, as scenarios make it “possible to work out options and indicators for taking action, ... as well as the ability to evaluate decision-making processes, actions to be taken, and strategies” (Kosow & Gaßner, 2008: 20).

In preface to his own narrative scenario analysis, Townsend (2014: 5) argues that in order for scenarios to be an effective thinking tool they must:

- Form a good story, they must be plausible (i.e. stem from events based on present conditions and emerging trends)
- Specific in terms of cause and effect
- Consistent and not contradictory
- Relevant in terms of important issues and future uncertainties
- Distinct from one another

Framing the aim of this paper through this logic, it is to explore key factors that contribute to the sustainability of AVs, and devise possible strategies based on the indicators of sustainable urban AVs, and possible strategies to achieve this aim.

### Phases of scenarios

In constructing scenarios there are five general steps (Kosow & Gaßner, 2008: 25)

1. Identification of scenario field
2. Key factor identification
3. Key factor analysis
4. Scenario generation
5. Scenario transfer

*Identification of scenario field* involves defining the scope of the scenario, i.e. timeframe, core issue(s), and scope (Kosow & Gaßner, 2008). In this paper, the scenario field focuses on autonomous passenger transport, and city-level actions that can be undertaken to promote the sustainable integration of AVs. As both the scope and timeframe have been established in the background, the literature review will complete the ‘scenario field’ by focusing on core issues. The method used to identify these issues will be what Hsieh and Shannon refer to as a directed content analysis (2005: 1281). This means that the focus of the literature review will be looking specifically for environmental issues that are expected to emerge from urban AV integration.

*Key factor identification*, involves selecting the central “variables, parameters, trends, developments, and events, which receive central attention during the further course of the scenario” (Kosow & Gaßner, 2008: 26-27). These factors will consist of the ‘purposive measures’ cities can pursue to address the core issues, and these measures will subsequently be used to “establish a sound

theoretical foundation for each scenario” (Kosow & Gaßner, 2008: 27). Both literature and interviews were used to identify the possible measures.

*Key factor analysis* is conducted to find which “possible future salient characteristics are conceivable in each case... this step can be carried out in numerous ways, [and] it always contains intuitive and creative aspects; these are essential for visualising the various future developments of any key factor” (Kosow & Gaßner, 2008: 27). This preliminary analysis consists of categorising the identified measures as either ‘facilitative’ or ‘restrictive’, for the purpose of ensuring AVs contribute to the sustainable mobility in cities. Facilitative measures will be defined as measures that encourage and enable AVs to lower their environmental impact, and/or for their operators to derive significant benefits from utilising them. Restrictive measures will be defined as measures that limit AVs and their operators from acting such that their environmental impact significantly increased.

*Scenario generation* will be generated narratively (Kosow & Gaßner, 2008: 61) through the information extracted from both literature and expert interviews. As can be seen below, four generic scenarios will be produced along two axes (Kosow & Gaßner, 2008), based on degrees of facilitation and restriction. The technique deployed by this research is what is known as a ‘creative-narrative technique’, as it is often used to produce normative scenarios. The reasoning behind the axes come from Boon et al. (2014) who shows that niche management strategies are often categorised as either facilitative or restrictive, and which can be derived from the narratives or anti-narrative expressed by the key actors.

*Scenario transfer* involves an additional step of applying generated scenarios to a specific context (Kosow & Gaßner, 2008). For this research, this step will be conducted and applied to Copenhagen, through evaluation (i.e. scoring) by the project leader for AV implementation in Copenhagen. This task is aimed at generating further knowledge on the practicalities and contextual constraints of these measures, and to get a better understanding of the possible challenges Copenhagen faces.

The initial approach was to use political feasibility to determine the most likely scenario, as the organisation responsible for implementation is a public actor. However, to truly gauge political feasibility would require AV implementation be to an immediate topic in the political discourse, and thus a more general task of highlighting key obstacles of each measure was asked of the primary interviewee: Annette Kayser. As the project manager for AV integration at Copenhagen’s technical and environmental administration, Annette Kayser was deemed the most qualified respondent.

The approach was inspired by a similar work by Bulkeley and Kern (2006), who identified four generic modes of governance for local climate policy. However, in contrast to their work, this paper has two key assumptions that prevent the use of this framework. The first is that the framework applies only to technologies already deemed environmentally superior, whereas this paper focuses on *how* AVs can be made more environmentally sustainable. Second, is the assumption that governance is required to further the development of a technology to help it mature; this paper assumes that AVs will become a reality over the coming decade, regardless of local governance.

In other words, based on the two assumptions that the technology is not guaranteed to be environmentally sustainable, and that it will not require governmental support to become competitive over the next decade, investigating the technology’s implementation more broadly across axes of levels of facilitation and levels of restriction, is a more apt point of departure to highlight possible scenarios and relevant municipal actions.

To visualise the methodology, an example will be outlined. Factor A, B, C, D, and E are shown/discussed/expected to be an important attribute in making AVs more environmentally sustainable in an urban setting. Factor A, B, and C are facilitative measures that can be utilised to make AVs more environmental sustainable. D and E, on the other hand, are restrictive measures that can be instituted to ensure sustainable outcomes.

These factors are presented to the manager of AV implementation in CPH, and evaluated based on feasibility and given a score between 1 and 5:

1. Highly unfeasible
2. Unfeasible
3. Neutral; lacking knowledge
4. Feasible
5. Highly feasible

The 1-5 scale was selected to give the respondent the ability to rate the measures in terms of degrees of feasibility, as well as giving them the lenience of providing a neutral answer. Depending on whether a measure is considered feasible or unfeasible will determine whether points are allocated toward the high or low scenarios, i.e. a facilitative measure deemed politically unfeasible will see points allocated towards S1 and S3. Furthermore, in scoring the various answers and applying them to the scenarios, the moderate answers 2 and 4, will give a score of 1 point, while the extremes 1 and 5 will give a score of 2 points.

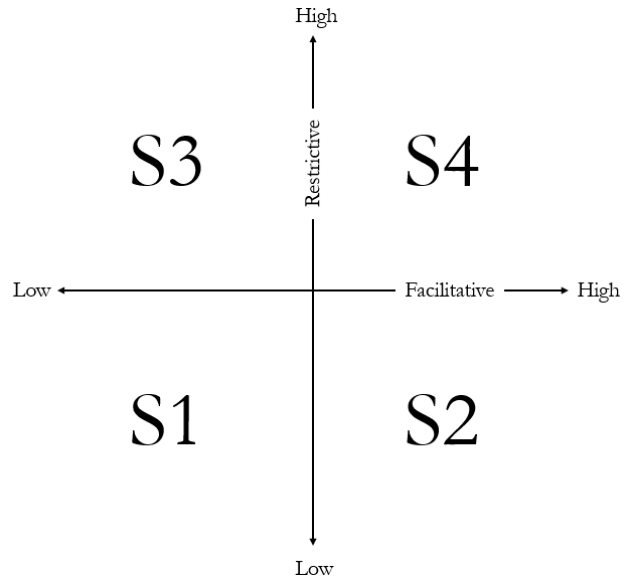


Figure 4. Scenario Matrix

If a measure is facilitative, then:

- A score of 1 = 2 points in S1 and S3
- A score of 2 = 1 point in S1 and S3
- A score of 3 = No points
- A score of 4 = 1 point in S2 and S4
- A score of 5 = 2 points in S2 and S4

If a measure is restrictive, then:

- A score of 1 = 2 points in S1 and S2
- A score of 2 = 1 point in S1 and S2
- A score of 3 = No points
- A score of 4 = 1 point in S3 and S4
- A score of 5 = 2 points in S3 and S4

Measure	Type:	Score	Point allocation			
	Facilitative Restrictive		1-5	S1	S2	S3
<b>A</b>	<b>F</b>	1	2	-	2	-
<b>B</b>	<b>F</b>	2	1	-	1	-
<b>C</b>	<b>F</b>	3	-	-	-	-
<b>D</b>	<b>R</b>	4	-	-	1	1
<b>E</b>	<b>R</b>	5	-	-	2	2
Total		15	3	0	6	3

Table 3. Example of scoring system

### Ethical considerations

Since the method for data collection includes the interviews of experts in the field, transcriptions of the interviews were summarised and sent to interviewees for corrections, and to ensure no sensitive or confidential information was divulged.

Moreover, before the use of any frameworks and figures from other sources permission was requested from the authors and creators of said frameworks and figures.

### Limitations

In terms of the limitations of this method, the scoring is based on the subjective opinions of a single group of actors – albeit the most relevant actor for AV implementation in Copenhagen. Moreover, the scoring system only allows answers of either moderate or high feasibility, which was chosen due to the future-oriented nature of this topic, meaning that actors outside of a few key municipal administrators and transport operators, very few have developed concrete action-plans for urban AV implementation.

Another limitation with this approach is the focus on the feasibility as an indicative measure for potential scenarios. As was clear throughout the research, AVs have yet to become common in political agendas. In addition, looking solely at feasibility means that the levels of environmental benefit are not represented. For example, multiple highly feasible measures might only bring modest gains, which can potentially be outweighed by a single highly unfeasible measure. In other words, future research – once empirical evidence becomes more accessible – should include on the quantifiable benefits of the various measures.



Finally, the limited informants is a significant limitation, as an ideal scenario-analysis should be based on the opinions and input of various groups and actors (Kosow & Gaßner, 2008). However, due to time and resource constraints, and the fact that only a select few actors have begun to think about AVs – let alone the sustainability-related concerns of urban implementation – having the most relevant actor answer these questions became the best workable option. In other words, while input was acquired from a broader range of actors, the final set of questions was only answered by a single actor-group.

### Ideal method



### Used method

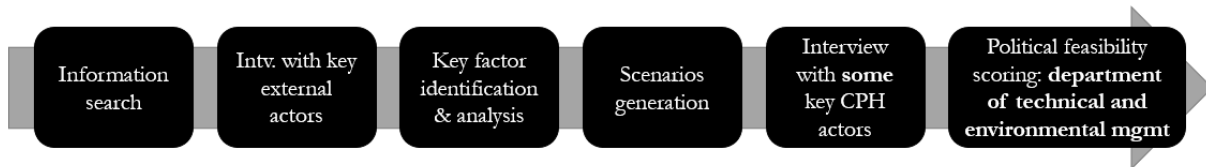


Figure 5. Method: Ideal vs. used

## 5 Literature review

Establishing the scenario field, entails identifying the timeframe, scope and core issues (Kosow & Gaßner, 2008). As only the latter remains to be established, this review will take stock of the core environmental issues of AV integration in cities, and if available, proposed measures to address said issues. These measures will be outlined clearly at the end of the review. These proposed measures is what will constitute the ‘key factors’ that are used in scenario analyses to construct the scenarios themselves (Kosow & Gaßner, 2008). Granted that the scenarios will be constructed on axes of facilitation and restriction, the measures will be categorised accordingly.

Prior to identifying the core issues, however, the chapter will cover EVs, as AV- and EV-technologies are beginning to converge (Fulton et al., 2017; Viegas & Martinez, 2017). This section serves to highlight the main concerns with regard to the sustainability of EVs, and to subsequently conclude that in the context of Copenhagen, EVs can be assumed more environmentally friendly than ICEVs, due to the renewable energies in the city’s current and future electricity mix. By extension, the main obstacles related to both EVs and shared mobility will be highlighted, including the inherent characteristics of AVs to overcome these obstacles.

### 5.1 Environmental impacts of electric propulsion

This section is not intended to be exhaustive, but will instead assume that studies summarised by the European Commission are reliable. Instead the purpose of this section will briefly cover notable life cycle assessments (LCAs) of EVs, and relate their potential impacts to developments in Copenhagen. The takeaway from this section is that while important, Copenhagen is undergoing a significant shift towards renewable electricity production, and are currently experimenting with vehicle-to-grid (V2G) technologies to improve the uptake of renewable energy (Nissan International, 2016). The V2G concept will be described at the end of this section.

In assessing the lifetime impacts of an EV, the different stages of a product’s life need to be considered. A key insight from LCAs is that context is critical, meaning that the impacts across the life cycle can be drastically different depending on where the ‘stage’ occurs. This is, in part, due to differing stringencies of regulation and electricity mixes across different countries (Hawkins et al., 2013).

LCAs are conducted by compiling an inventory of relevant environmental impacts relating to the extraction of raw materials, production of the various components, distribution, use-phase, and end-of-life (Nilsson, 2016). The environmental impacts are often measured in terms of their global warming potential (GWP), which uses Carbon Dioxide equivalents (CO<sub>2</sub>-eq) to unify the impacts of various gases have on warming the planet. In addition, studies often group extraction, production, and distribution into one ‘production’ category; as is the case for the studies looked at for this paper.

#### Production and end-of-life

The production is typically highlighted as one area in which EVs are less sustainable than traditional ICEVs. The reason for this is that EV production is much more energy intensive than that of an ICEV (Hacker et al., 2016). Roughly 70% more primary energy is required to produce an EV, largely due to the energy intensive process of production of the batteries and electric engine (European Commission, 2015). This means that the production phase accounts for roughly half of an EV’s GWP over the course of its life, with the battery production accounting for over a third of production-phase emissions (Hawkins et al., 2013).

While this production process could be powered by renewable energies, the materials required for their production are only found in high quantities in countries that have a highly fossil-based electricity mix (Hacker et al., 2016). For example, a study by DEFRA (2012) estimated that electricity produced in China produces 921g CO<sub>2</sub>-eq/kWh, while in the UK and US that number drops to 597g and 658g CO<sub>2</sub>-eq/kWh, respectively. In addition to CO<sub>2</sub> emissions, the materials such as cobalt and nickel used in the production of batteries have adverse environmental effects (Hacker et al., 2016).

An important distinction for both production and end-of-life estimates, is that they refer to fixed emissions per unit produced and disposed of. Therefore, the life-time of the vehicles have a significant impact on the vehicles' environmental impacts, as these fixed impacts are distributed across a greater amount of years (Ellingsen et al., 2016; Hawkins et al., 2013). In Europe, the end-of-life impact of EVs is relatively low, due to ability of battery recycling and incineration, which leaves the remaining ashes fit for landfilling (Hacker et al., 2016). In addition, numerous opportunities to further improve these processes remain, meaning further improvements to both recycling and production can be expected (Ellingsen et al., 2016). It will therefore be assumed, due to the 10 year timeframe that recycling will undergo further improvement in Denmark.

In relation to overall lifespan, Hawkins et al., (2013) found the extent to which GWP of EV is reduced relative to gasoline and diesel:

Lifespan (km)	Fuel type	% Reduced GWP
100.000	Gasoline	9-14
	Diesel	0
150.000	Gasoline	20-24
	Diesel	10-14
200.000	Gasoline	27-29
	Diesel	17-20

*Table 4. Relative GWP reduction of EVs*

If estimates used by researchers can be assumed as an indicator for improvement, then the last three years have seen the lifespan of batteries increase from 150.000km to 180.000km (Ellingsen et al., 2016; Hawkins et al., 2013).

Batteries, however, are not the only components with a lifespan. The material degradation of the vehicle body and components must also be taken into account. This becomes particularly relevant as vehicle utilisation increases, which is expected to rise greatly with the advent of AVs. At present, personal automobiles are stationary for 96% of their life (Shoup, 1997), which means that just a 4% increase constitutes a 100% increase to the utilisation rate. Moreover, one key benefits of EVs is their much lower number of moving parts (Arbib & Seba, 2017; Ellingsen et al., 2016), meaning that degradation from the use of autonomous EVs should result in further decreases in the vehicles' overall impact over the course of their lives.

## Use Phase

Across the life of automobiles, the use-phase has the highest environmental impact (Hacker et al., 2016). Even for EVs, nearly two-thirds of their lifetime impacts occur during use (Ellingsen et al., 2016). Unlike ICEVs, the in-use emissions of EVs are determined by the technology used to generate its electricity. If EVs are powered exclusively by burning coal, their impact may be greater than both their diesel and gasoline counterparts (Ellingsen et al., 2016; Hacker et al., 2016). In the case of the European electricity mix, however, EVs have a reduced GWP between 10-24% compared to ICEVs (Hawkins et al., 2013). As Copenhagen appears to have both a strong and growing position in terms of renewable energies in the city's electricity mix (København Kommune, 2016b), due to this growth in renewables, the energy origin will be assumed to be a negligible factor for the upcoming scenarios.

A common omission from LCAs of EVs is the inclusion of a concept of V2G, which in theory allows cities to invest in renewables by providing improved grid-stability. The way this occurs is by absorbing excess energy supply, and redistributing it when demand exceeds supply (Sioshansi & Denholm, 2010; Weiller & Sioshansi, 2014; Yilmaz & Krein, 2012). This dual-role is important, as it means that EVs can effectively assist the load-balance of the electrical grid when parked; by storing excess energy, and supplying it when required (Weiller & Sioshansi, 2014). The task of managing peak energy demand is typically fulfilled by generators that exist exclusively to meet peaks in demand (Weiller & Sioshansi, 2014). Moreover, unlike traditional generators, battery have the added benefit of providing instantaneous supply, without the need for a ramp-up period (Sioshansi & Denholm, 2010). V2G was implemented in Frederiksberg, Copenhagen in 2016 by Nissan, Enel and Nuvve, in order to test its viability in the city (Nissan International, 2016).

## 5.2 Synergies of AVs

### 5.2.1 E-mobility and autonomy

The connection between e-mobility and autonomy may not be immediately clear; the trends can easily be mistaken for two entirely separate technologies developing simultaneously. While there is certainly some truth to this, autonomy and electrification are not interdependent; a number of notable synergies exist between the two technologies (Marshall & Niles, 2014).

#### *Immature battery technology*

The inadequacy of batteries to provide the same performance as the internal combustion engine has long been the primary limitation of EVs (Bartlett, 2012; Noon et al., 2012). The problem is often referred to as 'range anxiety', and is the most frequently mentioned reason for consumers for not buying EVs (Bartlett, 2012). Battery technology is still immature, and the technology is still expected to improve (Chen, 2013; Ellingsen et al., 2016). A study conducted in 2014, found that over the past 21 years, the capacity of the common 18650 Li-Ion cell, had increased in capacity on average by 120mAh/year, or 3.5% (EPEC, 2015). Moreover, the issue of charging cycles, i.e. the number of times a battery can be recharged before the vehicle's achievable range is reduced (Barré et al., 2013), is a prevalent problem for EVs. Research indicates that charging cycles can be extended to some extent by encouraging certain behaviours, such as timing the point at which a vehicle is fully charged with departure time (Pelletier, Jabali, Laporte, & Veneroni, 2016).

A fleet of shared AVs will have attributes that can allow them to overcome a number of these hurdles. One such attribute is the ability to coordinate vehicles-charging time with data on mobility demand, counteracting issues such as range anxiety and charging time is not as significant as they are to private owners. This, coupled with the ability to seek out charging stations unsupervised

(Bakker & Trip, 2013; Noon et al., 2012), should be possible if the city provides such spaces. Moreover, given the urban context, the trip-distances are assumed not to exceed the distance required by any single trip.

#### *Lacking infrastructure*

The lack of charging stations has been a significant issue for widespread adoption. Firstly, charging a battery is a more time-consuming process than filling a tank. However, charging times have been improving significantly, with certain high-power charging solutions capable of charging a 24kWh battery to 80% in 15 minutes (BEAMA, 2015). These solutions are not widespread, however. Should cities install these chargers, it should become easier to justify the allocation of EV parking-and-charging solutions, which has been an issue over the past years (Bakker & Trip, 2013). As only six countries have EV adoption rates over 1% (International Energy Agency, 2017), installing dedicated infrastructure is difficult to warrant. Notably, Denmark is not on this list. One solution to this problem is, rather than being separate entities, chargers are now being integrated into cities' existing features, such as lamp posts (Eleftheriou-Smith, 2017). Perhaps the most impactful change, however, will come at the international level. In contrast to gas stations, electric chargers come in different shapes, and a harmonised standard has been highlighted as one of the most critical issues, as the differentiation creates unnecessary difficulties for all parties involved (Bakker & Trip, 2013; International Energy Agency, 2017).

To some degree, AVs will not suffer from the lack of infrastructure, as would a non-autonomous EV. Driving off to find chargers by themselves, is obviously one benefit, however the lack of infrastructure may have a significant impact on the uptake of AVs, assuming AVs will be electric. If this assumption is dismissed, then the lack of infrastructure would affect the degree to which AVs would be electric.

#### *Incompatible business models, poor aftersale market, and fewer work places*

The third obstacle is related to the change in business model that electrification necessitates. At present, when an OEM sells a vehicle, it is sold at a profit margin of less than 10% (Lazard & Roland Berger, 2016; Statista, 2016). This figure varies, depending on the model and target demographic (i.e. vehicle class: luxury, mass-market). Upon having sold the vehicle, the costs incurred by the customer, often translate into additional profits for the OEM, and the so-called after-sale market for automobiles is highly lucrative. For example, if you had to buy each individual component of a car, its price would rise to 300-400% (Investopedia, n.d.). According to a report conducted by Arthur D. Little (2015), German OEMs earned more than half their profits from the after-sale market, despite it only accounting for 23% of its revenues. Based on this alone, it makes financial sense for manufacturers to produce vehicles with as many breakable parts as possible. For most OEMs, manufacturing and selling EVs have not made financial sense, with the CEO of Fiat Chrysler Automotive publically imploring consumers not to buy the Fiat 500e (Beech, 2014)

If OEMs enter the MSP market, the inherent interest in additional costs through maintenance and breakable parts is removed. If they retain ownership, and earns revenue from the service of mobility, it would be in their interest to lower these additional costs. In numbers alone, EVs have roughly 1% the number of moving parts compared to ICEVs, or 20 vs. 2000 (Arbib & Seba, 2017). This point has been raised by OEMs as a negative aspect of EVs, as the simplicity of EVs will lead to reduction in the number of employees (Lawder, 2016).

For this reason, the paper will proceed on the assumption that OEMs will have a vested and growing interest in actively shifting the focus toward the becoming an MSP, in part due to the

political forces seeking to phase out gasoline and diesel (Castle, 2017; Harvey, 2016; Hetzner, 2017), and due to the growing mobility service opportunities enabled by AV technology.

### 5.2.2 Shared mobility and autonomy

Shared mobility refers to the shared use of a mode of transport. Carsharing is a term used to refer to the short-term use of a car, often for just a single trip, whereas renting refers to long-term use. This term doesn't denote by how many the vehicle is used by, which is where the term ridesharing is used. This term refers to the use of a vehicle by individual travellers, going to the same destination, sharing a vehicle and the costs associated with driving (Furuhata et al., 2013). Ridesharing is what referred to when referencing AV's ability to be used in a fleet operated by an MSP.

This practice could have environmental benefits, by improving the utilisation of a single vehicle, lowering the number of vehicles that needs to be produced, and possibly the number of vehicles on the road (Fagnant & Kockelman, 2014). In their shared AV-fleet simulation, Fagnant and Kockelman (2014) found that an 11% increase in the overall VKT would incur from shared AV-use. These assumptions are highly normative, as sheer economic factors could see a single shared AV being used more than the number of vehicles it replaces.

A study on the underlying motivations to rideshare found that people are frustrated by the volume of traffic, their fuel consumption, and worry about the emissions they produce (IEA, 2005), the costs of travel and time spent commuting (Agatz, Erera, Savelsbergh, & Wang, 2012), and the need to find parking (Stocker & Shaheen, 2017).

A key issue with ridesharing schemes is that they necessitate a level of flexibility on behalf of its users, be it willingness to accept a detour (Bicocchi & Mamei, 2014), or accepting variation in arrival and departure times (Stiglic, Agatz, Savelsbergh, & Gradisar, 2016). If the users accept these terms, the gains can be substantial. A study found that a willingness to detour 2000 meters could reduce the amount of trips taken by 1000 people living in the same city by 60% (Bicocchi & Mamei, 2014). In addition, a study of taxis in New York found that a wait-time flexibility of 30 minutes could mean that 70% of rides could be shared (Shmueli, Mazeh, Radaelli, Pentland, & Altshuler, 2015). Meeting points, as opposed to being picked up at the door show significant improvements to the system if users are willing to use these meeting points, rather than the vehicle arriving at their door (Stiglic, Agatz, Savelsbergh, & Gradisar, 2015).

Although these problems have been clearly identified, there has hitherto been few remedies to the problems of car- and ridesharing (Bauer, 2017). Additional issues with ridesharing include lack of trust and security (Gargiulo, Giannantonio, Guercio, Borean, & Zenezini, 2015), while carsharing suffers from a significant redistribution issue, whereby vehicles often need to be relocated after one-way use, leading to a lack of access where vehicles are most needed (Martin & Shaheen, 2011).

Through automation, a number of these shortcomings could be overcome, as AVs will be capable of redistributing themselves and effectively meet demand in ways that conventional carsharing schemes cannot (Wadud et al., 2016). It should be noted, however, that a problem known as 'dead-heading' (i.e. kilometres driven without a passenger) could offset the energy savings, if the systems are not optimised and coordinated (Schaller Consulting, 2017).

## 5.3 Core issues

While difficult to fully distinguish, three core issues with sustainable urban AV use were identifiable from the literature. These include higher vehicle kilometres travelled, cannibalisation of PT, and congestion. These issues are both interrelated and caused by external factors, however; rather than

outlining the myriad of issues individually, the sections below will instead focus on three main issues, while also including the other “sub-issues”.

### **5.3.1 Vehicle kilometres travelled**

At the centre of potential issues related to the widespread adoption of AVs, is the impact on vehicle kilometres travelled (Fagnant & Kockelman, 2014; Schaller Consulting, 2017; Viegas et al., 2016; Wadud et al., 2016). A core objective in sustainable urban mobility plans is to reduce VKT significantly, and AVs – despite increasingly integrated into these plans – have attributes that could lead to sharp rise in VKT (Fagnant & Kockelman, 2014; Wadud et al., 2016), creating a phenomenon referred to as ‘induced demand’ (Milakis et al., 2015).

As already discussed, higher rates of accessibility and lower cost could see AV integration contradict the objective of sustainable urban mobility. In spite of these competing drivers, a number of other factors will contribute to the overall VKT of AVs. These include the growth in MSPs, the degree to which ridesharing can be incentivised, the level of private AV ownership, and the type of traveller the mode of transport attracts.

As automotive OEMs have yet to extensively enter the mobility provision market, the growth in TNCs constitutes the clearest indicator of MSP growth. In looking at the current development of app-based TNCs, Schaller Consulting (2017) conducted a study in New York, which found that in 2016, TNCs provided 15 million monthly trips. This constitutes a threefold increase from the year prior; putting the number of trips on par with the city’s infamous yellow cabs and exceeding their kilometres travelled. This sharp rise means that the overall VKT within Manhattan, western Queens, and Brooklyn has risen 7%, a figure which happens to be the percentage a 2007 congestion pricing proposal would have reduced (Schaller Consulting, 2017). A similar study looking at new users, aged 19 and above, in the U.S. from demographics unable to drive (i.e. elderly, disabled), were estimated to contribute to a rise in VKT by 19% (Harper, Hendrickson, Mangones, & Samaras, 2016).

If behaviour regarding TNC-use is assumed to be an indicator of future behaviour for AV-use, Schaller Consulting (2017) found that the ‘pooling services’ offered by TNCs appear to have limited effects, as users seem to favour exclusive rides, despite potential savings. The added value of private mode of transport can also become an issue in terms of ownership. Although AVs has the potential to add significant value to ridesharing fleets, it similarly adds value to the individual owner, with respect to urban parking, cruising during congestion, and other general conveniences.

It remains uncertain as to whether shared AV fleets will be the final configuration produced by the advent of AVs. As studies have shown, when you consider the willingness to pay consumers exhibit when it comes to owning a vehicle with AV functionality. A recent study found that the willingness to pay for full autonomy show that most people would pay an additional \$4,500 (Daziano, Sarrias, & Leard, 2017). The price for autonomous driving capabilities are already being offered by a limited group of OEMs. Tesla Motors has recently announced that all their vehicles will be equipped with the hardware necessary for full autonomy<sup>10</sup>, which can be enabled at an additional fee of \$8,000 (Tesla, n.d.)

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<sup>10</sup> This does not enable full-autonomy immediately, but is instead is continuously improved through over-the-air software updates from Tesla; with early-adopters receiving the feature at a discounted price

## Narrative of Original Equipment Manufacturers

Extending on the trend outlined by Schaller Consulting (2017), an investigation of the sustainability reports of a number of OEMs was conducted. The purpose of this is to demonstrate the trend that OEMs are increasingly following an agenda of electrification, autonomy, and mobility service provision. The choice of using the sustainability reports to confirm this, was to reinforce that electrification, autonomy, and mobility service provision are indeed framed as environmentally sustainable in the narratives of the OEMs.

Original Equipment Manufacturer	Electric (alternative fuels)		Autonomy		Mobility service
	2012 // 2016		2012 // 2016		Founding year
Daimler (2012, 2016)	21 (6)	35 (9)	3	9	car2go (2008)
BMW (2012, 2016b)	32 (2)	49 (2)	0	11	DriveNow/ReachNow (2011)
Volkswagen (2012, 2016)	21 (7)	45 (5)	0	12	MOIA (2016)
Volvo Car Group (2012, 2016)	18 (4)	25 (1)	4	17	Sunfleet (1998)
General Motors (2012, 2016)	44 (5)	47 (5)	3	26	Maven (2016)

Table 5. Overview of OEM sustainability reports

### Uncertainty in OEM behaviour

Of the reports investigated, all show an increase in both e-mobility and autonomy. In the reports from 2012, electrification was primarily promoted in the form of plug-in hybrids, rather than battery-electric. For the 2016 reports, the electrification primarily refers to battery-electric. In addition, the emphasis on renewables energy in the electricity in the grid as a prerequisite for more sustainable EVs is mentioned fewer times in the 2016 reports. A sceptic may interpret the previous emphasis on renewables, as a way for OEMs to justify their lack of focus on EVs.

A similar, but greater increase can be found in the prevalence of autonomy within the sustainability reports of the various OEMs. In 2012, BMW and Volkswagen did not refer to this technology once, while the other OEMs referred to the technology only as semi-autonomous. In contrast, by 2016 most companies had made driverless technology central to their vision of the future, with some companies outlining specific strategies to this end, such BMW's 'Number One > Next' strategy (BMW Group, 2016b) and 'Transform 2025+' by Volkswagen (Volkswagen Group, 2016b)

In addition, all OEMs investigated had begun to provide mobility services, mostly in the form of carsharing. Among the companies, there is a significant disparity between when their respective services were founded, with Volvo being the earliest adopter in 1998. The degree to which this approach will become integral to their business remains to be seen. As both Lyft and Uber have demonstrated, there is a sizable and growing demand for convenient mobility services, and it is therefore assumed that incumbent OEMs would be interested in entering this market.

In spite of these trends, there is little to suggest that the OEMs are ready to undergo a drastic shift towards a service-oriented business model. This was inferred from the lack of vehicles that bear any semblance to those used by innovative pioneers, such as 2getthere, CityMobil2, and



Localmotors. In other words, traces of a shift towards the de-emphasis of performance and right-sizing of vehicles cannot be discerned from any of the reports, which are attributes highlighted by Wadud, MacKenzie and Leiby (2016) as positively affecting the AVs' environmental score. Moreover, although electrification has become more prevalent in the reports, mentions of other alternative fuels have remained stable, suggesting that additional market signals may be required to encourage OEMs to shift toward electrification.

### Fleet-based vs. private AV impacts

Finally, a study conducted by CityMobil2 divides the city into four distinct typologies and further into two types of ownership, private or fleet-based. Specifically, the study looked at variables such as daily trips per capita, average journey distance, and occupancy rates (CityMobil2, n.d.). For the purpose of simplifying information, only one such typology will be outlined, notably the 'city network' scenario, as its hypothetical car-ownership rate of 450 per 1000 inhabitants is closest Copenhagen's 377 per 1000 inhabitants. Below are the estimated figures by experts from a Delphi study conducted by CityMobil2.

As is the nature of Delphi studies, these figures should only be considered as rough estimates, the studies does cover the various disagreements among experts, and the key discussions there were had before the estimates were agreed upon. A point often highlighted as a pivotal throughout this study is the induced urban sprawl (CityMobil2, n.d.), which in the case of average journey distance makes it unclear to determine whether it will increase or decrease.

The study found that the fleet-based scenario is generally more environmentally positive than that of the privately owned AV scenarios. In fact, most of the gains, predominantly from eco-driving practices, i.e. up to 25% reduced energy use (Wadud et al., 2016), could potentially be offset by the additional VKT (CityMobil2, n.d.). However, there are certain areas such as number of daily trips taken and the choice to walk or bike that will need to be closely followed going forward, as even in the fleet-based scenario the environmental impacts of these factors are uncertain.

Variables & modal share	Private // Fleet	
$\Delta\%$ daily trips	10 to 30%	30%
$\Delta\%$ average journey distance	30%	-10 to 10%
$\Delta\%$ occupancy rate	-10 to -30%	10 to 30%
$\Delta\%$ ownership	-10 to 10 %	-30%
$\Delta\%$ private car use	10 to 30%	-30%
$\Delta\%$ shared car use	10 to 30%	30%
$\Delta\%$ public transport	-10 to -30%	30%
$\Delta\%$ walking/cycling	-10 to -30%	-10 to -30%

Table 6. Change in environmental variables due to AVs

Moreover, the degree to which AV technology makes AV mobility services appealing in relation to other modes of transport is important, as it may deter people from using otherwise greener modes of transport. Ultimately, higher VKT will be determined by technology’s effect on unlicensed drivers, increased occupied and unoccupied vehicles, and travel at higher speeds could potentially lead to a doubling or even tripling of VKT (Brown, Gonder, & Repac, 2014).

### 5.3.2 Cannibalisation of public transport

As can be seen in the study by CityMobil2, PT is a potential victim of advent of AVs, however this is only the case if the vehicles are predominantly privately owned, while the fleet-based scenario estimates a potential rise in PT ridership. This increase in ridership is crucial, as PT is both necessary to carry large volumes of commuters, but also has a significantly lower environmental impact than road-based transport (FTA, 2016). For this reason, the study by Schaller Consulting (2017) can be considered alarming, as it shows that TNC ridership is outpacing the growth in transit. Similarly, a scenario analysis by the Boston Consulting Group (Lang et al., 2016), showing that PT is likely to lose passengers to MSPs utilising AVs. Moreover, the users captured by TNCs in New York are largely unwilling to share their rides, and often consists of people who do not own a car, or would not have taken the trip, was it not for the service (Schaller Consulting, 2017). Over the past two decades the city has managed to accommodate additional mobility demand through its transit system, which would have been impossible through increase automobile use, due to the city’s pre-existing problems with congestion (Schaller Consulting, 2017).

Based on the axes of city policy (inactive vs. supportive) and primary mode of ownership (private vs. fleet), the Boston Consulting Group simulated four scenarios for urban transportation. The impact areas measured were: number of vehicles on the road, number of accidents, number of parking spaces, and emissions (Lang et al., 2016). All scenarios saw positive impacts across all nearly all impact areas, with the exception of the scenario where the city has no policy to promote AV adoption, and the primary mode of ownership is private ownership. In this scenario parking remained the same, while the number of vehicles decreased by 1%, accidents by 19%, and emissions by 9%. In contrast, the scenario where the city is actively involved in promoting AV adoption and the primary ownership is fleet-based and shared, the number of parking spaces decreased by 54%, number of vehicles by 59%, accidents by 87%, and emissions by 85%.

Policy // Ownership	Number of vehicles	Number of parking spaces	Accidents	Emissions
<b>No policy // Private</b>	-1%	0%	-19%	-9%
<b>Involvement // Private</b>	-8%	-5%	-55%	-23%
<b>No policy // Fleet-based</b>	-46%	-39%	-86%	-81%
<b>Involvement // Fleet-based</b>	-59%	-54%	-87%	-85%

Table 7. Effect of policy and ownership on AV impacts

Positively, in all considered scenarios, EV adoption is expected to increase, and consumer surveys have shown that just 9% of consumers surveyed believe that AVs will be powered by traditional internal combustion engines (Lang et al., 2016). Interestingly, the scenario shown to be the most desirable based on its impacts; active involvement and fleet-based, has the lowest use of PT in the

urban modal mix. In other words, the privately provision mobility service is better for the city overall, which stands in contrast to the previous concerns highlighted by Schaller Consulting (2017). This is likely based on the finding that policymakers have been shown to prefer a free-market with numerous private mobility service actors, and that urban mobility plans are yet to incorporate AVs into their future mobility visions (Lang et al., 2016).

As already established, the free-market approach is, however, unlikely to produce a positive environmental outcome. An ideal role for MSPs to fulfil would be to use their vehicles to serve as 'feeders' for main PT arteries (Viegas et al., 2016). The use of AVs as feeders for PT arteries are present across most studies that describe positive outcomes from AVs, which argue that an optimal modal-split must be determined between PT, shared AV fleets, and shared rides (Stocker & Shaheen, 2017). Based on such conditions, a study based on Lisbon, Portugal found that existing rail services, combined with first/last-mile service from shared AVs could cut emissions by one third, and eliminate the need for 95% of public parking (Viegas et al., 2016). These effects could be further amplified once land reclamation occurs from the uprooting of parking, allowing for greater facilitation of walking and biking, which in turn could translate into greater use of public transit (CityMobil2, n.d.).

With that said, it cannot be assumed that cities' existing PT networks will become immediately strengthened by AVs. It will take time for people to grow accustomed to sharing the AVs, meaning it will be difficult to reach high vehicle occupancy rates (Schaller Consulting, 2017). In this transition-period, VKT per capita is estimated to increase between 5-11% (Fagnant & Kockelman, 2014), and if the MSPs cannibalise PT, this number may be substantially higher (Fagnant & Kockelman, 2016). With that said, Schaller Consulting notes that the "The modelling shows that changes in travel and vehicle mileage are generated primarily from the combination of demand-responsive service and shared use of the vehicles, with automated operations being of secondary importance" (2017: 5), suggesting that lessons learnt from contemporary ridesharing schemes would be applicable.

MaaS is one such budding, contemporary concept. This concept was first defined as "a system, in which a comprehensive range of mobility services are provided to customers by mobility operators" (Heikkilä, 2014). A more comprehensive definition of this concept, used by the MaaS-Alliance is "Mobility as a Service (MaaS) puts users, both travellers and goods, at the core of transport services, offering them tailor-made mobility solutions based on their individual needs. This means that, for the first time, easy access to the most appropriate transport mode or service will be included in a bundle of flexible travel service options for end users." (Maas-Alliance, n.d.).

The objective of MaaS is to make urban mobility more attractive by combining a city's various transport offerings into a single platform, usually a mobile app, based on a single fee. 'MaaS service providers' and 'mobility service providers' are effectively joined together on a single platform. The service provider manages the interface, marketing, customer service, and contract management, while the platform provider handles data integration, booking, payment, and data collection, and the mobility provider controls the capacity, tickets, data, and APIs (Lund, 2016). In offering this platform, MaaS has the potential to lower the environmental impact of urban travellers, by lowering individual car use and promoting greater use of public service (Lund, 2016). Mobility services have been estimated to reduce road energy consumption by up to 20% (Wadud et al., 2016).

Therefore, finding ways in which AVs can be directly integrated into these systems, will in turn play a significant role in lowering AVs environmental impact. Research on MaaS in relation to environmental impacts is predominantly focused on how to attract existing/prospective car owners, rather than existing PT users (Holmberg et al., 2016). If the latter is the only demographic affected by the implementation of a MaaS system, then positive environmental outcomes are unlikely (Holmberg et al., 2016; Stocker & Shaheen, 2017; Thomopoulos & Givoni, 2015; Wadud

et al., 2016). As shown by Wadud et al. (2016), mobility services could lead to a decline in road-based energy consumption by up to 20%, but it ultimately relies on extensive integration with cities' existing PT systems (Schaller Consulting, 2017; Viegas et al., 2016; Wadud et al., 2016).

### 5.3.3 Congestion

Congestion is the last major issue that was identified as pivotal in integrating AVs, and while the direct effects of congestion may only be up to a 4% decrease in road-based energy demand (Wadud et al., 2016). While this may seem miniscule, the overall energy wasted due to poor traffic flow and reducing the frequency of accident is estimated to be 2.6% by 2020 (Schrank, Eisele, & Lomax, 2012), and 4.2% by 2050 (Wadud et al., 2016). This figure includes both light- and heavy-duty traffic, and does not distinguish between urban or non-urban driving. It does, however, suggest that AVs can have a significant impact on congestion mitigation.

The first is that the expected phenomenon of deadheading or deliberately circling the block to avoid paying for parking. (Arbib & Seba, 2017; Schaller Consulting, 2017; Shanker et al., 2013). How cities discourage this behaviour may have significant impacts on the city's congestion, and a measure that is often used to directly lower the VKT are road pricing schemes, effectively increasing the cost of travel, based either on distance, origin, destination, or a combination (T. D. Chen, 2015). These schemes are found in cities around the world such as London, Gothenburg, and Milan, and have all demonstrated a proof of concept (Crocì, 2016). In addition, one of the advantages of AVs is their ability to communicate with one another, and collectively ensure congestion is reduced (Arbib & Seba, 2017; Dokic et al., 2015; Viegas et al., 2016), however since human-driven vehicles do not have this ability, the period of coexistence could see this benefit reduced, and in some cases even worsen congestion (Cox & Hart, 2016). To address this issue, measures could be taken to separate AVs from human-operated vehicles, either through dedicated lanes, or zones wherein only AVs would be allowed to drive.

The second issue is that of AV interaction with other road users, such as cyclists and pedestrians. Using game-theory to describe the simple act of crossing a busy street, Millard-Ball (2016) argues that the high levels of rule-obedience AVs will exhibit, and their inevitable in-built aversion for causing human harm, will leave them at a great disadvantage among road users who will exploit these traits, as soon as they become aware of how AVs will react. Millard-Ball asserts that "Crossing the street, even at a marked although unsignalised crosswalk, requires an implicit, instantaneous probability calculation: what are the odds of survival? The benefit of crossing the street more quickly, rather than taking a long detour or waiting for a gap in traffic, is traded off against the probability of injury or even death" (2016: 1). The author concludes that by a combination of regulatory changes, physical design, and enforcement, people must be conditioned to avoid interference with AVs as much as possible (Millard-Ball, 2016). A clear suggestion put forth is to have distinctive typologies of roads: roads for vehicles, where vehicles and humans are physically separated, or enforcement is high, and roads for pedestrians, where vehicles drive slowly, and will always yield (Millard-Ball, 2016).

## 6 Findings

The findings below will provide the combined measures derived from literature and expert interviews. To highlight the measures, they will be **bolded**. Following this summary are the generic scenarios that were narratively constructed from these measures, and finally the measures will be transferred to Copenhagen, based on their feasibility.

### 6.1 Identified key factors and analysis

This section outlines the key factors that were identified through interviews with experts. These included responses from the municipalities in Berlin, Amsterdam, Gothenburg and the innovative pioneers, namely 2getthere, GATEway project, CityMobil2, and Volvo's DriveMe project.

#### 6.1.1 Facilitative measures

Throughout literature and the interviews, the notion of dedicated features to facilitate AVs ability to be sustainable emerged. These included zones, lanes, stations, and parking. In terms of zones, i.e. a space exclusively dedicated to automated transport, was seen in both the niche testing spaces, as well as the systems developed by 2getthere. The purpose of these **dedicated zones** is to create controlled spaces for AVs and automated transport to operate, unaffected by human-driven vehicles. In addition, controlled spaces allow for improved throughput and increased safety according to Robbert Lohmann from 2getthere. As underscored by Cox and Hart (2016), the mixing of human-operated with AVs could actually worsen congestion, which negatively contributes to the environmental performance (Wadud et al., 2016). One of 2getthere's solutions to ensure physical separation is through elevated roadways, but the opinion of Adriano Alessandrini from CityMobil2, is that this approach is likely too extreme and expensive for most cities. He argues that outside of recently rich and rapidly growing cities, like the Emirates, it would be too much to radically alter the existing infrastructure.

*"...in most countries, we are not rebuilding the streets to have the vehicles isolated from everything else. The automated vehicles will need to go on the normal streets, and those streets will need to be safer."  
(Adriano Alessandrini, CityMobil2)*

Dedicated lanes, while promoted by 2getthere is somewhat of contentious topic among the municipalities interviewed. Both Berlin and Amsterdam have this topic under consideration, but as it stands the idea has limited support, and is only thought of as an option under limited circumstances.

*"I generally think it is not a good strategy, but I think there are small changes we can make. Like better curves, and more legible road-signs. Dedicated lanes... probably not. The ability of the vehicle must be to be flexible"  
(Luca Ricci, Senate Administration for Environment, Transport and Climate Protection, Berlin)*

*"[Dedicated lanes] is something we are discussing, mostly related to the main arteries, but most people in the municipality do not see it as a positive development – unless it turns out that it is the only way to make it possible, and it is shown to have a positive influence, then it would be an option"  
(Anne Blankert, Senior Advisor Traffic Management, Amsterdam)*

A more functional alternative of dedicated lanes are **high-occupancy lanes**, which are lanes only accessible to vehicles that contain above a certain number of passengers. Car-pooling lanes are an example of these, and rather than giving preferential treatment toward AVs, they would instead encourage and facilitate higher occupancy rates, regardless of whether they have a human-driver. In contrast to dedicated lanes, which would lose their value once AV penetration increases, occupancy lanes retains their function, regardless of the number of AVs on the road. As these lanes

lower travel time, they could potentially negate the increases to travel times likely to occur from shared mobility (Fagnant & Kockelman, 2014).

*“How we ensure higher occupancy depends on the vehicle combination – in Gothenburg we currently have high occupancy lanes. How we tax transportation will also become important, as right now it is all based on fuel”  
(Mikael Ivari, Senior Advisor of Urban Transport Administration, Gothenburg)*

The topic of AV parking was another feature under consideration, as the land dedicated to parking is often the topic of literature (Litman, 2014; Rodoulis, 2014), and this was echoed in interviews with both Amsterdam and the DriveMe project. In the case of Amsterdam, in a feasibility study conducted by the Boston Consulting Group (2016), the topic had become relevant as the city had recently constructed large, central, **underground parking lots**. The municipality had voiced concern that since AVs do not need parking the same way conventional vehicles do, the underground parking complex would become redundant, but they concluded that:

*“...people were thinking we were wasting money on underground parking being built now, but we concluded that these parking lots can still be used” (Anne Blankert, Senior Advisor Traffic Management, Amsterdam)*

The rationale behind this is that demand for mobility alters throughout the day, leading to an inevitable excess of vehicles (Fagnant & Kockelman, 2014), and in contrast to building parking complexes on the periphery of the city, as a means to reclaim space dedicated to parking in the city.

*“The DriveMe is also about opening up new opportunities for cities, to have them designed in a much better way to take advantage of them being driverless – to reclaim city space. Having external parking is one of the bad examples, because it would increase VKT.” (Jan Hellåker, DriveMe)*

*“The parking complex should preferably be in the city, so the autonomous vehicles do not need to go in and out of the city. Even if you had fewer cars in the future, these underground parking will still be useful, because you can begin to remove on-street parking” (Anne Blankert, Senior Advisor Traffic Management, Amsterdam)*

In addition to providing central parking complexes that allow cities to derive more benefit from AVs in the form of additional space, the use of **dedicated “stations”** was the final feature that could be identified as necessary in order to lower the environmental impacts of AVs. The logic behind these stations is that, rather than encourage AVs travel the additional distances for a door-to-door service, an increase in the number of dedicated stations – such as contemporary bus stops – the city could both lessen the distance people need to travel by foot, while also lowering the distances AVs would have to travel.

*“We are thinking of an in-between of door-to-door and public transport, with more stations, where people would have to walk 200 meters, instead of longer walking distances”  
(Anne Blankert, Senior Advisor Traffic Management, Amsterdam)*

Aside from investments into features that are designed for the AVs, a second type of feature is one that can be understood as limiting the interaction and interference from the surrounding environment. As highlighted previously, parking complexes can consolidate parking, in turn allowing for the **removal of on-street parking**. On-street parking was another existing feature that impedes the ability of AVs to function optimally, in turn forcing them to drive at lower speeds than necessary, which lowers throughput and worsens congestion. This was a point that brought across by Alessandrini, who believed that relatively minor changes to the urban environment could have a significant effect on the performance of AVs.

*“They need to reinvent mobility completely, you need to limit private car parking. You need to change the physical environment to make more liveable. Reduction of parking is easy for this, but also to allow our vehicles to go at higher speeds. Even though our vehicles can go 40km/h, we can only go 12km/h. We need to have ability to go higher speeds, so the whole city needs to be restructured and reconceived. To do this, you need to think about removing road-side parking.” (Adriano Alessandrini, CityMobil2)*

In addition to stationary vehicle impeding the performance of AVs, so too will other road users that will likely exploit the programmed obedience of AVs. If cities manage to strike a balance between the interactions between human-operated and AVs, what remains will be road users who only use the roads for a short period of time to cross the street.

*“There are two things that come up repeatedly, and it's not safety. It's the loss of jobs, and the automated stopping. Pedestrians simply won't care, because they will force right of way.”*  
(Paul Copping, GATEway Project)

As outlined by Millard-Ball (2016) the two ways to address this issue is to either design infrastructure to avoid this problem, or by changing regulation to sufficiently discourage this behaviour through combination of **penalizing jay-walkers**, changing regulations to ensure OEMs are not liable for accidents, and **physically preventing the interaction between AVs and other road users**.

A final way in which cities can facilitate the sustainable integration of AVs is by incorporating them into existing systems. From the literature review, it was found that a **high-voltage charging** grid could play a significant role in reducing the overall number of AVs on the road, granted that the downtimes are shorter (T. D. Chen, 2015). In estimating the effects of a rapid charging on the capacity of shared autonomous electric vehicles (SAEV) to displace conventional cars, it was found that for SAEVs with an 80-mile range, upgrading a 240 volt charging infrastructure to 480 volt, the amount of privately owned vehicles displaced by a single SAEV increases from 3.7 to 5.5; if the vehicles have a 200-mile range, the numbers change to 5.4 to 6.8, respectively (T. D. Chen, 2015). **Integration with V2G systems**, while not of immediate concern for the majority of interviewees was shown as capable of further lowering the environmental footprint of AVs (Sioshansi & Denholm, 2010), and encourage MSPs to park their AVs in times of low demand.

Another topic that emerged from talks with Movia, is their interest to integrate the PT system with MaaS, in order to couple their system with first- and last-mile transport. However, since their operation is subsidised, the degree to which they could offer this service is limited. This service would therefore have to be provided by private actors. The notion of findings ways to encourage providers to partake in such a system was prevalent across interviews, but with no clear measures, the general **use of financial incentives** was selected as a measure to encourage greater participation in MaaS by MSPs.

### 6.1.2 Restrictive measures

In terms of the measures designed to actively restrict AVs from becoming environmentally unsustainable, these included road pricing, quotas on the number of vehicles, enforced MaaS integration, AV-driving confined to certain areas, limiting the use to certain demographics, mandatory partnerships with PT operators, and a mandatory average occupancy rate.

The primary objective of restrictive measures would be to lessen the use of AVs, in order to offset the additional use coming from travellers opting for AV transport at the expense of more

environmentally sustainable options, such as PT or biking/walking, or to take trips they would not otherwise have taken.

One potential measure would be to institute a **road pricing scheme**. These schemes work by directly increasing the price of road-based travel, and thereby lowering the demand. Out of Copenhagen, Amsterdam, Berlin, and Gothenburg, only the latter had one such scheme in place. Although effective, these schemes are often politically unfavourable.

*“I have heard [road pricing] come up, but we don’t have this system yet. I think [politicians] prefer to first raise the cost of buying the vehicle through taxes first.”*

*(Luca Ricci, Senate Administration for Environment, Transport and Climate Protection, Berlin)*

*“We thought of pricing the road to prevent empty cars. Now you pay a lot of parking, and it is the only way we discourage people from going with car.”*

*(Anne Blankert, Senior Advisor Traffic Management, Amsterdam)*

The notion that the system could self-regulate was also speculated, as overuse and subsequent congestion could lead to other options becoming more favourable. This sheds light on what a potential baseline scenario could look like, should the city be a complacent actor in AV integration.

*“In most scenarios that we envisioned, public transport would lose a lot of their share, because of its price. Unless you regulate it, or if regulates itself because it leads to so much traffic.”*

*(Anne Blankert, Senior Advisor Traffic Management, Amsterdam)*

A second approach to reduce the number of vehicles would be to directly **limit the number of vehicles allowed on the road through a quota system**. Unlike a road pricing scheme, however, this type of system would be difficult to justify imposing on individual owners of AVs, but it is commonly used approach around the world to limit the number of taxis in cities (Schaller Consulting, 2017). Respondents were unable to go into depth on this issue, despite currently being used, as it is often a matter at the national level.

*“We don’t have [taxi licenses], and that is also a national issue. I believe it the national transportation agency that requires taxis to comply with certain requirements, which imposes certain costs. And it has become a big issue, when Uber and Lyft doesn’t fit under this legislation, making it cheaper for them to conduct business than other taxi companies.” (Mikael Ivari, Senior Advisor of Urban Transport Administration, Gothenburg)*

A second category pertaining to restrictive measures on AVs, is to enforce desirable behaviour. These include enforcing the use of the MaaS system, constraining the use of AVs to limited areas and roads, requiring mandatory occupancies, right-sizing, or partnering with local PT operators.

As MaaS is increasingly becoming a key feature in sustainable urban mobility schemes, there are two general ways to increase uptake and utilisation of the system. Either the city tries to encourage its use, or by **forcing MSPs to integrate** with it. While the former will certainly be less contentious, the latter may be a probable option.

*“The idea is to create an environment where MaaS is so useful to use, and not to force someone. If it doesn’t work, forcing them to do it would be an option” (Anne Blankert, Senior Advisor Traffic Management, Amsterdam)*

Right-sizing, or the design of vehicles to match the utility of the vehicle as this measure has been found to reduce road-based energy consumption by up to 45%, and **enforcement of right-sizing** thereof was therefore assumed to be an additional measure.



Another measure is the **restriction of AVs to certain areas**, or ‘tether’ them to certain PT stations, this was largely interpreted as a measure, as an inverse of a dedicated zone, designed to keep human-operated vehicles out; this zone keeps AVs in. It was agreed upon by all interviewees that widespread door-to-door transportation is a highly unwanted scenario, and just one foresaw the possibility of the PT agency offering this type of service.

*“If we think long-term, then we can see our own door-to-door application coming to the city, this is probably the last step for this type of automation. Door-to-door doesn’t necessarily fit our strategical view... We are not interested in making money, but to move people in a sustainable way.”*

*(Luca Ricci, Senate Administration for Environment, Transport and Climate Protection, Berlin)*

Finding measures that could ensure occupancy rates remain high are mostly indirect, but another option that was discussed – without much knowledge as to *how* this could be done – was having some form of **requirement for high occupancy rates**.

*“[On knowing whether a vehicle is driving empty, or how many passengers it contains] ... We did not discuss it, but we all agreed that it would be technically feasible... I was thinking that you could use the MaaS service through the information you give the mobile application”* (Luca Ricci, Senate Administration for

*Environment, Transport and Climate Protection, Berlin)*

Another measure that might become required is the use of **mandatory fuel-types**, or limits on what drivetrains can be used by mobility service providers. While there is certain a trend towards electrification, and certain synergies between e-mobility as autonomy, the expectations as to whether or not electrification is guaranteed differed.

*“[On mandating the use of specific fuel types] I think in terms of electric, it could quickly become this way. The large cities around the world are trying to get rid of diesel vehicles. For the longest time we have been in a situation where OEMs would have lost money if they produced electric vehicles, but autonomy could allow change their cost structure by instead focusing on a service-model.”*

*(Jeppe Juul, Ecological Council, Copenhagen)*

*“I think [electrification and autonomy] are completely unrelated, but just happen to be coinciding at the same point in time. As long as you have automatic transmission and drive-by-x system, I don’t see why the powertrain would matter.”* (Jan Hellåker, DriveMe)

*“The AVs in my project are electric; right now there are no providers collaborating with us that have AV-ICEVs”* (Luca Ricci, Senate Administration for environment, transport and climate protection, Berlin)

*“Actually, one year ago we just assumed AVs could have any type of fuel. We did assume that EVs are developing, and if it takes 10 years for AVs to develop, then it will likely be EVs.”*

*(Anne Blankert, Senior Advisor Traffic Management, Amsterdam)*

Another topic that was loosely referred to throughout interviews can be summarised as **limits on operational hours** and **limited use to certain demographics**. As the technology becomes widely adopted, it could serve a dual-role, partly working as a door-to-door MSP, and for the public transport system. The door-to-door service is particularly damaging during rush hour, and may only be necessary for certain demographics. As these were roles frequently mentioned across interviews, it was assumed that these could in turn be used as purposive measures, depending on the city’s objectives.

By extension, a final restrictive measure would be to directly tie AV use through a **partnership with local** operators. While this measure was not explicitly mentioned by interviewees, it was

inferred through discussions on MaaS and the potentially damaging behaviours of MSPs and private actors, suggesting that AVs may need to be tied to the public sector in order to achieve environmentally positive outcomes. Since the PT companies seem uninterested in providing door-to-door service, partnerships with AV operators may be better way to ensure the private and public mobility providers have aligned objectives, as opposed to private actors solely acting as sub-contractors for the public sector.

*“If you no longer sell to customers, there are tenders, comparisons, you buy large fleets. The only way to win is low price. The profits will come in the service – that is where the margin is: in selling rides.” (Adriano Alessandrini, CityMobil2)*

## 6.2 Generic scenarios

As shown in the method, the categorisation of measures across two dimensions yield four generic scenarios. This section delineates the possible scenarios narratively.

### 6.2.1 Scenario S1: **Asleep at the wheel (Low R, Low F):**

In this scenario not much, if any, action is taken to ensure AVs operate in an environmentally friendly manner. As a result of this complacency, the current prevailing trends can be assumed to shape the developments going forward.

#### *Vehicle kilometres travelled*

With respect to VKT, a sharp rise can be expected, along with an increase in the number of vehicles. This is largely due to the appeal of autonomous technology to be operators and individual owners alike. A pivotal factor in shaping the balance between privately owned and fleet-based vehicles, will be the timing of the technology, and the speed at which either individuals or operators adopt these vehicles. Since the municipal government will have limited involvement in the management of this market, current trends indicate that will likely be dominated by a combination of OEMs, TNCs, and private individuals. Consequently, any restraining factors will be market-based, and as speculated by the respondent from Amsterdam and CityMobil2, this may come as congestion from excessive AV traffic, and thus lower appeal to users.

*“[Uber, Google, and Lyft is...] absolutely what made [OEMs] wake up, and create these new mobility service units. If they don't do it, they could be reduced to tier-0 supplier to the mobility industry.” (Jan Hellåker, DriveMe)*

#### *Congestion*

The lack of involvement from the municipality means that there will likely be a rise on congestion. Most of the vehicles operated by OEMs and TNCs will be small and pod-like, causing significant congestion during hours of peak traffic. In addition, pedestrians and cyclists dominate the streets, at the expense of motorised transport, as they show little regard when crossing streets. And even outside of rush hour, a number of the AVs will cruise the streets empty to avoid parking fees, while another portion will drive far outside the city to cheaper parking areas.

This scenario will also see a significant influx of privately owned vehicles, which collectively force the city to retain large amounts of long-term parking lots. Moreover, due to the absence of efforts to substantially expand the infrastructure for EV charging, a portion of these privately owned AVs will use internal combustion engines as their drivetrain.

*“For me it is just a matter of timing, this is a personal view. If systems become available to citizens that are cheap and effective and high quality, then they won't need to own cars. If you start with a shared system, people will just use them. If instead you make the private car more convenient, then you start a revolution that could kill public transport for good. It is a matter of who will give the kind of service that people want first.”*  
(Adriano Alessandrini, CityMobil2)

#### *Cannibalisation of PT*

In this scenario, the effects of this system on PT are likely to be devastating, partly as a consequence of PT agencies' aversion toward door-to-door transportation, but also from the competition of a door-to-door service that is far more convenient. Being only slightly more expensive, a shift will occur from ridership of PT to MPSs. Absent incentives to integrate with existing transport system, the interests of private actors will likely stand in opposition to that public interests, and the winner-takes-all effect could see this type of system rapidly permeate the city, preventing any reaction from the city administration.

#### **6.2.2 Scenario S2: The Green Miles (Low R, High F)**

In this scenario the city focuses on facilitating the environmentally sustainable attributes of AVs, namely electrification and shared mobility. However, the city overlooks any measures to counteract the inevitable drivers toward rapid expansion of AV mobility providers, with OEMs even more involved compared to the baseline, since the city will signal a desire to shift toward fleet-based mobility, as opposed to privately owned vehicles.

#### *Vehicle kilometres travelled*

In this scenario vehicles kilometres are likely to exceed that of the baseline scenario, albeit with fewer AVs on the streets. Fleet-operators will dominate, likely discouraging private ownership to a significant extent, due to stark differences in overall cost of transportation. With that said, the initial rate of adoption may be relatively slow, depending on the timeline of the projects that the city chooses to construct. In other words, too much facilitation may, counterintuitively lead to slower uptake.

*“I don't think any OEM would want to put requirements on the infrastructure, because it would delay the commercialisation of the technology.”* (Jan Hellåker, DriveMe)

In this scenario, the overall VKT pivots on the extent to which the city can effectively encourage sharing of AV rides, through the use of high occupancy lanes, dedicated stations, and by promoting the AVs as an extension of the PT network. Moreover, central parking complexes have been constructed to absorb AVs during off-peak traffic, while high-powered charging stations have been installed to lower the number of AVs needed in the fleet, and encourage operators to use electric drivetrains.

#### *Congestion*

Relative to the baseline scenario, congestion within this city has been significantly reduced. Through efforts to separate both AVs and human-operated vehicles, as well as preventing and discouraging unnecessary interaction between AVs and other road users, the flow of traffic is improved. This will happen in spite of a high adoption rate, since the provision of central parking, dedicated stations, and high occupancy lanes will encourage higher degrees of shared use, but also ensure that when demand is low, the AVs will not remain on the road.

#### *Cannibalisation of PT*

As a result of encouraging the shared use of AVs, PT will fall out of favour. While the strong presence of AVs will have an effect on commuters to use PT to and from the city, there will likely be a strong preference toward AV-use within the city itself. By extension, the use of multi-modal transportation will decline, since the AV system is likely to be sufficiently flexible for the majority of trips. Depending on the extent the PT system invests in their own system, the PT company might shrink due to loss of revenue, or added costs from having to fund their own fleet.

### **6.2.3 Scenario S3: Speed-limiting progress (High R, Low F)**

By focusing exclusively on the potential threats of AV-based transport, the city in this scenario may only achieve a limited range of benefits, which could be desirable if the primary objective is to enhance the city's PT and MaaS systems.

#### *Vehicle kilometres travelled*

The overall VKT will not deviate drastically from the current level. Through the active restriction of AVs across both times of day and designated areas, their appeal to the general population will be limited. Only few actors will find it economically viable to provide mobility services in this city, and may instead focus their growth elsewhere. Moreover, through the effects of both road pricing and fixed limits to the number of AVs allowed on the road, the cost to use AVs will be higher, and they may therefore be treated similarly to contemporary taxis. Depending on the breadth of the restrictions, and whether road pricing applies to privately owned vehicles, the number of privately owned AVs will also be limited, used only by the richer segments of the population.

#### *Congestion*

The effects on congestion can be difficult to determine in these conditions. In restricting the growth of AVs in the city, the city also prevents itself from exerting a greater degree of control over a larger number of vehicles, assuming that AVs are under greater control of the city through various V-2-X installations. Instead the city would remain in a situation of having to indirectly control the behaviour of human drivers. This would also mean foregoing the potential of making a greater percentage of the vehicles in the city electric, as an added requirement for AV ownership. Moreover, with human-operated and privately-owned vehicles continuing to dominate the roads, the city limits itself from drastically reducing the number of parking lots.

As a result, the level of congestion will likely be a product of other policies targeted towards human drivers, as opposed the active management of AVs. This system does, however, allow the city to target specific areas of the city, wherein people formerly incapable of accessing mobility can now have access, but overall the AVs will have a limited effect on the city's congestion. The continued presence of human-operated vehicles will be the primary reason for congestion.

#### *Cannibalisation of PT*

In this system, the city's PT and multi-modal mobility is likely to flourish. The limited use of AVs could mean that the AVs could be used to specifically target shortcomings in both systems, improving their ability to function as intended. Due to the limited applications of these vehicles, the owners of these vehicles will most likely be the PT agency, who will be able to comply with strict rules of vehicle-size and fuel-types.

The most notable consequence of this approach will be incremental progress within the city, and restraint on the creative turns the technology might take. Although the city might have its PT system strengthened, a number of the indirect benefits and transformative effects of AVs will not be felt, leading to a general policy of fixing present problems, rather than realising new possibilities.

#### **6.2.4 Scenario S4: A U-Turn in Automotive Impacts (High R, High F)**

In utilising a two-pronged approach to manage the environmental impact of AVs, the city gives themselves the capacity to proactively manage the system in real-time, as well build upon the opportunities afforded to the city by automation.

##### *Vehicle kilometres travelled*

As many of the measures are directly aimed at reducing VKT, the overall VKT is likely going to be the lowest of all possible scenarios, or fall in between S2 and S3. Vehicle ownership will also be highly uneconomical in comparison to using the city's mobility fleet. Unlike S3, the fleet-operators will be subject to measures that both facilitate and restrict their capacity to expand, meaning that the number of fleet-based vehicles will be higher compared to said scenario. Moreover, due to the city's comprehensive focus on electric infrastructure, all fleet-based AVs will be electric, and refrain from ghost-driving due to the easy access to parking and V2G installations, which provide a revenue while parked.

In spite of being accessible to the majority of urbanites, due to subsidised first- and last-mile PT offerings, their use will be conditional and therefore not the most economical solution for all trips. At the same time, the use of AVs is actively managed through variable road pricing throughout the day, ensuring that door-to-door use of AVs is kept to manageable levels.

##### *Congestion*

As a result of the investments in central parking complexes, the city has been able to reclaim spaces, subsequently allowing for a greater flexibility in separating AVs from cyclists and pedestrians. In utilising high occupancy lanes, dedicated stations, and zones to keep the traffic moving smoothly. With the added economic potential afforded to fleet-operators by the facilitative measures, the deterring restrictive policies are less harmful to their business, and as a result restrictive policies such as right-sizing and quotas have had a lower effect on pushing mobility providers out of the city. Congestion in this city is minimal, as multi-modality thrives. This has in part been achieved through the integration of AVs to make the system robust and flexible, but also through investments using revenues from the central parking complexes, and road pricing scheme.

##### *Cannibalisation of PT*

A second reason for the low congestion is the high use of the PT system. Autonomous buses have lowered operation costs, and the success of the MaaS system means that the PT system can adjust to varying levels of demand by using AVs either as a sink during periods of exceeding capacity, and as feeders during under-capacity.

Despite not offering the same opportunities for unrestrained market growth as scenarios S1 and S2, the city's combination of facilitative and restrictive measures have made the business environment stable, yet competitive. The implementation of AVs have been drawn on to encourage both mobility providers and mobility users to act in benefit of the city, and the movement of its people. It is for this reason that this scenario is considered the most optimal; an assumption that may be untrue, but for the purpose of the upcoming discussion, this scenario will be used as the ideal reference point for what Copenhagen ought to be striving for.

### **6.3 Feasibility scoreboard**

Below are the scores that were provided by the project manager for AV implementation in CPH.

Measure	Type:	Score	Point allocation			
	Facilitative Restrictive		1-5	S1	S2	S3
Dedicated AV zones	F	1	2	-	2	-
High occupancy lanes	F	5	-	2	-	2
Dedicated central parking	F	3	-	-	-	-
Dedicated stations	F	4	-	1	-	1
Dividers for AVs and other road users	F	1	2	-	2	-
Severe jay-walking punishment	F	1	2	-	2	-
Removal of on-street parking	F	4	-	1	-	1
Subsidies to promote PT integration	F	5	-	2	-	2
High-voltage charging station investment	F	3	-	-	-	-
Vehicle-to-grid integration	F	5	-	2	-	2
Road pricing	R	4	-	-	1	1
Enforced MaaS integration	R	5	-	-	2	2
Enforced right-sizing	R	3	-	-	-	-
Quotas for number of AVs	R	3	-	-	-	-
Self-driving constrained to specific areas/roads	R	3	-	-	-	-
Mandatory partnership with local PT operator	R	3	-	-	-	-
Required average occupancy rate	R	1	2	2	-	-
Limited fuel-types	R	4	-	-	1	1
Limits on operational hours	R	3	-	-	-	-
Limit use to certain demographics	R	1	2	2	-	-
Total		62	10	12	10	12

Table 8. Scenario Transfer; Copenhagen Feasibility Scorecard

As the feasibility scoreboard shows, the scores in Copenhagen are inconclusive. Of a possible total of 100 points, the city scored 62. Of this number 32 and 30 were from facilitative and restrictive measures, respectively. However, if neutral scores are eliminated, i.e. scores of 3, then 7 of the 20

measures can be removed. 5 of the 7 neutral scores were from the restrictive measures. This can indicate two things. Either Copenhagen is hesitant to consider restricting this new technology outright, or that knowledge is still required to even speculate as to feasibility of these measures. Based on the interviews conducted for the research, the latter is a more probable explanation.

As for the scenarios, S1 and S3 scored 10 out of a possible 40, whilst S2 and S4 scored 12. Based on these scores, it is not possible to determine what scenario is likely. However, since the highest possible score for each scenario is 40, an argument can be made that Copenhagen are as of yet, either unprepared or – by virtue of the topic yet to become part of the city’s agenda – incapable of thinking longer-term with regard to feasible measures.

Based on the comments provided by Annette Kayser, the latter of these appear to be the case. A lack of knowledge with regard to the technology, and how the city will need to evolve around it, are key obstacles to thinking of how this technology could be shaped to contribute to sustainable mobility.

### **Feasible measures**

In terms of measures scored as ‘feasible’, the comments were largely supported by favourable contemporary trends. Measures such as high occupancy lanes and dedicated stations are already talking points among politicians, and based should therefore be possible to implement to facilitate AVs. Moreover, added support to integrate AVs with public transport was another measure deemed highly feasible, as Copenhagen recognises that the bulk of mobility will be provided by the city’s metro and rail services. To further meet this object, an enforced MaaS system was also deemed feasible, but rests largely on the proportion of private to fleet-based vehicles in the city. Favouring certain fuel types is currently an ongoing measure in Copenhagen – especially the promotion of electric drivetrains – at least within the public transport sector, and extending this was also deemed feasible.

Other measures such as the removal of on-street parking, V2G integration, and road pricing were considered feasible, but pivoted on certain prerequisites and existing political agendas. The removal of on-street parking, for example, would likely need further justification in terms of what the reclaimed space will be used for. V2G is highly feasible, but only once the technology has matured, and road pricing is currently a measure that is perceived favourably among the city’s politicians, despite it not currently being used.

### **Unfeasible measures**

Measures that were deemed unfeasible can be broadly categorised as hard-handed, i.e. strict and uncompromising. Measures such as physically dividing AVs from other road users, punishing said users from interfering with AV traffic, and enforcing certain occupancy rates were deemed highly unfeasible. The Copenhagen’s approach is very much in line with the other cities in which interviews were conducted, in that they will likely require that AVs are capable of mixing with traditional modes of human-operated transport during the transition phase. For this reason, dedicated zones were considered unfeasible, and measures that would either punish or restrict other users from engaging in behaviours previously allowed, were highly unfeasible. Similar to the sentiment from the DriveMe project, AVs ought to enable opportunities; not limit other forms of mobility. Finally, a measure mandating a certain average occupancy rate was, similar to previously interviews, thought to be something that should be achieved through incentives based on user benefits.

### **Neutral measures**

The measures that scored as neutral, were largely measures where additional knowledge was still required, even in order to articulate any expectations. Central parking, for example, remains one measure where the city does not yet know, whether external or central parking is more favourable – and what the allocation between the two ought to be. As for high-voltage charging, the issue was economic, and who would be responsible for installing these chargers. Only if they are to be used to PT, would the city be the primary investor. As for right-sizing, although the concept was welcomed, further knowledge as to the technical feasibility is required. Furthermore, the notion of directly capping the number of AVs on the city roads will depend on regulation, as no current law permits cities to engage in the practices. Additional limits such as restricting AV use to specific areas, or based on time-of-day were not deemed desirable based on the aforementioned principle that AVs should be able to integrate with the existing traffic.



## **7 Discussion**

The use of AVs to contribute to sustainable urban mobility is a topic that will undoubtedly grow over the next decade. As of this moment, the issue is not in focus. Although political discourses and regulatory trends to limit emissions and energy use are on-going, discussing AVs in these terms is too distant to tangibly consider. This discussion situates the findings on this research within the existing theoretical debates on SNM, which outline the expected path for development of innovative and radical technologies. Firstly, the nurturing describes the need for strong, wide networks to facilitate learning. Secondly, empowerment outlines the two ways in which these technologies are exposed to, and accommodated by, the socio-technical regime. The discussion concludes with author's reflections of the methodology used.

### **7.1 Nurturing AVs for sustainable outcomes**

In reference to SNM, there is very little to indicate that any efforts can be undertaken during the initial 'shielding' phase of the technology. As of now, environmental benefits are taken as a given, due to the restraining attributes of the protective spaces, and the fact that the majority of AVs being tested by radical, innovative pioneers run on electric drivetrains, thereby meeting an important criteria for sustainable mobility. Furthermore, in terms of behaviour, i.e. potential overuse of the technology, the setting in which AVs are tested do not allow for these behaviour to emerge, for the simple reason that the spaces are constrained and thereby limiting the use of AVs for anything but predetermined trips.

In contrast, the nurturing phase – which SNM posits will follow the shielding phase – will bring options to investigate the possible measures to a greater extent. This phase involves selecting the various uses, and building networks around the technology. Herein lies the ability and opportunity to think in terms of roles and limits to the technology's impacts. A starting point to this is to articulate expectations, and to actively find ways make these expectations shared across the city (Schot & Geels, 2008). It is in this process that environmental and social aspects enter the discourse (Schot & Geels, 2008), and purposive measures can become a tangible point of discussion. For these reasons, if this phase is pre-empted and a level of involvement by influential actors, such as regulators, one can assume that this process could be expedited.

Throughout the expert interviews, due to their semi-structured format, the nurturing phase could be discerned through the topics that informants would bring up. Among these were market and user preferences, regulations and policies, and technical aspects, all of which have been identified as common learning processes in niche nurturing. Theory posits that environmental concerns emerge in this stage, and that this stage offers the greatest opportunity to pre-empt environmental impacts. However, as shown by the feasibility scoreboard, this line of thinking is currently beyond the sphere of concern currently occupying Copenhagen's administrators and implementers. Moreover, while learning constitutes a significant barrier, so too does decisions taken at the national level. As noted by a number of the informants; cities do not make the rules, they only decide how to apply them.

### **7.2 Empowerment of AVs for sustainable outcomes**

SNM teaches us that the empowerment phase of an innovative technology has two forms, fit and conform and stretch and transform. The former entails applying society's current selection pressures and standards upon the technology, and subsequently demonstrating its superiority, whereas the latter draws on purposive measures that help advance the technology and impede existing technologies (Boon et al., 2014; Schot & Geels, 2008; Smith & Raven, 2012).

## Fit and conform

Assuming that all technological niches develop and integrate in a general pattern, AVs will have to at some stage fit into the existing regime, and conform to its rules and practices (Hoogma, 2002). This process can be understood in two ways, one is that the innovative technology loses its transformative edge, and that rather than change surrounding environment and its selecting pressures, it instead complies with the existing system's practices and rules. However, it can be difficult to point to a specific technology that did not undergo this initial pressure, as it takes time and knowledge for society to realise and draw on the potential of new technologies (Geels, 2005; Schot & Geels, 2008; Twomey & Gaziulusoy, 2014). In other words, this is the period wherein the technology can clearly demonstrate its superiority to existing alternatives. One example of this was Tesla, and its explicit efforts to demonstrate that EVs both travel far, i.e. comply with existing selection pressures, and outcompete existing ICEVs in terms of performance (Musk, 2006) and safety (Weisenthal, 2013). AVs will, similarly, be subjected to similar standards and what these standards are could affect how the technology evolves. By this logic, pre-existing road pricing schemes and high-voltage charging stations<sup>11</sup>, could have a significant effect on demonstrating the value of AVs in terms of adjusting to and utilising these measures, respectively.

Since this form of empowerment is primarily designed to improve technologies by forcing it to compete against the existing regime, an emphasis on this approach will likely constrain the technology in scenarios S1 and S3, depending on the extent to which the city targets the technology with additional restrictive measures. An overreliance on this form of empowerment not only dulls the transformative edge of the technology, it is also more likely to adopt the characteristics of the already dominant technology (Schot & Geels, 2008). For this reason, it can be established that if the city wants to realise the technology's ability to contribute to sustainable mobility, it must include measures that exceed fitting and conforming.

## Stretch and transform

The process of stretching and transforming, i.e. institutionalising new practices and criteria as a consequence of a niche innovation becoming dominant (Schot & Geels, 2008), could be applied to a number of measures identified in this research. Granted that stretching and transforming relates to the measures designed to predominantly benefit AVs, measures such as high occupancy lanes, high-voltage chargers, and V2G can be utilised by non-AV users/operators can be eliminated. The measures that can be classified as such, are the following:

- Dedicated parking
- Dedicated zones
- Dedicated stations
- Dividers between AVs and other road users
- Severe jay-walking punishment
- Removal of on-street parking
- Subsidies to promote PT integration

Notably, of these measures 7 measures, only 3 were scored as feasible. Furthermore, of these measures a shared sentiment from Copenhagen, is that these measures could be used to further other agendas. Dedicated stations could serve as traditional bus stops, removal of on-street parking

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<sup>11</sup> These two examples were chosen, as they are measures that are currently in use, and that have benefits that pertain to EVs in general; not only A-EVs.

is favourable, depending on what the reclaimed space is used for, and subsidies to promote PT integration run aligns with the city's current agenda to strengthen the PT system.

Although MSPs have been shown to be possible contributors to rising congestion, VKT, and cannibalisation of PT, an argument can be made that cities ought to promote their presence. In terms of environmental impact, MSPs are likely to have a worse environmental impact than PT, but granted that demand for mobility with greater flexibility and precision will persist, an absence of purposive integration of MSPs – or even banning their existence – would only lead to a greater adoption of privately owned vehicles with AV capabilities. Purposive integration, on the other hand, allows for a greater degree of management, and thus greater control over the VKT, congestion, and extent of PT cannibalisation. Although direct PT integration may be the configuration allowing for the greatest degree of control, legislation in Denmark would need to change in order for PT to offer the service currently provided by taxi companies and TNCs. In other words, while early promotion of MSPs constitute a radical technological leap, and is likely to be met with backlash from incumbent mobility providers, such taxi companies. However, such a step may likely be what is required to establish a foundation on which incremental adjustments, through policies and legislation, can be utilised to steer MSPs toward more positive environmental outcomes.

In other words, the overarching objective during the stretch and transform phase should be discourage private ownership, not to undermine incumbent taxi companies per se. These companies often constitute a significant political force, and it will be important to encourage them to adapt early into the process of urban AV integration.

With that said, the feasibility scoreboard indicates that no concrete measures can be considered at this moment. The number of unknowns currently surrounding desirable AV integration are too numerous to suggest that any specific measure is guaranteed to have beneficial effect. If the scoring is to suggest anything, however, it does point to measures that encourage and facilitate more sustainable behaviours, rather than restrictive measures. This aligns with the shared sentiment across interviews, which is that AV integration should be to create new opportunities through interaction with other urban systems and goals.

### **Recommendations for Copenhagen**

Based on the results of this research, there are a number of areas that Copenhagen could begin to focus on at present. The first is that, while AVs are undergoing development within their shielded spaces, the city can focus on vision-building and trying to further a national legislative agenda to reduce uncertainty. The former will allow for all current and future actors to gain an insight into likely and desirable implications of the technology, and to encourage involvement prior to the technology's deployment. Copenhagen, like many other cities, have used this tool to great effect, and based on the general impression from the experts interviewed; it is not difficult to imagine the most desirable outcomes at a general level. As for the latter, if successful, will allow actors to make commitments otherwise prevented by uncertainty.

Moving forward, each of the identified measures will require additional research to gauge feasibility and ensure optimal implementation. As such, the city should consider earmarking funding for this purpose, as their resources and pre-existing network will allow for a more thorough extension of this research.

Finally, if the city can – through vision-building – successfully frame the technology as an opportunity for sustainable mobility, the city should not hesitate to engage in highly restrictive measures in the initial phases of widespread deployment. As highlighted throughout the paper, the

technology – and the business-model it will likely utilise – allows for rapid diffusion. Failing to restrict the technology initially may lead to an overdependence and a subsequent issue of adjusting the user's and provider's behaviour to accommodate the city's overall interests for sustainable mobility. This may be further warranted by the additional time the city will need in order to implement the facilitative measures, some of which may take time to implement.

## 7.3 Reflections on research method and results

### Research reliability

The reliability of research refers to the degree to which findings are repeatable (Bryman, 2004). In terms of this research, the semi-structured interview format utilised to extract 'measures' is likely the least reliable aspect of the research, as it was a highly iterative process. In practice it meant that initial interviews were broad, often straying from the topic of purposive measure for sustainable outcomes. As the process progressed, there was a clear and positive evolution in the interviews' value, in terms of yielding specific measures and through better framing of questions. Granted that experts were asked to speculate and voice their expectations, there is a degree of uncertainty to the results, as well as strong prevalence towards measures already in place; meaning that these measures do not fit the criteria for 'consistent over time' (Bryman, 2004; Walliman, 2006). This is to be expected, granted that the topic is based around future scenarios, and the technology has yet to impact society. The research did, however, find notable consistencies in terms of expectations from the actors interviewed.

Speaking to the method, however, the overarching framework used to score the measures is considered reliable, albeit premature at this point in time. The generation of scenarios is as questionable as the measures ultimately derived from the research, but should only be considered as 'segments of reality' (Kahn & Wiener, 2000), and their role was to provide the reader with a sense and justifications for what a desirable future *could* look like. It must be noted, however; that the exclusive focus on transport of people, is likely to limit the scenario, as the transport of goods using AVs may have a strong effect on how the technology develops and is integrated.

### Research validity

In relation to theory, the research was able to use SNM to categorise the emergent measures. The generalisability of this research, is believed to be applicable to countries with a high level of economic development. While the interviews were predominantly conducted in Northern Europe, most the measures that were identified in the research, are common across the globe in various forms. With that said, the results of study does not claim to be generalisable, however, the framework should be applicable to any context. Moreover, additional indicators to determine likely scenarios would have strengthened the research, but due to time constraints this was not possible. The effectiveness of the respective measures is perhaps the most limiting omission in this regard, since one measure could have the effectiveness of all the others combined.

The internal validity of the research, i.e. the extent to which causal statements are supported by the study (Bryman, 2004; Walliman, 2006), should be questioned to the extent that the authors interpretation was a significant factor in the generation of measures. While most measures were directly extracted from literature and interviews, some level of interpretation was used to generate measures, such as subsidies to promote PT integration. As for the scenario themselves, their construction was based on the aforementioned measures and numerous assumptions, and granted the complexity of urban transport systems, should be read with a strong degree of scepticism. This same critique could be extended to the scenario analyses that were used to inform this research.

## **8 Concluding remarks**

The specific aims of this study were four-fold; firstly, to generate an understanding of key measures cities need to consider to integrate autonomous vehicles for achieving sustainable urban mobility. Secondly, to understand the possible future scenarios of AVs and their environmental implications. Thirdly, to evaluate the feasibility of these measures in the context of Copenhagen to understand the likely scenario the city will face. Finally, to identify the underlying obstacles Copenhagen is likely face in applying these measures.

This thesis has argued that autonomous vehicles are destined to revolutionise our cities in the coming decades, and ensuring the technology remains on track to contribute to sustainable urban mobility will become ever more relevant. Preparatory action and purposive measures will be necessary to guarantee this end, as the technology will – by virtue of its beneficial, yet often contradictory attributes – force cities to make compromises to the technology in order to shape its role.

By interviewing key actors from the cities and the mobility industry, and review of key literature, this thesis has identified a range of critical measures that are critical to ensure the mobilisation of AVs for a sustainable future in the cities. In total 20 measures were identified and broadly categorised as restrictive and facilitative. The facilitative measures are designed to enable and encourage AVs to contribute to sustainable mobility. These measures include dedicated AV zones, high occupancy lanes, dedicated central parking, dedicated stations, dividers for AVs and other road users, severe jay-walking punishment, removal of on-street parking, subsidies to promote PT integration, high-voltage charging station investment, and vehicle-to-grid integration. The restrictive measures are those that restrict AVs from operating unsustainably. These included: Road pricing, enforced MaaS integration, enforced right-sizing, quotas for number of AVs, self-driving constrained to specific areas/roads, mandatory partnership with local PT operator, required average occupancy rate, limited fuel-types, limits on operational hours, and limit use to certain demographics.

In doing so, this thesis suggests four likely scenarios of AVs environmental implications that could emerge from cities action, and inaction to implement these measures. Should cities elect to prioritise the technology's contribution to sustainable mobility, they will need to institute both restrictive and facilitative measures. The baseline Scenario 1 is characterised by the exacerbation in congestion, VKT, and cannibalisation of PT. Scenario 2 consists of high VKT, albeit with a high degree of electrified transport, with issues such and PT cannibalisation and congestion only moderately reduced. Scenario 3 sees all core issues addressed, but at the expense of other beneficial characteristics of AVs, while in Scenario 4, all issues are addressed, and the city is able to both manage and attract MSPs, despite its relatively stringent rules for AV operators.

In the context of Copenhagen, their current future remains unclear, as the research was unable to discern any outstanding scenario based on the feasibility scoring of the various measures. The main obstacles for Copenhagen will be to generate knowledge on the potential of the technology in Copenhagen, and how to integrate the technology with existing sustainable mobility plans. As the future will be largely dictated by legislative action around this technology, it is pivotal that the technology be made tangible to the city's policy-makers, and the possible measures enter the discussion as soon as the first vehicles begin operating on the open road, but preferably before that. Although the research was not able to provide concrete advice on how the city ought to proceed, the provided list of measures and the framework utilised to construct possible scenarios, could be a general way the city understands this presently intangible problem. While the compiled list of measures is not exhaustive, the framework, along with its categorisation should remain useful as more possible measures emerge.

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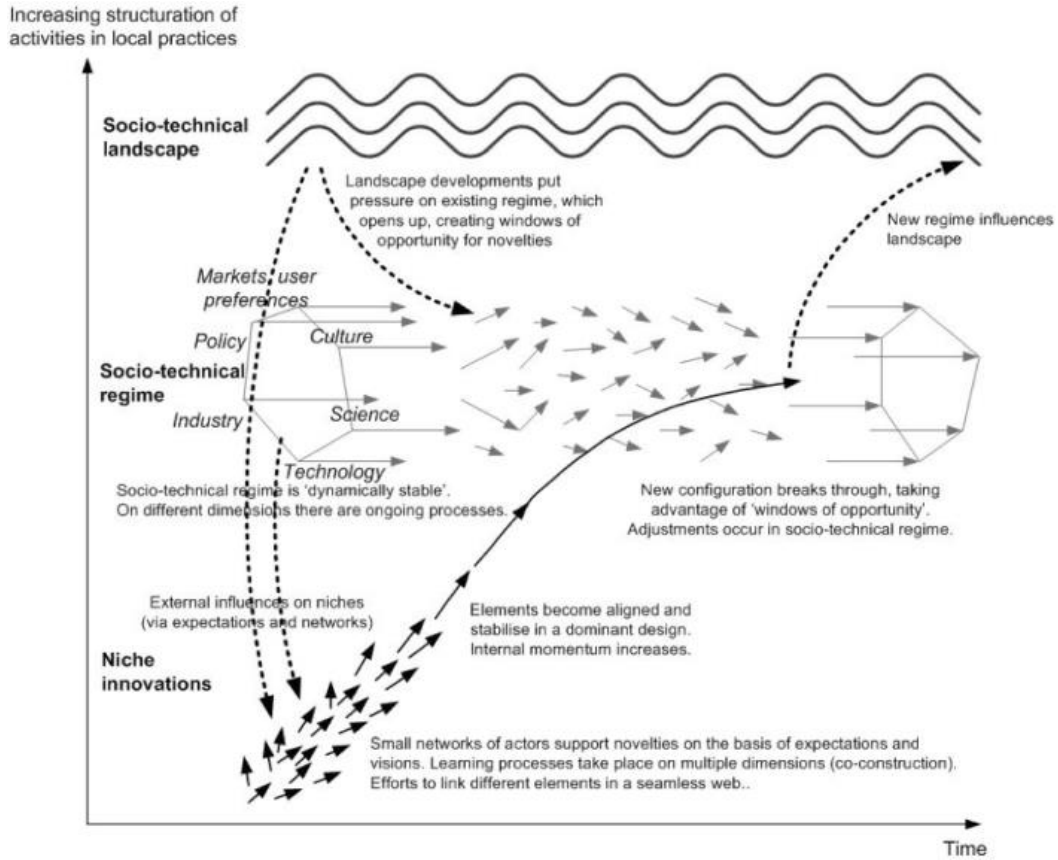
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# Appendix

## Figures



*Multi-level Perspective (Schot & Geels, 2008)*

### Concept elaboration

#### Transition theory

According to scholars of transitions Kemp, Geels, and Dudley (2011: 4), transitions are “long term-term processes (40-50 years), which are outcomes of alignments between multiple developments; they are not caused by a single factor such as a high oil price, a transport innovation or a government intervention”. Based on this understanding, the diffusion of AVs will not be a function just its inherent merits, but numerous external factors.

While contemporary literature and reports on the topic of AV implementation and the potential of the technology frequently refers to the technology’s likely impacts as ‘radical’, ‘innovative’, and ‘disruptive’ (Anderson et al., 2014; Arbib & Seba, 2017; Litman, 2014; Meyer et al., 2017), transition theory teaches that the technology’s success is contingent on whether the existing regime actively resists its presence, the role played by local ‘niches’ in exploring the potential for transformative change and the conditions the allow the technology to develop (Kemp, Geels, & Dudley, 2011).

## **Coevolution**

A core understanding of transitions is their co-evolutionary nature, and their successful diffusion through the integration into various parts of society. This is explained by Sartorius (2006: 274), saying “co-evolution implies that successful innovation in general and successful sustainable innovation in particular, has to acknowledge the involvement of, and mutual interaction between, more than the mere technical and economic spheres”. Knowledge of this coevolution tells us that technological innovation, while it can emerge as an application in just about any part of society, to succeed it must integrate with business strategies, user practices, and institutions (Foxon, 2011).

## **Path Dependence**

Another central tenant to transitions is the phenomenon of path dependence, which results from private companies actively trying to reduce risk (Arthur, 1989). It describes how companies, rather than seek to develop and produce innovative technology, remain within safe boundaries, averse to taking a risk in producing a product that may not sell. As a consequence of this behaviour innovation occurs incrementally within businesses (Geels, 2005), which leads to larger system-wide effect referred to as technological lock-in (Unruh, 2000).

## **Technological lock-in**

The automobile and the sociotechnical regime built around it has had a profound impact on urban and suburban areas. Cities have evolved to suit the automobile, which has in turn made their inhabitants dependent on the mode of transport (Newman & Kenworthy, 2006). This phenomenon is referred to as technological lock-in (Unruh, 2000). We can observe this development first-hand, through the suburban sprawl of North American cities, and the dispersal of shopping malls, and other amenities, which effectively entrench the automobile at the expense of other modes of transportation (Newman & Kenworthy, 2006).

## **Multi-level perspective**

The multi-level perspective (MLP) is the product of the synthesis of these concepts, thus giving researchers an overview of the dynamics of transitions. The MLP conceptualizes transitions as occurring at three different levels, the landscape, regime, and niche. The way in which these level interact and apply pressure dictates the pathways of innovation and the impact of radical technologies on society (Twomey & Gaziulusoy, 2014). A visual representation of this framework can be found in the appendix.

In brief, the socio-technical landscape, or macro-level, describes the larger, underlying forces that shape and select certain technologies. It exerts both pressure on the socio-technical regime and niches, and consists of cultural patterns, macro-economic, and political developments (Markard and Truffer, Geels).

The socio-technical regime is composed of seven dimensions: technology, user practices and application, the symbolic meaning of technology, infrastructure, policy, and techno-scientific knowledge (Geels, 2005). These tenants act in unison to create a stable system, comprised of the current structures that make up the current practices and routines, rules, and technologies that help the existing socio-technical system prevail. This provides stability, which is largely positive, but also creates technological lock-in. As a result, progress at this level is typically incremental, as incumbent actors benefit (Geels, 2005).



At the lowest level is the ‘niche’, a protected space created for experimentation and radical innovation (Geels, 2005; Markard & Truffer, 2008). These niches are designed to temporarily shelter the technological innovation from ‘mainstream selection pressure’ present in the market at large, and allows for actors to interact in a much less coordinated way (Smith & Raven, 2012). This is believed to support innovation, as the regime’s routines and practices do not determine and shape actions (Markard & Truffer, 2008).

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