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Is the driverless future sustainable? - Strategic uncertainties and system impacts

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Abstract

Future sustainability impacts of driverless vehicles are subject to significant uncertainty which arise from complex systemic interactions within the transportation system and parallel social trends influencing transportation. One approach used to holistically address impacts of driverless vehicles is societal scenarios which capture and problematize the complex interactions. However, they are speculative in their nature and sensitive to the pre-conceptions and knowledge of the experts developing the scenarios. In this paper, multiple scenarios developed in several different studies are compared to create a deeper and broader understanding of system impacts of driverless vehicles and the future society with driverless vehicles than what is achieved through individual scenario studies. The findings show that there are four strategic uncertainties shaping the development: the role of the public and private sector, policy making for driverless vehicles, the impact of the sharing economy and the pace of driverless technology development. Most of the studied scenarios report higher traffic volumes than today. Impacts on social equity and the role of public transport vary significantly between the scenarios. Furthermore, the scenario studies expect the sharing economy to be an enabler to curb growth in travel volumes which is important if climate goals for transportation should be possible to meet. Further research efforts should address impacts of driverless vehicles in more systematic forms than societal scenarios but with wider system delimitations than in existing simulation studies.

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Keywords: Driverless vehicles, automated vehicles, system impact, explorative scenarios, system analysis

1. Introduction

Finding ways to achieve a sustainable and desirable future transportation system is an urgent matter in the pursuit of meeting non-negotiable global climate targets (Gössling et al., 2018). Automated driving might enable and catalyze major sociotechnical shifts in the transportation system and the mobility of passengers and goods (Fagnant and

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Kockelman, 2015). The ongoing technology development and initial deployment (China Daily, 2017; Nobina, 2018; Volvo Cars, 2018; Waymo, 2018) is casting some light on how driverless vehicles[†] behave in traffic situations but wider, long-term impacts on the transportation system, environment, land use, social equity and other societal factors are to a large extent still unknown. Assessing societal impacts of driverless vehicles is challenging since they are embedded components in the wider sociotechnical transportation system (Papa and Ferreira, 2018). How the development of driverless vehicles, and its impacts, will unfold is not only dependent on the technology development of driving automation systems but is also related to structural sociotechnical aspects of transportation and mobility in general such as policies and regulations, the actor networks and consumer behavior (Fraedrich et al., 2015). This implies that impacts from driverless vehicles will appear on various system levels and affect each other in complex systemic impact paths and feedback loops (Gruel and Stanford, 2016; Innamaa et al., 2018; Milakis et al., 2017b). Therefore, net effects on a societal level, are complex to predict.

Various simulation studies of driverless vehicles have been performed, typically evaluating traffic and accessibility impacts (Davidson and Spinoulas, 2016; Meyer et al., 2017) or services with driverless taxis in urban areas (Bischoff and Maciejewski, 2016; Burghout et al., 2015; Fagnant and Kockelman, 2014). Transport simulation models provide quantitative results but require specific assumptions on many uncertain parameters. Simulations provide useful insights for the specific case that is simulated but are limited to the defined case, the specified causal model structure and availability of data. Multiple studies have addressed transport policy issues for driverless vehicles by synthesizing results from various types of studies such as simulations, technical tests, comparisons with other technologies, market forecasts and transport and land-use economics to asses potential impacts, however with little focus on systemic feedback loops in the system (Cavoli et al., 2017; Fagnant and Kockelman, 2015; Litman, 2018; Milakis et al., 2017b; Williams et al., 2017).

A more holistic and explorative approach is research developing scenarios for the future society and transportation system with driverless vehicles. Such studies have been done by several research groups (Kristoffersson and Pernestål Brenden, 2018; Milakis et al., 2017a; Papa and Ferreira, 2018; Pernestål Brenden et al., 2017; Tillema et al., 2017, 2015; Townsend, 2014). Typically, societal scenario[‡] studies are developed with the purpose of challenging conventional thinking and showing that there are numerous plausible potential futures. The studies provide rich descriptive stories on how the future might unfold. Scenario studies address the development and implications from a high-level system approach and consider trends and factors from wider system delimitations than what is possible to do in simulation studies. On the other hand, scenario studies are speculative in their nature and the results are highly sensitive to the backgrounds, pre-conceptions, knowledge and interests of the researcher(s) and experts developing the scenarios as well as the culture, and discourse they are embedded within.

In this paper, multiple scenario studies are analyzed and compared to identify common trends and potential future developments. By using several scenario studies made by experts in different countries and contexts with different areas of expertise, the aim of this study is to create a deeper understanding of which alternative scenarios there are for the future society and transportation system with driverless vehicles. The aim is thus to leverage existing explorative research with a systematic analysis of:

- Which key trends are shaping the development of driverless vehicles?
- What does the future society look like and which system impacts are generated by driverless vehicles in the scenarios?
- Which similarities and differences are there among the scenarios regarding the development and system impacts?
- What type of developments could make driverless vehicles contribute to a sustainable transportation system?

[†] Driverless vehicle(s) is used to denote vehicles with SAE level 5 automated driving system (SAE International, 2018). For vehicles with lower levels (1-4) of automated driving systems the term automated vehicle(s) is used.

[‡] *Societal scenario(s)* and *scenario(s)* will be used interchangeably to denote descriptive future images of the transportation system and society of the kind presented in societal scenario studies.

The contributions of the work presented in this paper include an assessment of how complex, sociotechnical aspects might shape the development of driverless vehicles. It complements existing studies by addressing many of the concurrent societal developments ongoing in parallel to the development of driverless vehicles that influence how the future unfolds. The results presented in this paper can further be used as a reference for designing simulation studies and putting existing simulation results in a societal context. Also, the method used in the paper is a novel method for systematic comparison of societal scenarios. The method can be used for any topic but is in this paper applied to the development of driverless vehicles.

2. Method

The approach in this paper is to compare and analyze societal scenario studies to get a better understanding of potential future developments and impacts of driverless vehicles. The intention is not to identify the most likely future development. Rather, the ambition is to systematically assess multiple future societal scenarios developed in several studies to identify common development paths and analyze system impacts generated by driverless vehicles.

Scenario studies can be performed for many different purposes and there is a wide range of approaches and techniques for developing scenarios (Bishop et al., 2007). In section 2.1, different scenario study types, and in particular the types used in this paper, are presented. The method for comparison and analysis of the societal scenarios developed in this paper is presented in section 2.2, and how the selection of societal scenario studies is performed is presented in section 2.3.

2.1. Scenario study types and scenario development techniques

In this paper the focus is on scenario studies that have an explorative approach and present descriptive images of potential futures. Such studies are performed with an underlying assumption that the future development is inherently uncertain and that there is not one determined future. Rather there are several plausible futures that there is a value in exploring to be prepared for future events. Explorative scenarios do not represent the most probable future events (Johansen, 2018). Instead, they are used to explore different plausible development paths, enhance the understanding of causal processes and to challenge conventional thinking around a specific topic (Wright et al., 2013). Explorative scenarios thus differ from predictive scenarios which resolve around answering what will happen and from normative scenarios in which the purpose is to assess how a specific target can be met (Börjeson et al., 2006).

The most common technique to develop explorative scenarios is the Intuitive Logics (IL) technique (Bishop et al., 2007; Johansen, 2018). At the core of IL is to analyze key trends and identify the two most influential strategic uncertainties that impact the future development (Wright et al., 2013). These two trends are denoted as *scenario axes* and are combined to create four scenarios, see Fig. 1. The four scenarios are then further elaborated later in the IL development process. Typically, this development process involves a group of experts representing various actors and perspectives of the system under study.

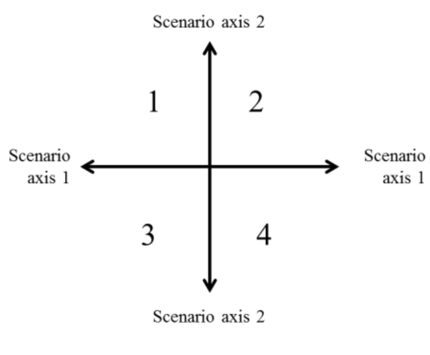

Fig. 1 In the IL method two scenario axes are identified and combined to create four societal scenarios (1-4)

Another explorative scenario technique is the Alternative Futures (AF) which is based on elaboration of fixed scenario archetypes (Bishop et al., 2007). In contrast to the IL technique, where scenario axes are used to define the scenarios, AF uses four pre-defined general archetypes for societal development: *Growth* – economic growth will continue being a key purpose for society and it will persist along with other major trends, *Collapse* – critical social, economic or technological systems fail because of internal or external forces or events, *Constraint* – economic growth is either unsustainable or unwanted and society is organized around other sets of values (e.g. environmental, religious, cultural, etc.), and *Transformation* – disruptive technological breakthrough (usually in robotics, artificial intelligence and/or genetic engineering) enables an entirely new form of society (Dator, 2009). The archetypes are then developed to scenarios for the specific system under study.

2.2. Method for comparison and analysis of societal scenarios

Methods for synthesizing, comparing and making meta-analysis of societal scenarios have, to our best knowledge, not been applied to the field of impacts of driverless vehicles, but to related fields such as transport and land-use (Bartholomew and Ewing, 2008; Creutzig, 2016) and energy (Schmid et al., 2013; Silberglitt et al., 2003). One approach to meta-analysis of scenarios is to describe the solution space of possible futures and how the development is related to a range of technological and social factors. Another approach seeks to analyze many societal scenarios to estimate the most likely development(s). The method applied in this paper belongs to the former approach. The proposed method to compare several scenario studies has two main benefits over individual scenario studies.

- By using multiple societal scenario studies, a larger sample of future scenarios is analyzed and thus a more robust representation of the various potential futures with driverless vehicles is achieved.
- The most common societal scenario method (IL) relates scenarios against only two strategic uncertainties. The proposed method incorporates strategic uncertainties from multiple societal scenario studies and maps all scenarios against a larger set of strategic uncertainties. Thus, the different scenarios are represented in a way which allows for a more thorough analysis of how a larger number of different strategic uncertainties shape the development.

The method developed to compare and analyze societal scenarios is general for explorative scenarios, but in this paper, it is applied to the development of driverless vehicles. The method addresses the following questions: 1) which are the most important strategic uncertainties shaping the development for driverless vehicles? 2) which system impacts do different types of developments generate?

The intention is not to make a detailed analysis of information presented in the scenario descriptions, as these are often written as narrative histories to provide colorful pictures rather than exact predictions (Bishop et al., 2007). Instead, the aim is to capture the overall trends and developments described in the scenario studies. The method is intended as a framework to overcome the heterogeneous nature of societal scenario studies to support a systematic qualitative assessment of those studies. The method is outlined in Fig. 2 and in the remainder of this section a description of all steps in the method is given.

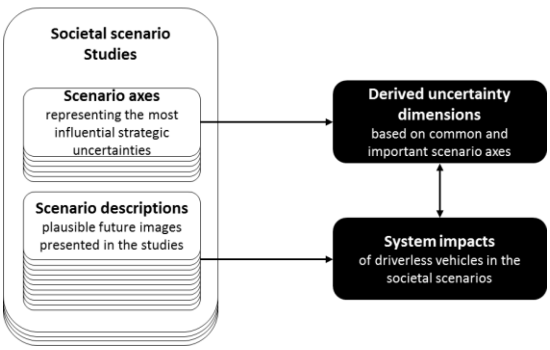

Fig. 2 The comparison method for analysis of societal scenarios. The left side of the figure with white boxes indicates the societal scenario studies and data that can be directly obtained from them. The right side with black boxes indicates analytical tasks.

First, the scenario axes from the IL studies are extracted. The scenario axes were in the original scenario study chosen to represent the most important strategic uncertainties for the specific context of the study. Similar axes are combined and grouped into a set of derived uncertainty dimensions (sometimes in this paper also denoted as uncertainty dimensions) which describe the main strategic uncertainties for the system under study. The number of uncertainty dimensions is the same or smaller than the number of scenario axes.
The second step is a mapping of all societal scenarios against the uncertainty dimensions. This is done by placing all scenarios on a scale for each uncertainty dimension. Scenarios developed with other explorative scenario methods than IL (e.g. the AF technique) are also mapped on the derived uncertainty dimensions. This mapping is done by a qualitative interpretation on how the characteristics of each scenario relates to the respective uncertainty dimension as illustrated in Fig. 3. In some studies, features relating to the uncertainty dimension are expressed explicitly and some studies require more interpretation. The result of the mapping is a multi-dimensional representation of all the scenarios capturing how they relate to the uncertainty dimensions, thus capturing the features of the scenarios in the most important aspects.

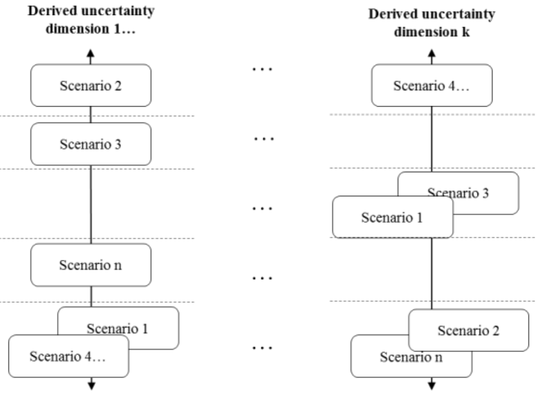

Fig. 3 Illustration of the mapping process of the societal scenarios against uncertainty dimensions, i.e. step (ii) in the method (see also Fig. 2.).

Next step is to identify system impacts in the scenarios. Sophisticated frameworks for analysis of system level impacts of driverless vehicles are emerging (Innamaa et al., 2018) but in this paper the analysis is based on a simplified representation of system level impacts suited for to the information available in the scenario studies. Impacts in five areas are analyzed: the vehicle fleet size, the vehicle fleet composition, the usage of vehicles in the fleet, the role of traditional public transport and social equity. Five variables representing these impacts are used for the analysis which are presented in Table 1.

Table 1 Variables used to describe system level impacts of driverless vehicles in societal scenarios

System impact variable	Definition
Vehicle fleet size	Total road vehicle fleet size compared to the fleet size of today
Driverless vehicles in fleet	Driverless vehicles in fleet as the share of the total vehicle fleet size
Total Vehicle Kilometers Travelled (VKT)	Total VKT produced by the total vehicle fleet compared to today
Traditional public transport service level	The availability, service level and usage of Public Transport (PT) services offered by the public sector compared to today
Social equity	To what extent the direct benefits and externalities from driverless vehicles are distributed equally among various social groups (e.g. people living in urban areas & rural areas; low & high income groups; existing car users, children, disabled, elderly, people without driver's license) compared to today

Similar to the process of deriving uncertainty dimensions, the assessment of system level impacts is based on a qualitative interpretation of the societal scenarios for each of the system level impact variables. The availability and type of information differs significantly between studies. Some studies present quantitative estimates of the variables whilst others require interpretation of qualitative descriptions. Hence the obtained results for the system level impact variables should be interpreted mainly in relation to the result for other scenarios and not in absolute terms.

The final step of the method is a qualitative analysis of the societal scenarios with regards to the uncertainty dimensions and the system level impacts. This analysis explores: how are the societal scenarios distributed among the uncertainty dimensions? Are there societal scenarios from different studies with similar characteristics? Are there correlations between the scenarios' characteristics in terms of their relation to the uncertainty dimensions and their system level impacts?

2.3. Selection of scenario studies

In this paper, existing studies of societal scenarios of driverless vehicles serve as the empirics for the analysis. To enable a systematic review aligned with the aim of this paper the following selection criterion are used to scope relevant studies.

- The study should have an explorative research focus and apply an explorative scenario technique.
- The study should address potential development paths (e.g. scenario axes), present future images (i.e. scenario descriptions) and present information on how the development of driverless vehicles have influenced society.
- Academic literature and grey-literature are both relevant if the method and approach used in the scenario study is explicitly presented.

To find academic scenario studies, a literature search was performed in the databases: SCOPUS, Web of Science and TRID using the keywords: "future" AND "scenario" AND "automated vehicles" OR "self-driving vehicles" OR "driverless vehicles". The literature search resulted in 280 papers of which two meets the selection requirements for this paper. Two grey-literature reports are selected in addition to the two academic papers. Three other academic papers identified that could serve as complementary reading but that are not meeting the selection criteria for this paper (Fraedrich et al., 2015; Gruel and Stanford, 2016; Papa and Ferreira, 2018).

3. Data – the societal scenario studies, scenario axes and scenario descriptions

The societal scenarios serving as empirical data is gathered from four societal scenario studies (Milakis et al., 2017a; Pernestål Brenden et al., 2017; Tillema et al., 2015; Townsend, 2014). Altogether these scenario studies contain 16 scenarios for the future transportation system with respect to driverless vehicles. In the following sections, the background, purpose and focus, scenario development technique and primary content of the scenario studies are presented.

3.1. The societal scenario studies

The four studies have been performed by four different research groups at institutions independent of each other. One of the studies was led by researchers at KTH and VTI in Sweden (Pernestål Brenden et al., 2017). The study is oriented towards passenger transport. The same research group later complemented these societal scenarios with a freight perspective (Kristoffersson and Pernestål Brenden, 2018). Researchers at Delft University of Technology (Milakis et al., 2017a) have performed a similar study with focus on passenger transport in a Dutch context. The KiM Netherlands Institute for Transport Policy Analysis carried out a scenario study that examined potential futures and wider impacts of driverless vehicles (Tillema et al., 2015). This explorative scenario study was complemented with a study (Tillema et al., 2017) that evaluated how different development paths can lead to the respective scenarios in Tillema et al. (2015). The fourth scenario study was developed in the US by Townsend (2014) as a part of a research project at the Rudin Center for Transport Policy and Management at New Yok University that focused on the role of transport planning in the future transportation system.

In the scenario studies there are two different types of scenario development approaches applied: the IL technique (Milakis et al., 2017a; Pernestål Brenden et al., 2017; Tillema et al., 2015) and the AF technique (Townsend, 2014), both briefly introduced in section 2.1. The three IL studies used workshops where researchers and external experts from academia, industry and public bodies have been contributing to the development of the scenarios. The workshop format, number of workshop and role and degree of involvement from the external experts varies between the studies, as can be seen in Table 2. One notable difference is how the scenario axes and first versions of the scenarios were identified and developed. In Tillema et al. (2015) and Milakis et al. (2017a) the authors performed these stages by their own and then used workshops with external experts to validate and adjust the scenarios and also to estimate system impacts of the scenarios. Pernestål Brenden et al. (2017) involved external experts already in the first stages performing the identification of scenario axes and the initial development of scenarios during workshops. In the AF technique study the scenarios are created by applying findings from an extensive literature review (Mondschein, 2014) to the four scenario archetypes (see section 2.1) forming a narrative for the future transportation sector. External experts were not involved, as in the IL studies, and the scenarios are developed by the report author. In the study the perspective on the transportation system is broad and includes various accessibility aspects but wider societal developments like economic development, the development of energy systems and demographics are fixed across the different scenarios.

The scenario studies differ in how the scenarios are presented and what type of data is used to form the narrative. Two studies provide mainly qualitative descriptions of the societal scenarios (Tillema et al., 2015; Townsend, 2014) while others also provide systematically derived numerical estimates on high-level impact parameters such as the vehicle fleet composition (e.g. how many driverless vehicles will there be in the future vehicle fleet) and travelled vehicle kilometers (Milakis et al., 2017a; Pernestål Brenden et al., 2017). Tillema et al. (2015) provide a non-numerical mapping of potential system-level impacts in the different societal scenarios. A summary of the scenario studies' scope, methodological approach, type of scenario description and quantified impact parameters is presented in Table 2.

Table 2 Key characteristics of the compared scenario studies.

Study	Case study area, Time horizon, Scenario development technique	Scenario development process and data sources	Scenario descriptions format	Quantified impact parameters
Pernestål Brenden et al. (2017)	Sweden, 2030 and 2050, IL	Three expert workshops – total 40 experts from 23 organizations. Complemented by freight workshop - 17 experts from nine organizations.	Descriptive text, illustrations and numerical impact parameter estimations	For each scenario: •Total vehicle fleet size •Share of driverless vehicles in fleet (%) •VKT total fleet •VKT by driverless vehicles (%) •S-curves for market adoption rates
Milakis et al. (2017a)	the Netherlands, 2030 and 2050, IL	Two workshops – paper authors. Third workshop - 20 experts from academia and other organizations.	Descriptive text, illustrations and numerical impact parameter estimations	For each scenario for 2030 and 2050: •Share of driverless vehicles in fleet (%) •VKT total fleet •VKT by driverless vehicles (%) •Change in value of time (%) •Road capacity change (%) •S-curves for market adoption rates

Tillema et al. (2015)	the Netherlands, not stated, IL	Qualitative and explorative scenario development by report authors. Four expert workshops to validate and adjust scenarios developed by authors - Experts from different fields and types of organizations. Number of experts not stated.	Descriptive text, illustrations and impact parameter estimations	For each scenario: •Capacity •Volume of car traffic •Public transportation •Bicycle use •Automated freight transport •# of parking places •Spatial distribution •Social inclusion •Traffic safety •Environment and livability •Auto makers market •# of car dealerships •Drivers (bus and freight)
Townsend (2014)	USA, around 2030, AF	By report author based on literature review.	Descriptive text and illustrations	Not systematically quantified. Some quantified impacts presented in descriptive text

3.2. Scenario axes and scenario descriptions

In the three studies using the IL method, scenario axes were identified to represent trends that are assumed to have a high impact on the development but how these trends will unfold is highly uncertain, i.e. strategic uncertainties. The scenario axes are summarized in Fig. 4. More elaborated descriptions of the scenario axes are presented in the respective study. A summary of the most important aspects of the scenarios descriptions is presented in appendix A – scenario descriptions.

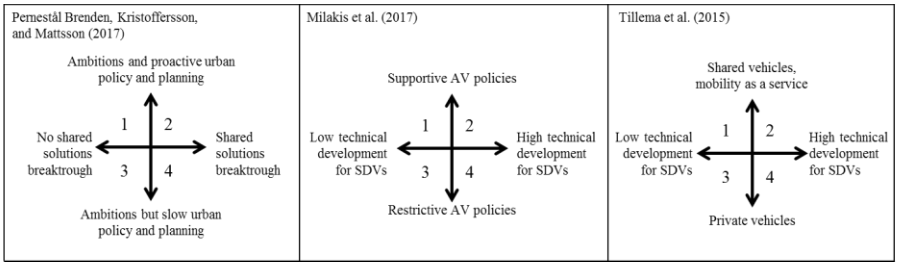

Fig. 4 scenario axes in the three studies using the IL method that sets the prerequisites for the scenarios (indicated by 1-4) in the IL studies (Milakis et al., 2017a; Pernestål Brenden et al., 2017; Tillema et al., 2015)

4. Analysis

In this chapter a comparison and analysis of the scenarios in the following areas is presented: which strategic uncertainties are shaping the development of driverless vehicles, how the development in the scenarios have unfolded with regards to the strategic uncertainties, what system level impacts there are in the scenarios and finally how the development with regards to the strategic uncertainties are relating to the system level impacts.

4.1. Strategic uncertainties – what is shaping the development of driverless vehicles?

There are similarities among the topics of the scenario axes between different studies. The six scenario axes identified in the three IL studies are all related to one of three topics: policy making, sharing economy and technology.

Two out of three studies have identified a policy-related axis as one of the scenario axes. Pernestål Brenden, Kristoffersson, and Mattsson (2017) uses one scenario axis related to the ambition level of holistic transport- and urban planning indicating that a low ambition level will enable private commercial actor to lead the development.

Milakis et al. (2017a) identifies one policy-related scenario axis as whether policies for driverless vehicles will be restrictive or supportive. These two similar policy-related scenario axes are highlighted with green color in Fig. 5.
Two of the studies have identified the potential adoption of the sharing economy in general and the sharing of vehicles and rides in particular as one scenario axis which is represented by purple in Fig. 5 (Pernestål Brenden et al., 2017; Tillema et al., 2015). This scenario axis includes several factors, such as; whether people will own private vehicles in the same way as today or if people will rely on rental cars or mobility services and whether people will prefer to travel by their own or are willing to share their travel. In the studies, the willingness to share personal data (e.g. data on travel patterns and consumption patterns) with external actors is described to be a key enabler for sharing economy solutions.
The third topic for scenario axes in the studies is the pace of technical development for driverless vehicles which is marked with orange color in Fig.5 (Milakis et al., 2017a; Tillema et al., 2015). In these studies, the technology for automated driving is assumed to sooner or later enable driverless vehicles but how fast that development happens is uncertain. The scenario axis is ranging from automated vehicles to driverless vehicles. In Fig. 5 a mapping of similar scenario axes in the IL studies is presented.

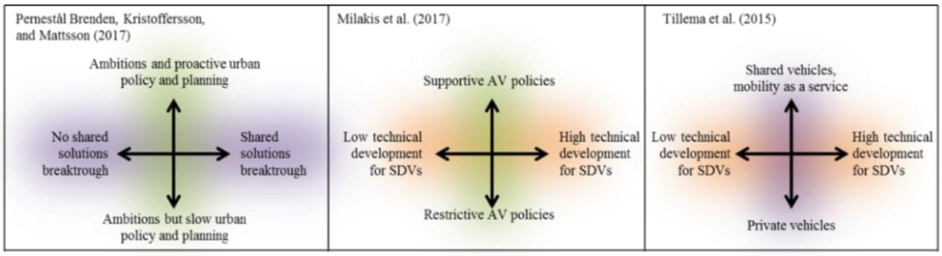

Fig. 5 Color mapping of similar scenario axes in studies using the IL method

Based on the three common topics in the scenario axes, four uncertainty dimensions, representing the main strategic uncertainties, for comparison of the societal scenarios are derived, see Table 3. The policy topic is split in two distinctly separate uncertainty dimensions (I and II). (I) represent the role of the private and public sectors while (II) describe how supportive the policy making for driverless vehicles is. Uncertainty dimension (III) is related to the potential breakthrough of the sharing economy in general and the transport sector in particular, and (IV) is related to the pace of technology development for driverless vehicles.

Table 3 - Derived uncertainty dimensions from the IL studies' scenario axes

Domain	Derived uncertainty dimension
Policy	I - Whether the private sector or the public sector are leading the development of society in general, and the development of transportation services in particular II - Whether the policy making for driverless vehicles is restrictive or supportive
Sharing economy	III - Whether sharing economy solutions have no breakthrough or have a breakthrough. This applies to transportation related areas (i.e. sharing vehicles and sharing rides) but also to sharing economy solutions in general assuming the sharing economy is a general trend independent of sectors. Sharing data (e.g. travel data) to service providers is assumed to be an enabler for sharing economy solutions
Technology	IV - Whether the technology development for driverless vehicles happens in a low pace (without mature driverless vehicles available on the market) or in a high pace (with mature driverless vehicles available on the market)

4.2. Comparison of societal scenarios for driverless vehicles

To systematically compare the societal scenarios, all scenarios (from both IL and AF studies) are mapped against the uncertainty dimensions. Fig. 6 illustrates the results of the scenario mapping where the blue color shadings represent the characteristics of each scenario in relation to the four uncertainty dimensions. Further in the paper the scenarios will be presented with their respective names without reference to their original study, see Fig. 6 for study references of the scenarios.

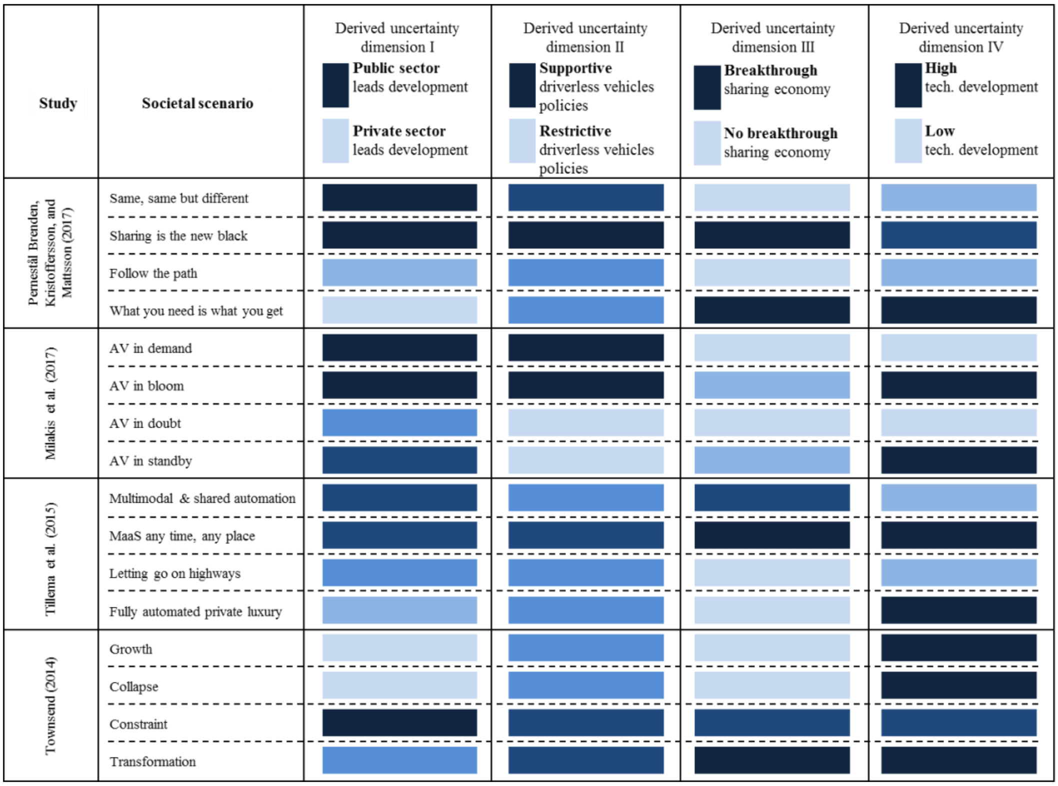

Fig.6 the societal scenarios mapped against the uncertainty dimensions with the blue color shading represents the mapping of the scenario to each of the four uncertainty dimensions according to the scale presented in the top of each column.

For uncertainty dimension I, most of the scenarios are based on that the public sector will lead the societal development. In a minority of the scenarios it is assumed that the private sector leads the development. Mainly the variations between the scenarios are expressed as how active the public is in proactively organizing and providing transport infrastructure and services. Regarding uncertainty dimension II, seven of the scenarios are mapped in the middle of the scale meaning that the policy making for driverless vehicles is passive, i.e. neither supportive nor restrictive. For uncertainty dimension III there is a tendency that either the sharing economy have had a large breakthrough (six scenarios) or that it has not had a breakthrough (nine scenarios). Only one of the scenarios is mapped in the middle of the scale. Uncertainty dimension IV has a similar pattern where the technical development is assumed to either be high (ten scenarios) or low (six scenarios).

Four classes of scenarios among different studies with similar characteristics are identified.

Business as usual and preservation of present trends. In the scenarios “Follow the path” and letting go on highways” neither the public nor the private sector is clearly leading the development, there is no breakthrough of sharing economy solutions, the technical development for driverless vehicles is moderate and there are supportive policies for driverless vehicles. These scenarios could be interpreted as a linear extension of the present situation.

Expectations on new technologies for sustainability. In the scenarios “Same, same but different” and “AV in demand” the public sector leads the development, there is no breakthrough of the sharing economy solutions, the technical development for driverless vehicles is moderate and there are supportive policies for driverless vehicles. These scenarios are similar the *business as usual and preservation of present trends* scenarios but with stronger public governance and implementation of progressive transport policies driven by an ambitious sustainability agenda giving the classes different characteristics.

Integrated mobility services based on shared driverless vehicles. In the scenarios "sharing is the new black" "mobility as a service: any time, any place" and "constraint", the public sector leads the development, there is a breakthrough of the sharing economy, there's a high technical development for driverless vehicles and supportive policies for driverless vehicles. In this class of scenarios, the sharing economy and ambitious public transport have led to an integrated transport system with widespread mobility services based on automated traditional public transport concepts complemented by driverless vehicles.

Private driverless vehicles dominating the market. The scenarios "fully automated private luxury", "growth" and "collapse" are scenarios where the private sector leads the development, there is no breakthrough of the sharing economy, there is a high technical development for driverless vehicles and relatively supportive policies for driverless vehicles. In these scenarios driverless vehicles constitute a popular mode of transport but are almost exclusively privately owned. Two of the scenarios ("Growth" and "Constraint") in this scenario class are from the AF study (Townsend, 2014). Although their characteristics are very similar in terms of the uncertainty dimensions the scenarios unfold very different due to events and trends external from the uncertainty dimensions.

4.3. System-level impacts of driverless vehicles in the societal scenarios

The impacts of driverless vehicles in the scenarios are analyzed on five variables for system-level impacts, see Table 1. The results from the analysis are presented in Fig. 7.

Study	Societal scenario	Vehicle fleet size ++ large increase + increase o No/minor change - decrease -- large decrease	Driverless vehicles in fleet ++ large share of fleet + small share of fleet o No/minor share of fleet	Total VKT ++ large increase + increase o No/minor change - decrease -- large decrease	Traditional PT service level ++ large increase + increase o No/minor change - decrease -- large decrease	Social equity ++ large increase + increase o No/minor change - decrease -- large decrease
Pernestål Brenden, Kristoffersson, and Mattsson (2017)	Same, same but different	+	++	+	+	+
	Sharing is the new black	-	++	-	-	++
	Follow the path	++	+	+	o	o
	What you need is what you get	o	++	o	--	--
Milakis et al. (2017)	AV in demand	o	+	+	o	o
	AV in bloom	-	++	++	-	++
	AV in doubt	o	+	o	o	-
	AV in standby	o	o	+	-	o
Tillema et al. (2015)	Mulitmodal & shared automation	--	+	o	+	o
	MaaS any time, any place	-	+	+	--	++
	Letting go on highways	+	o	+	o	o
	Fully automated private luxury	o	++	++	--	+
Townsend (2014)	Growth	+	+	++	-	--
	Collapse	++	++	++	--	-
	Constraint	--	++	--	++	++
	Transformation	--	+	-	+	+

Fig. 7 System impacts of driverless vehicles in the scenarios. The impact variables are defined in Table 1. The color coding indicates scenarios belonging in the same class of scenario (section 4.2). Yellow → *Business as usual and preservation of present trends*, orange → *Expectations on new technologies for sustainability*, red → *Integrated mobility services based on shared driverless vehicles*, green → *Private driverless vehicles dominating the market*.

The total vehicle fleet size varies among the scenarios and there are examples of scenarios with large increase ("Follow the path", "Collapse") and large decrease ("Multimodal and shared automation" and "Constraint" and "Transformation").

The share of driverless vehicles in the vehicle fleet is none or minor in two scenarios ("AV in standby" and "Letting go on highways"). Seven scenarios have a small share of the fleet constituted by driverless vehicles and seven scenarios have a large share of the fleet constituted by driverless vehicles.

In three scenarios VKT is decreasing compared to today ("Sharing is the new black", "Mobility as a Service any time, any place" and "Constraint"). In ten scenarios VKT is increasing and three scenarios have similar levels of VKT as today.

For the impact on traditional PT, eight scenarios have decreasing service quality. This does however not necessarily mean that shared traveling is not present in scenarios with large decreases of PT. In both "What you need is what you get" and "Mobility as a Service (MaaS) any time, any place" traditional public transport has to a large extent been replaced by MaaS concepts where vehicles and rides are shared, operated by private actors. In the scenarios "Fully automated private luxury" and "Collapse" the traditional PT has deteriorated mainly because of that driverless vehicles offers a comfort and service level (for the ones who can afford a private driverless vehicle) which public transport can't compete with. In four scenarios there is an increase in traditional PT service level.

Social equity is varying significantly among the scenarios and there is no general tendency for an increase or decrease.

4.4. Relationships between the derived uncertainty dimensions and system impacts

Which are the relationships between the uncertainty dimension and system impacts? In this section two analyses addressing this question are presented. One that assess the system impacts in the four scenario classes of identified in section 4.2. This analysis assesses impacts among scenarios with similar mapping to all the uncertainty dimension. The second analysis assess relationships between the uncertainty dimensions and system impacts across all scenarios.

Expectations on new technologies for sustainability scenarios (orange in Fig. 7) are relatively consistent in their system impacts with no or moderate increase in vehicle fleet size, moderate or large shares of the vehicle fleet composed by driverless vehicles, increases in VKT, no or moderate increase in traditional PT service level and no or moderate increase in social equity. Similar system impacts are observed in the scenarios in the scenario class *Business as usual and preservation of existing* (yellow in Fig. 7) which have moderate or large increases in vehicle fleet size, a minor or small share of the vehicle fleet consists of driverless vehicles, VKT increases, there are no significant change in neither the service level of traditional PT nor social equity compared to today. In both scenario classes there is neither a breakthrough of sharing economy solutions nor a high pace of technology development for driverless vehicles which can be an explanation for the absence of scenarios with reductions in vehicle fleet size and VKT.

Integrated mobility services based on driverless vehicles scenarios (red in Fig. 7) have more drastic system impacts and some distinct variations of impacts between the scenarios. The total vehicle fleet size decreases and small or large shares of the vehicle fleets are constituted by driverless vehicles. Regarding total VKT and traditional PT service level the results varies significantly among the scenarios in the scenario class. "Sharing is the new black" and "Constraint" have decreases in VKT while "MaaS any time, any place" has an increase in VKT. For traditional PT service level "Sharing is the new black" and "MaaS any time, any place" have decreasing levels while in "Constraint" the service level of traditional PT is largely increased compared to today. All scenarios in this scenario class have large increases in social equity. The major difference among the scenarios in this class is the role of PT where in "Constraint", driverless vehicles are used to replace existing high-capacity bus services and to serve as last-mile feeders, all facilitated by the public sector. In the other two scenarios, "Sharing is the new black" and "MaaS any time, any place", traditional PT to a large extent have been replaced by door to door driverless MaaS (especially in areas where it is not profitable with traditional PT) that is offered by private actors, often as parts of public-private partnerships.

The scenario class *Private driverless vehicles dominating the market* contains three scenarios that all have small or large shares of driverless vehicles, large increases in VKT and decreases or large decreases in traditional PT service level. “Fully automated private luxury” is having no significant change compared to today of the vehicle fleet size and a moderate increase of social equity while “Growth” and “Collapse” have increasing fleet sizes and decreasing social equity.

To assess relationships between the uncertainty dimensions and system impacts in all scenarios, a comparison of the scenario mapping in Fig. 6 and the system impacts in the scenarios in Fig. 7. Fig. 8 presents the identified relationships which are represented by arrows indicating the direction of the relationship.

Derived uncertainty dimension		Vehicle fleet size	Driverless vehicles in fleet	Total VKT	Traditional PT service level	Social equity
I	**Public sector** leads development	↘			↗	↗
	Private sector leads development	↗			↘	↘
II	**Supportive** driverless vehicles policies		↗			↗
	Restrictive driverless vehicles policies		↘			↘
III	**Breakthrough** sharing economy	↘		↘		
	No breakthrough sharing economy	↗		↗		
IV	**High** tech. development		↗		↘	
	Low tech. development		↘		↗	

Fig. 8 identified relationships between the development with regards to the uncertainty dimensions and the system-level impacts. The direction of the arrow indicates the direction of the relationship (e.g. scenarios where the public sector is leading the development tend to have smaller vehicle fleet sizes compared to scenarios where the private sector is leading the development).

In scenarios where the public sector is leading the development the vehicle fleet size tends to be smaller, the traditional PT service level is higher and there is a higher level of social equity compared to scenarios where the private sector is leading the development. The breakthrough of sharing economy is related to smaller vehicle fleet sizes and less VKT compared to scenarios with no breakthrough of sharing economy. A high pace of the technology development for driverless vehicles tend to generate scenarios where there are higher ratios of driverless vehicles in the vehicle fleet and lower service levels of traditional public transport compared to scenarios with lower pace of technology development. Supportive policies for driverless vehicles correlate with scenarios that have high ratios of driverless vehicles in the vehicle fleet and increased social equity compared to scenarios with more restrictive policies for driverless vehicles.

As expected, the differences across the scenarios with respect to the uncertainty dimensions are not enough to explain all the variation in impacts across the scenarios. Likely, combinations of the different aspects of the uncertainty dimensions (as in the four scenario classes) in combination with omitted variables are important factors to explain system impacts. There are not necessarily direct and linear causal relationship from the uncertainty dimensions and the system impacts which also likely influence the results.

5. Discussion

5.1. Environmental and social sustainability in a future with driverless vehicles

VKT is strongly linked to energy consumption and other emissions, therefore an increase of VKT is strongly correlated with increasing greenhouse gas emissions, although highly dependent on the fuel type for ICE vehicles or electricity mix for electric vehicles. Furthermore, increased VKT also links to potential network capacity and congestion issues, noise emissions and a car-centered society. Previous research indicates that in order to comply with climate goals, new cleaner fuels and transport innovations is not enough if total transport volumes grow as forecasted (Åkerman, 2011). The results in this paper show that automated driving is not necessarily a technology enabling a sustainable development due to the potential VKT increase. 13 of the 16 scenarios imply that VKT will be on similar or higher levels compared to today. This indicates that it is unlikely that climate goals can be reached in those future scenarios. One of the scenario studies (Pernestål Brenden et al., 2017) discusses that the reported impacts on VKT in the scenarios in this study are underestimated compared to simulations of similar cases (OECD International Transport Forum, 2015). Wadud et al. (2016) indicate that even though automated driving and shifting to non-fossil fuels provide significant energy efficiency effects, they are likely to be counteracted by increases in travel demand caused for example by the enabling of car travel for new user groups (previous non-drivers) and reduced value of time for car travelers.

Social aspects are highlighted explicitly in several of the analyzed scenarios and mobility related social inclusion or exclusion is discussed. In scenarios with a high availability of shared driverless taxis (e.g. scenarios in the class *integrated mobility services based on shared driverless vehicles*) the mobility is enhanced for elderly, kids and other groups today lacking access to car-mobility as drivers or access to appropriate PT services. Equity improvements from shared driverless taxis are only present in scenarios where the public sector is leading the development. In "what you need is what you get" the commercial actors offering driverless taxi services only operate in large cities, which in combination with a death-spiral for traditional PT, makes the mobility related equity between residents in urban areas and rural areas more uneven than today. Social inclusion related to improved access to car-mobility for new user group might be negative from a VKT perspective, which highlights a potential conflict between environmental and social sustainability aspects of driverless vehicles. Scenarios with the private sector leading the development and with privately owned driverless vehicles show decreased social equity. In one example ("Collapse"), the absence of PT makes wealthy people ride private driverless vehicles while less well-off groups rely on grassroot mobility organizations offering transit with driverless vans. Many of the social aspects highlighted in the scenarios, such as unequal availability of driverless taxi services and the potential barrier for less well-off groups to access private driverless vehicles due to high purchase costs, are also identified in research literature although this area is not extensively addressed (Cavoli et al., 2017). The results presented in Fig. 8 indicate a relationship between supportive policies for driverless vehicles and social equity. However, this is likely an effect of the public sector leading the development as a confounder for both supportive policies and social equity in combination with that supportive policies for driverless vehicles increases the share of driverless vehicles in the fleet and thus enabling social benefits from driverless vehicles to be spread.

5.2. Technology development, the sharing economy and their impacts on VKT

All scenarios with a breakthrough of the sharing economy also have a high pace of technology development for driverless vehicles. One potential explanation is that the experts developing the scenarios understand driverless vehicles as an enabler for vehicle and ride sharing services. Another explanation can be that a broader breakthrough of the sharing economy in other domains than transport to a large extent rely on cheap and reliable transportation of objects (i.e. the products exchanged in the sharing economy) which can be enhanced by driverless vehicles and automated delivery robots. Alternatively, this relationship could be explained by an assumption that the breakthrough of the sharing economy enables more efficient utilization of driverless vehicles and therefore improving the forecasted returns on the high development costs for driverless vehicles.

In the scenarios, a breakthrough for the sharing economy is related to reductions in the total vehicle fleet size and (relative) reductions in VKT. In several scenarios the main mechanism for limiting VKT growth is ride sharing. A few scenarios report improvements in accessibility without increased mobility by improved digital solutions for remote working that reduces the need for travel. Since vehicle fleet size and VKT is related with energy consumption and emissions while they also have implications on e.g. road and parking infrastructure, land-use and spatial development (Fraedrich et al., 2018; Innamaa et al., 2018) the smaller fleet size and reduced VKT related to the breakthrough of the shared economy are important sustainability aspects. The impacts on VKT and fleet size of driverless vehicles is studied in several simulation studies. Simulation results indicate that with 100% penetration of driverless vehicles, private driverless vehicles increase VKT with 20-70% compared to today, driverless taxis increase VKT with around 10% and VKT impacts of shared driverless taxis ranges from -25% to 30% (Pernestål and Kristoffersson, 2019). In other words, simulations show that shared driverless taxis might in some cases reduce VKT and in some cases increase VKT depending on the urban area that have been studied, assumptions about the performance of the taxi service and the number of empty trips by driverless taxis. However, in general, the simulation studies confirm the effects reported in the scenario studies that scenarios dominated by private driverless vehicles likely generate more VKT than scenarios dominated by shared driverless vehicles.

From an accessibility point of view, driverless vehicles could have a positive net effect even in cases with large increases in VKT (when considering both increased travel demand and empty-driving) due to the potential to increase traffic flow and effective road capacity (Meyer et al., 2017). The accessibility impacts are likely unevenly distributed spatially with positive impacts in well-connected rural areas and less positive or negative in city centers. This indicate that accessibility improvements in rural areas can generate urban sprawl which in turn generate additional VKT. This effect is present in several scenarios (e.g. the scenario “Growth”).

5.3. Reflections on societal scenarios for driverless vehicles

The analyzed scenario studies show many similarities although developed by different research groups in three different nations and to some extent using different scenario development processes. The narrative descriptions and detailed content of the scenarios vary but the identified strategic uncertainties are similar, and all IL studies have at least one of the scenario axes being represented by a similar scenario axes in another study. The four derived uncertainty dimensions are all topics that are also highlighted as important and uncertain in literature studies on the development and implications of driverless vehicles (e.g. Cavoli et al., 2017; Fagnant and Kockelman, 2015; Litman, 2018; Williams et al., 2017).

There are similar themes recurring among the scenarios from various studies indicating that certain ideas related to the development of driverless vehicles seem to be widespread. The identified correlations between the uncertainty dimensions and system impacts among all scenarios in the studies (Fig. 8) indicate that there are common beliefs among the various researchers and experts developing the scenarios on what system impacts different forms of developments will have.

There is a discrepancy between the scenarios analyzed in this paper and the typical type of cases being studied in simulation studies. Simulation cases most often focus on urban areas and replace all vehicles with driverless vehicles and assume that driverless taxis will be operated by one monopolist actor. This case is similar only to one scenario (“What you need is what you get”). In future research, societal scenarios can be useful to base the design of simulation cases to better correspond with various plausible sociotechnical developments.

The sixteen analyzed explorative scenarios contain many different combinations of realizations of the most important strategic uncertainties. Explorative scenarios are not intended to generate preferable futures but to picture plausible development given the unfolding of the strategic uncertainties. The results of the analysis of system impacts indicate that most of the scenarios do not represent a sustainable future transportation system. Policy makers should place special attention to the strategic uncertainties with a potential to influence the future in a sustainable direction (e.g. an ambitious public sector leading the development and the breakthrough of the sharing economy). It is also clear from the analysis that policy is an important factor shaping the future development of driverless vehicles with two of the four uncertainty dimensions being related to policy issues. Since the development of driverless vehicle risk not being sustainable, a complement to explorative scenario studies could be normative scenarios and in particular backcasting studies where one or more pre-defined scenario(s) meeting sustainability targets are used to identify plausible paths on how they can be achieved (Åkerman, 2011).

6. Conclusions

The results presented in this paper highlight important aspects of the development and impacts of driverless vehicles by using a novel method to compare and analyze sixteen explorative scenarios from four different studies. The comparison showed that there are four main strategic uncertainties shaping the development, on a societal level, for driverless vehicles: I - Whether the private sector or the public sector are leading the development of society in general, and the development of transportation services in particular. II - Whether the policy making for driverless vehicles is restrictive or supportive. III - Whether sharing economy solutions have no breakthrough or have a breakthrough. IV - Whether the technology development for driverless vehicles happens in a low pace or in a high pace.

Based on the development in relation to the four strategic uncertainties, four classes of scenarios with similar characteristics that are present in several studies have been identified: *Business as usual and preservation of present trends*, *Integrated mobility services based on shared driverless vehicles*, *Expectations on new technologies for sustainability*, *Private driverless vehicles dominating the market*.

The system impacts of driverless vehicles varies significantly among the scenarios indicating that the impacts of driverless vehicles can be very different depending on policies, behavior related social and cultural aspects and the pace of the technology development. However, most of the analyzed scenarios report impacts that do not comply with desirable futures from a sustainability perspective (i.e. increasing VKT and/or decreased social equity). This mean that other forces than the identified strategic uncertainties likely will be required to steer the development in a sustainable direction.

Certain relationships between the strategic uncertainties and system impacts in the scenarios have been identified. From a sustainability perspective, important relationships to consider are: scenarios with a breakthrough of the sharing economy gives scenarios with less VKT and scenarios with the public sector leading the development is related to higher levels of social equity. However, the results need to be understood together with other research methods with more specific and narrow focus (e.g. simulation studies and evaluation of field trials). Also, these relationships need to be studied with higher detail focusing on their systemic behavior to assess causality and validity.

To further enhance the understanding of impacts from driverless vehicles, research in the layer between detailed simulations and high-level scenarios are needed. As of today, many potential impacts from driverless vehicles are discussed and assessed in the academic literature but the systemic interaction between impacts and opposing impacts need to be addressed. Research approaches based on systems thinking focusing on conceptual modeling of impact paths and feedback loops might be a useful way to build models with the complex systemic relationships made explicit. One approach could be to use an interdisciplinary approach combining existing theory from transport research combined with multi-stakeholder workshops to collaborative develop conceptual models of impact paths for various scenarios with driverless vehicles. Also, most of the research on impacts of driverless vehicles is focusing on passenger transport and especially driverless cars. Research on impacts of freight transportation and logistics with automated vehicles is so far lacking even though there are several clear benefits of automation in the freight sector (Kristoffersson and Pernestål Brenden, 2018). The two mentioned topics could be combined to study impacts from freight transport with driverless vehicles with a systems' thinking approach which would advance methodological approaches as well as deepen the understanding on system impacts of driverless vehicles.

In this paper images of what the future might look like are analyzed. However, the question of what a desirable and sustainable future transport system with driverless vehicles meeting non-negotiable climate goals looks like need to be explored in the light of recent technological advancements in automation and electromobility. Future studies with normative scenarios, with backcasting as one potential method, should seek to outline sustainable development paths for driverless vehicles.

The findings of this paper highlight that there is not one single determined future scenario for driverless vehicles. There is a wide range of plausible future scenarios and the development will be strongly influenced by non-technical factors that are not directly related to driverless vehicles, such as the role of public planning and the sharing economy. This means that how the future society with driverless vehicles will look like to a large extent is a matter of collective and political choice and is not a predetermined outcome of driving automation technology.

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Appendix A. Scenario descriptions

Table 4 The analyzed societal scenarios presented in short. The number in brackets after the scenario name indicates the scenario's relation to the respective scenario axes in Fig. 4

Study	Scenario name	Description
Pernestål Brenden et al. (2017)	Same, same but different (1)	There has been a long period of developments towards sustainable manufacturing and energy generation but structures for consumption, land-use and societal patterns remain similar as of today. The transportation system is fossil free and powered by electrical roads and charging infrastructure. There is a large fleet of all forms of electric vehicle, many with driving automation. Cars are still mainly privately owned and seldom

		shared with others. The freight industry has been pushed towards more efficient operations through proactive policy interventions and platooning is common on the electric highways.
	Sharing is the new black (2)	The government have implemented a policy agenda for sustainable development. This created a new paradigm with ambitious transport system planning has created an efficient transportation system. The mobility and freight transport services and value chains are fully integrated and the public and private have merged to one integrated ecosystem. The government has made sharing of transport data mandatory which enables efficient and consolidated transport of people and goods but is by some being experienced as a “big brother” society.
	Follow the path (3)	In many aspects life is like similar to the mid 10’s and even if new technology has been developed it has not led to major technology shifts. The transport system is still based on private vehicles with efficient public transport alternatives only in the large cities. The introduction and uptake of driverless vehicles has been slow in Europe compared to Asia, mainly because of the lack of efficient policies and functional business models. Cooperative driverless vehicle concepts have not been implemented on a wide scale neither for passenger nor freight transport.
	What you need is what you get (4)	The combination of sharing economy, abundance of consumer data and aggressive commercial actors has created a wide and rich service landscape. At least in the urban areas where there is an attractive market potential. Several markets have been consolidated to a few dominating actors that are experts in creating commercial value out of consumer data. There has been an explosion of tailored mobility, goods and package delivering solutions, especially in the cities with driverless vehicles being an important technology to enable the services.
(Milakis et al., 2017a)	AV in demand (1)	The transportation sector has been failing to transform in line with climate and sustainability goals. The Dutch government foresaw many benefits with driving automation and launched a supportive legislative framework for testing and development of driverless vehicles. However, the technical challenges proved difficult and safety concerns halted the introduction. Automated driving is restricted to motorways and customer demand is low.
	AV in bloom (2)	Europe has experienced a long time of high economic growth which boosted the technology development for automated driving. Governments in the EU together with the industry pushes the frontiers for vehicle to vehicle communication and automation. The Dutch government incentivizes driverless vehicles and especially for shared driverless vehicles which leads to a relatively rapid market uptake.
	AV in doubt (3)	The general development is characterized by low economic growth rates and failures to transit to a sustainable economic paradigm. Technical problems, no supportive policies and a low interest from customers halts the introduction of driverless vehicles. Once available on the market driverless vehicles are only allowed on motorways and not in urban areas due to the risk of experiencing new types of traffic problems in an urban environment with a mix of conventional vehicles and driverless vehicles. The customer demand for driverless vehicles is basically nonexistent.
	AV in standby (4)	There has been a period of rather slow economic development in Europe. There are no real drivers for the Dutch government to pursue ways of implementing driverless vehicles neither are there any considerable consumer demand or available funds for public investments in vehicle to infrastructure communication. In 2030 there is just a small fraction of the vehicle fleet that was automated even though the technology was mature but the market demand for driverless vehicles is starting to grow at this point.
Tillema et al. (2015)	Multimodal and shared automation (1)	The sharing economy has become a norm and people often share vehicles and rides with each other. The transportation system has developed in a direction to facilitate shared vehicles and rides through public transit, car pools and mobility services and privately-owned vehicles are not very common anymore. In cities more and more are using active modes of transportation. The technology for driving automation is not sophisticated enough to enable driverless vehicles but both cars and trucks are using automation on highways.
	Mobility as a service: any time, any place (2)	There has been a vast breakthrough for sharing economy which in combination with a rapid technological development for driverless vehicles have made mobility services with shared driverless vehicles the dominating mode of transportation. Public transport as we once knew it is gone and now urban transport is done with so called “people movers”. There are several service providers operating fleets of driverless vehicles and the government has actively supported driverless vehicles in general and shared-ride services in particular.
	Letting go on highways (3)	In many aspects the transportation system is still the same as before. The technology development of driverless vehicles has been slow and the most advanced cars available on the market has automated driving systems of SAE level 4. Driverless vehicles are usually privately owned and driverless vehicles have made no dramatic change to the way the transportation system is organized.
	Fully automated	The consumption-oriented economy is still flourishing like in the mid 10’s. With very sophisticated driverless vehicle technology but a low willingness to share rides, driverless vehicles are to a large extent privately

	private luxury (4)	owned. Driverless vehicles are filled with gadgets and for many of their owners they play an important role as a social status symbol. Privately owned driverless vehicles offers comfortable travel and tend to make more and longer trips.
Townsend (2014)	Growth	Solar power and driverless vehicles have created a new type of suburban life with de-centralized energy production and commuting with driverless vehicles. Large commercial actors have taken over the design, development and operations of the road and digital infrastructure and gained monopoly status.
	Collapse	The technical development in the transportation sector is completely market driven and there is no central coordination on standards for communications between vehicles and between vehicles and infrastructure. A vast range of cheap driving automation technologies and driverless vehicles from international OEMs with poor interoperability has flooded the market and been adopted by consumers. This creates a new wave of private motorism with increased congestion problems and no major benefits of collaborative driverless vehicles have been realized.
	Constraint	Periods of storms damaged the transportation infrastructure and created a financial crisis. In the aftermath a new era for centrally planned public transit emerged where autonomous bus rapid transit systems complemented by autonomous feeder vehicles are key components. The new public transit system in many ways was a success and improved accessibility and generated economic growth.
	Transformation	Disruptive technological development systems and a new social paradigm have created a new type of urban life with extreme densification where people lives in micro-apartments without storing space. This has created urban environments where some areas are for housing and working while other areas are allocated for storing stuff that are transported on-demand to the housing areas by automated logistics. In the cities there have been huge increase in walking and bicycling and consumer goods and food is moved around by automated delivery vehicles of all kind.