Potential pathways for carbon emission reduction in road passenger and freight transport

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The transport sector is transforming towards carbon neutrality. Recent technological advancements have great potentials to significantly reduce carbon emissions in the sector. This paper reviews several concepts that potentially contribute to a carbon neutral future of road passenger and freight transport. These concepts are categorized into Automation, Connectivity, Decarbonization, and Sharing (ACDS). ACDS concepts for passenger transport include automated personal vehicles and group vehicles, connected and automated vehicles, mobility as a service, alternative propulsion systems, car-sharing, ride-sharing, and ride-hailing. On the other hand, ACDS concepts for freight transport consider eco driving assistance systems, automated trucks, on-road/sidewalk delivery robots, the Physical Internet, electric and fuel cell trucks. An overview of the concepts is provided focusing on their advantages and disadvantages, as well as their technology maturity, which is defined by current technology readiness level (TRL) and market development stage. Potential contributions of the concepts are discussed in view of greenhouse gas emission reduction within technological pathways. It is concluded that all the concepts need to be combined and integrated in a smart way to enable a carbon neutral transportation sector.

Keywords: carbon neutral mobility, passenger transport, freight transport

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1. Introduction

Climate change is one of the most challenging issues of our time, mostly caused by human activities. Being the second largest emitter, the transport sector is account for 14 % of all human-made greenhouse gas emissions today. Of which, about 70% of global anthropogenic CO_2 emissions come from road transport *(1)*. It is expected that both passenger and freight transport activities will increase in the future, making emissions from the transport sector doubled by 2050 *(1),* if carbon neutral mobility solutions are not developed and applied effectively.

As the Paris Agreement set an international target to limit global warming to well below 2^oC, with extra efforts limit to 1.5^oC, it has become vital to reduce CO_2 emissions caused by the transport sector in general, and road transport in particular. Several governance bodies of different levels have announced their plans to achieve a carbon neutral economy and society, e.g., the European Union strives to become the first climate neutral continent by 2050 with their Green Deal *(2)*, while Finland aims to have carbon neutral transport and mobility by 2045 *(3)*.

Carbon neutrality refers to a net result of zero carbon emissions. It can be achieved by balancing the amount of carbon emitted to the atmosphere and the amount of carbon absorbed from it by using carbon sequestration methods or carbon offsetting mechanisms *(4)*. One of the main efforts is to phase out the use of fossil fuels in our economy by measures such as reducing energy consumption, enhancing innovation for low carbon technologies, and increasing the share of renewable energies. Carbon neutral mobility requires effective combinations of different measures, i.e., high energy efficient vehicles, electric vehicles, sustainable power generation, limitation of vehicle numbers and the number of trips taken.

To achieve carbon neutrality, transitions to sustainable mobility are required. Most studies on mobility transitions to carbon neutrality focus on assessment of technological solutions for either passenger or freight transport, for example alternative propulsion systems and fuel types *(5, 6)*, connected vehicles and systems *(7-10)*, autonomous driving *(11–13)*, shared mobility *(14–16)* (passenger transport), automated trucks *(17)*, delivery robots *(18–20)*, Physical Internet *(21–23)* (freight transport). However, a comprehensive review of carbon neutral concepts for both types of road transport is still missing.

Furthermore, it is important to review technological advancements in the light of key factors, which significantly transform the mobility systems towards sustainability. In *(24)*, the authors provide a conceptual review of nine different pathways with strategies, agents, and narratives addressing elements of sustainable mobility. By combining these pathways, they created three Grand Narratives, namely Electromobility (replacement of existing fossil-fuel based vehicles by electric vehicles), Collective transport 2.0 (shifting from ownership to usership to increase load factors and occupancy rates), and Low-mobility societies (societies rely on fewer and/or shorter trips). In line with this conceptual view, the European Commission published a report on future of road transport where various aspects of the mobility system are discussed. It is believed that mobility in the future will be automated, connected, low-carbon and shared *(25)*.

Therefore, the aim of this paper is twofold: [1] providing an overview of existing and future mobility concepts utilized for road passenger and freight transport with potential for carbon neutral mobility, and [2] discussing visions and pathways towards carbon neutrality for road transport.

2. Methodology

The paper is based on literature review and secondary data analysis. The concepts are categorized according to four dominant factors that will potentially shape the future of road transport as mentioned in *(25)*, namely Automation, Connectivity, Decarbonization, and Sharing (ACDS). General description, advantages and disadvantages of the concepts are analyzed from various sources, including scientific papers, reports from national and international organizations, as well as mobility companies.

One main focus is paid to technology maturity of the concepts, using the approach applied in *(26)* that depicts technology maturity based on the corresponding technology readiness level (TRL) and market development stage. TRL consists of 9 levels ranging from 1 (lowest) to 9 (highest) while market development indicates six stages from R&D, Demonstration, Introduction to Growth, Maturity, and Decline. TRLs and market development stages of the concepts are identified from review papers on recent developments, market reports, as well as by searching for existing applications in the market. Based on TRL and stage of market development, technology maturity of the concepts is illustrated.

Additionally, main elements and actors for a carbon neutral mobility future are addressed from the literature. Potential contribution of the concepts to realize the carbon neutrality target is analyzed by considering how a concept possibly reduces carbon emissions, e.g., by cooperating with other concepts. It is important to note that of course also non-technological factors are important to achieve a carbon neutral future in the transport sector, but this paper only focuses on technological pathways. Furthermore, carbon neutral fuels are not considered.

3. Overview of carbon neutral concepts for road transport

3.1 ACDS concepts for road passenger transport

3.1.1 Automations concepts

Automated mobility solutions in this section can be divided into personal (i.e., cars) and group transit mobility (i.e., buses/shuttles) *(11)*.

Automated cars

There are six levels of automation in road traffic defined by SAE, ranging from no automation, driver assistance, partial automation, conditional automation, high automation, to full automation *(27)*. Automated cars at levels 1 to 3 are already available in the market, offering greater safety and comfort and making driving simpler. Meanwhile, several automobile companies, e.g., Daimler, BMW, Tesla, are developing and producing prototypes of automated cars at levels 4 and 5, and it is expected that they will operate on roads in the near future. Many governments worldwide are also preparing for a future of mobility including automated vehicles *(12, 28)*.

Automated buses/shuttles

The introduction of automated vehicles can contribute to public transport, with their potentials in improving safety in urban areas, operating as cheaper and more convenient first/last mile transport solutions, decreasing congestion and improving the global service for the user *(12, 28)*. Automated public transport, together with new mobility services, will offer users a wide range of options in order to choose the most appropriate mobility mode for any personal trip, thereby providing the possibility to reduce their dependency on private cars while satisfying their needs for travelling comfortably. One strong characteristic of automated buses is that they can be not only on-schedule, but also on-demand. There have been a large number of automated bus pilots conducted over the last few years, with many of them took place in Europe, the USA, and China *(12)*.

3.1.2 Connectivity concepts

Connected and automated vehicles (CAVs)

Connected vehicles are vehicles that communicate with the driver, other vehicles in traffic, mobility infrastructure, digital sources, pedestrians, and any other actors by utilizing different communication technologies *(29)*. The market for connected vehicles is expected to be highly promising, revenue from connected services is projected to double by 2023, in comparison to 2017 *(7)*. Many new functionalities are facilitated by connectivity, not only automated driving, but also customer-related services. By combining effective communication between the vehicle and all actors of the mobility system (Vehicle-to-X) with autonomous driving ability, CAVs can improve vehicle safety, as well as efficiency and commute times. However, CAVs could facilitate either dramatic decarbonization of transportation or equally dramatic increases in transportation sector emissions. The net environmental impacts of CAVs depend on law-making and decisions at international, national, and local levels *(10)*.

Mobility as a Service (MaaS)

MaaS is based on the idea of a user-centric, multimodal, sustainable and intelligent mobility management and distribution system *(15)*. It is a subscription-based service integrating various mobility providers through a digital platform. This platform offers users the service based on what plan is the most suitable solution for their needs. The service is offered in the form of bundling in which products and services are put in a package at a pre-defined price. The bundling of options strengthens interconnection between various transport modes, and at the same time, enables users to find and chose different transport means that they are not usually be able to travel on *(16)*.

3.1.3 Decarbonization concepts

Electric vehicles (EVs)

EVs refer to several types of vehicles that utilize electricity at different shares for traction *(5)*, i.e., battery electric vehicles (BEVs – fully-electric), plug-in hybrid vehicles (PHEVs – both conventional combustion engine and electric drive, whereby the battery can be charged at the grid), and range extended electric vehicles (REEVs – electric, supported by a small internal combustion engine). Potential GHG reductions of EVs are reported to be between 25% (HEVs), 50-80% (PHEVs) and 90% (EVs) *(32)*, yet it strongly depends on the technologies of electricity production and vehicle production processes, especially with regards to batteries.

Fuel cell vehicles (FCVs)

FCVs have almost the same components for propulsion as EVs; the difference lies in the supply of electric energy. In FCVs, the fuel cell generates electricity by converting the primary energy stored in a hydrogen tank, emitting only water and heat. As a zero-emission process, FCVs are considered as an important replacement of conventional vehicles in order to clean the transport sector. Due to the high energy density of the hydrogen tanks and faster refueling process, FCVs have typically longer driving range than BEVs *(6)*.

3.1.4 Sharing concepts

Shared mobility is the short-term access to shared vehicles depending on needs and convenience of the users, without requiring ownership of the vehicles *(14)*. Together with automation, these concepts have great potentials to completely transform urban transport systems.

Car-sharing

Vehicle-sharing includes not only car-sharing but also bike/scooter-sharing, yet this paper only focuses on the former. Car-sharing is a concept in which vehicles are owned by providers and individuals subscribe to their service to use the vehicles for a fee. One of the main advantages is that it facilitates the transition from ownership to usership of cars. For example, it was estimated that in Bremen, each car-sharing vehicle replaces 11 privately owned cars, and only 37% of the users have their own car. In London, on average, car-sharing users have a total travel distance 56% less than car owners per year. The average vehicle occupancy in shared mobility is 2.6 in comparison to 1.6 of all cars *(13)*.

Ride-sharing

In ride-sharing pools, multiple travelers share the same vehicle, i.e., cars or vans, for similar origins and destinations under similar departure times. Carpooling is comprised of at least three commuters in a car, while vanpooling typically include 7 to 15 people using the van together. There are many incentives for ride-sharing, exemplarily in the USA, e.g. exclusive lanes for carpool vehicles, specific points for pickups and drop-offs *(14)*. Ride-sharing can increase occupancy rate to 2-5 people per car or 5-10 people per van or minibus *(12)*.

Ride-hailing

In this concept, mobility users can access private vehicles, which are ride-sourced for paid on-demand services via an app. Advantages of this mode are for example usually less waiting time, higher reliability than taxi services, and no need for parking from the user side. Ride-hailing can create impacts on travel behaviour, such as choice of travel modes, total mileage travelled, and trip frequency *(33)*.

3.2 ACDS concepts for road freight transport

3.2.1 Automation concepts

In freight transport, automation concepts include long distance transportation (long monotone routes and high load) and local-, respectively last mile delivery (short flexible transport routes with low load). Concepts for long distance transportation are ecoDAS and automated trucks, while delivery robots have been introduced as so-called last mile delivery technologies.

Eco driving assistance systems (ecoDAS)

DASs are part of vehicles of any kind since many years, including trucks. The driver gets support by the system, get warned by it in dangerous situations, while controlling and overseeing the traffic situation at any time *(34)*. Special ecoDAS has been developed in order to close the gap between different driving behaviors of drivers in different situations (e.g., urban environment vs. highway) leading to an optimized usage of the powertrain. In this way, ecoDAS can decrease the fuel consumption by up to about 12% compared to normal driving *(35)*.

Automated trucks

Long distance transportation can be predefined for the application of automated trucks, due to high driving performance and monotonous routes. Besides increasing safety and operator comfort, fully automated trucks have a potential to reduce fuel consumption and emissions on long distance transportation. In many sectors in heavy duty transportation, autonomous driven trucks are already in use in closed areas for many years, (e.g., self-driven container handling vehicles) *(36)*. Currently, automated trucks are under functional tests on highways to clarify the key challenges for economical, reliable and safe deployment *(17)*.

On-road autonomous delivery robots (RADRs)

Current trends in the supply chain, like eCommerce, same-day delivery, just in time delivery and flexible delivery destinations, force service providers to be more flexible in the last mile delivery. Thus RADRs have been developed; they may deliver parcels and goods in urban areas in the near future *(19)*, e.g., Nuro delivery robots *(37)*. The usage of automation in last mile transporters allows the driver of the vehicle to fulfill other tasks during driving between the destinations, or even no person present in the vehicle *(18)*.

Sidewalk autonomous delivery robots (SADRs)

Over the last years, SADRs have been developed, introduced and tested globally, yet most projects are in the pilot phase. Some of the self-driven robots combine the delivery box and the reception box in one autonomous driven vehicle, in order to reduce the amount of unattended receptions within an urban area, thereby decreasing inner-city traffic *(19, 20)*. A main part of these concepts is the usage of electrical driven robots as they are not facing the challenge of the high-required reaches within their routes, e.g., Starship delivery robots *(38)*.

3.2.2 Connectivity and sharing concepts

The Physical Internet (PI)

The PI is a recently developed concept, which refers to a globally interconnected logistics system in which logistics networks are connected by a standardized set of collaboration protocols, modular containers and smart interfaces to increase efficiency and sustainability *(39)*. The PI creates a global transportation network of centers, called PI Hubs. Goods are transported on optimized routes according to the utilization of transporters and covered distances from PI Hub to PI Hub within the transportation network. This approach has both advantages and disadvantages. On the one hand, the PI transportation network requires more single transportations as well as more handling and dispatching effort. On the other hand, the distribution of goods via PI Hubs within this PI transportation network enables an increase of efficiency of single transports because of optimized routes, high utilization levels and a low number of required empty runs, which directly lead to economic and ecological advantages *(22, 23).* A roadmap to Physical Internet was created by *(40)* presenting the current stage of development and strategies towards 2040.

The PI is believed to be a crucial concept in order to reach zero emissions in 2050 in the logistics sector, served as an umbrella approach to integrate many other ADS concepts. In particular, automation in long distance transport addresses specially the transport between the PI Hubs, contributing to increase efficiency and reduce emissions. Last mile delivery services are a highly important part of the PI network, by delivering goods and parcels from the last hub to the customer. Automated delivery robots will enable an optimized and automated route planning according to the flexibility in delivery service and transport capacity utilization, which supports a reduction of traffic in urban areas and the corresponding emissions.

The PI and sharing

One of the most important factors for efficiency in transportation is the load capacity utilization within the transport vehicles. Therefore, the development of PI container is a critical step for a successful PI implementation. PI containers are characterized by their modular shape, reusability and ability for interconnection. Using standardized, modular PI containers enable the possibility to share transport capacity within the PI network *(21, 22)*. For example, *(41)* created and produced prototypes called Modular Logistics Units in Shared Co-Modal Networks (MODULUSHCA).

3.2.3 Decarbonization concepts

This section describes two main alternative propulsion concepts: electric trucks and fuel cell trucks. It is estimated that in 10 to 15 years a third of all trucks and busses on our streets will be driven by alternative drive systems, most of them fully electric, providing that necessary infrastructure is available *(42)*.

Electric trucks (ETs)

Fully electric trucks require large batteries, which leads to a loss of transport capacity. Furthermore, infrastructure that allows efficient and fast charging of the batteries need to be installed in order to meet the requirements of full electrification in long distance transportation. Current developments in battery technologies will make fully electrified trucks for long distance transportation more and more reasonable, e.g., eActros (Mercedes-Benz), FL electric (Volvo) and eCascadaia (Daimler) are currently under customer test *(43–45)*.

Fuel cell trucks (FCTs)

Fuel cell technology is already established to be used in cars and buses, yet its application in heavy duty vehicles is still facing difficulties. The main objectives in research in the last few years regarding the usage of fuel cells for heavy duty vehicles are costs, performance, and durability *(46)*. Nevertheless, in 6/2020, Hyundai announced that world’s first fuel cell heavy duty trucks have been delivered to Switzerland *(47)*. On the other hand, in China, FCTs have been in operation for some years, e.g., Refire.

3.3 Technology maturity

The analysis of the concepts concerning their strengths and weaknesses, TRL, and market development stage is summarized in **Table 1**. It is important to note that, even though each of the concept has potential to lower carbon emissions in the sector, it can be achieved only under certain conditions, i.e., a renewable-based energy system, corrective measures from policy makers to limit negative impacts, matured technologies to reduce costs, user acceptance for new technologies, and advocating for modal shifts.

As can be seen in **Figure 1**, none of the currently reviewed concepts are mature in large scale yet, as the most advanced technologies are in the Growth stage. This indicates that these concepts will play important roles in the market in the near (Growth and Introduction) to far (R&D) future. Sharing concepts have the highest maturity level, as car-sharing, ride-sharing and ride hailing are all on the frontline. Among all automated vehicles, automated cars, which are now going to be introduced to the market, are the most mature ones, while automated buses are under demonstration and automated trucks are between R&D and demonstration stages. All of the connectivity concepts are in the stage of R&D today, except for MaaS, with its position in Demonstration stage. Regarding decarbonization concepts, EVs are the most advanced concept with its growth in the market while electric trucks are demonstrated by user tests today. Fuel cell vehicles, on the other hand, are at Introduction phase.

TABLE 1 Summary of Carbon Neutral Concepts for Road Transport

Concept	**Advantage**	**Disadvantage**	**TRL**	**Market Develop-ment**	**Source**
Passenger Transport					
Automation					
Automated cars	- More comfort - Cost reduction - Reduce accidents, fuel consumption and emissions - Mobility access for disadvantaged groups (no license people, disabled, minor, elderly, people in remote areas) - Shifting from ownership to usership - Potentially integrated in public transport which reduces parking demand - Reduced costs of transport	- Concerns on safety and reliability issues - Potentially induce travel demand - Potentially increase of traffic congestion, obesity, urban sprawl - Potentially reduce mass public transport use, walking and cycling - Potential social impacts, i.e., unemployment - User acceptance	8	Introduc-tion	*(12)* *(13)*
Automated buses			6-7	Demons-tration	
Connectivity					
CAVs	- Reduce accidents - Reduce distances between vehicles on roads - Improve efficiency of mobility systems - Less traffic enforcement personnel	- Risk for cyber attacks - Potential for incidents at intersections - Need for new design of collision avoidance and pedestrian detection	5-6	R&D	*(8) (9)* *(30)* *(31)* *(34)*
MaaS	- Higher service quality - Competitive pricing - Increase interaction between providers and users - Potentially reduce private vehicle purchase and usage - Potentially reduce congestion, parking need	- Potential to be unsustainable if competing with active modes and public transport - Low participation of car drivers	7-8	Demons-tration	
Decarbonization					
EVs	- High potential to reduce emissions - High efficiency - Low noise - Improve air quality	- Long charging time - Short driving range - Sensitive to ambient temperatures - High costs - Environmental issues of batteries - Charging infrastructure required	9	Growth	*(5) (6)* *(32)* *(48)*

Concept	Advantage	Disadvantage	TRL	Market Develop-ment	Source
		- Environmental benefits depend on the electricity generation			
FCVs	- High potential to reduce emissions - High efficiency - Quick refueling - Long driving range	- High cost - Gas station infrastructure required - Environmental benefits depend on the hydrogen production	8-9	Introduc-tion	
Sharing					
Car-sharing	- Reduce vehicle fleet size - Reduce modal share for car use and parking need - More efficient use of road space - Potentially reduce vehicle kilometers travelled - Support shifting from ownership to usership	- Potential for larger scale automobile share - Higher congestion, bigger spatial-functional separation	9	Growth	*(11)* *(13)* *(14)* *(15)* *(33)*
Ride-sharing	- Higher commute efficiency - Cheaper - Reduce commute stress - Last/first mile solution	- Potential to have longer commute times	9	Growth	
Ride-hailing	- Shorter waiting time - Reduce need for parking - Last/first mile solution	- Potential to increase trip frequency	9	Growth	
Freight Transport					
Automation					
ecoDAS	- Continuous and optimized driving profiles	- User acceptance - User attentiveness	3-4	R&D	*(17)* *(19)* *(34)* *(35)* *(36)*
Automated trucks	- Increase road safety - Increase fuel efficiency - Increase driver productivity - Optimize vehicle utilization - Reduce freight cost	- Unclear legal situation - Driver acceptance - Potential of manipulation	5	R&D	
RADRs	- Reduce costs - Increase urban freight efficiency	- Limited load - User acceptance - Complex sensor systems required	4-5	R&D	
SADRs	- Lower costs than normal last mile delivery - Increase flexibility	- Limited range - Weight limited	6-7	Demons-tration	
Connectivity					
PI	- Increase efficiency - Reduce emissions - Potentially faster delivery - Lower costs - Facilitate electric trucks	- Require more single transportation steps - More handling and dispatching efforts	3-4	R&D	*(22)* *(23)* *(40)*

Concept	**Advantage**	**Disadvantage**	**TRL**	**Market Develop-ment**	**Source**
	- Facilitate micro transport vehicles				
Decarbonization					
ETs	- Increase efficiency - Reduce emissions	- Heavy batteries - Short driving range - More expensive than conventional power trains	6-7	Demons-tration	*(42)* *(46)* *(47)*
FCTs	- Increase durability - Increase performance	- Unclear production situation of H_2 - Need of infrastructure - Expensive	8-9	Introduc-tion	

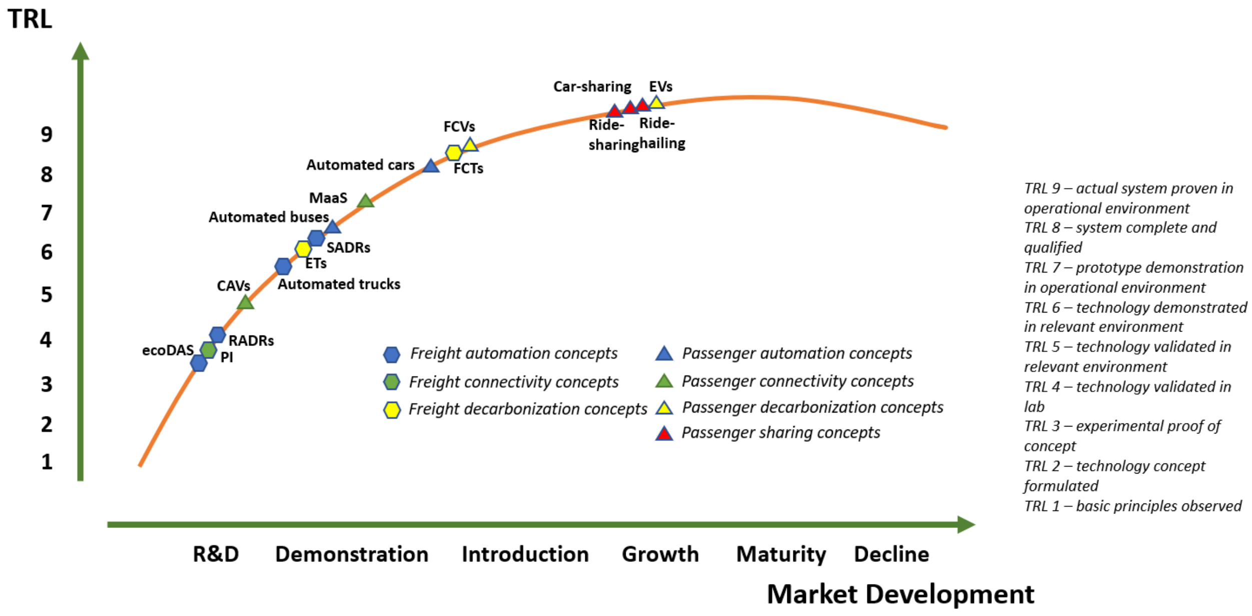

Figure 1 Technology maturity of carbon neutral mobility concepts

4. Visions and pathways towards carbon neutral mobility

4.1 Visions for carbon neutral mobility

This paper adopts the visions for sustainable mobility described by *(24)*. The elements of carbon neutral mobility are efficiency, alteration, and reduction.

- Efficiency: transitions to more efficient vehicle technologies and fuel shifts, as well as applications of digital solutions that enhance efficiency of the whole mobility systems.
- Alteration: the existing mobility systems dominated by automobiles alter to various modes of transport, resulting in reduction of private use of cars and increasing use of public transport. The efficient public transport system also provides access for all mobility-disadvantaged groups.
- Reduction: the focus on reducing motorized travel demand and the need to travel by efficient urban planning and frequent use of teleworking.

By definition, Reduction is excluded from this paper as it is out of the scope. The concepts are linked to Efficiency and Alteration pathways according to their definition and potential. Potential contributions of the concepts to realize the low-carbon mobility target is analysed by considering how a concept possibly is able to reduce carbon emissions, e.g., by cooperating with other concepts. Based on technology maturity states of the concepts, possibilities to combine them into technical pathways are divided into short-, mid-, and long-term visions.

4.2 Technological pathways

4.2.1 Road passenger transport

As mobility systems are highly complicated, achieving carbon neutral mobility demands an effective combination of different concepts. Automation concepts need to be integrated in connectivity and sharing concepts to enhance occupancy rate, reduce vehicle ownership and limit personal vehicle usage. In addition, it is critical that new technologies will not compete with public transport, rather support it to increase user travel experience, e.g., by providing comfortable first/last mile solutions.

In particular, combination of automated technologies and sharing concepts brings high potential for sustainable mobility. Automation promotes the use of car-sharing services as vehicles can be available at the right place and time when they are required. A simple replacement of traditional cars with automated cars would result in the same occupancy rate (1 person) while riding alone, yet with self-driving car-sharing, more people can be transported (between 1-5) *(12)*. Depending on suitable policies and effective urban planning, a shared economy combined with automated mobility concepts can reduce the vehicle fleet size and potentially the vehicle kilometres travelled *(11, 13)*.

4.2.2 Road freight transport

Together with the ADS approaches, the concept of PI has been designed as a roadmap in order to reach the goal of a CO_2 neutral transport network for freight transport by 2050. As the PI serves as a framework for this future scenario, technologies need to be implemented and connected to one another in order to fulfil the corresponding requirements. The aforementioned technologies and concepts are able to support the extra logistics part of the transport process within the PI network to become more effective and CO_2 neutral. As described, these cover long distance transportation as well as last mile delivery. The second part of the PI Hubs are the nodes (Hubs), where goods need to be handled and reformed to load units again. The technologies in this paper do not address the process of goods handling within these nodes in detail. However, it is necessary to examine technologies enabling an emission-free Hub system in order to achieve CO_2 balance of the whole network.

4.3 Carbon neutrality for road transport in a nutshell

Figure 2 indicates Efficiency and Alteration pathways for passenger and freight transport, respectively. In short-term vision, Efficiency is the driving force, with sharing concepts, EVs and FCVs playing the key role. In mid-term, however, advanced technologies and services such as automated vehicles, delivery robots and MaaS will be an important factor for both Efficiency and Alteration pathways. Looking at long-term perspective, the logistics system will be the main player, along with integrated concept such as CAVs.

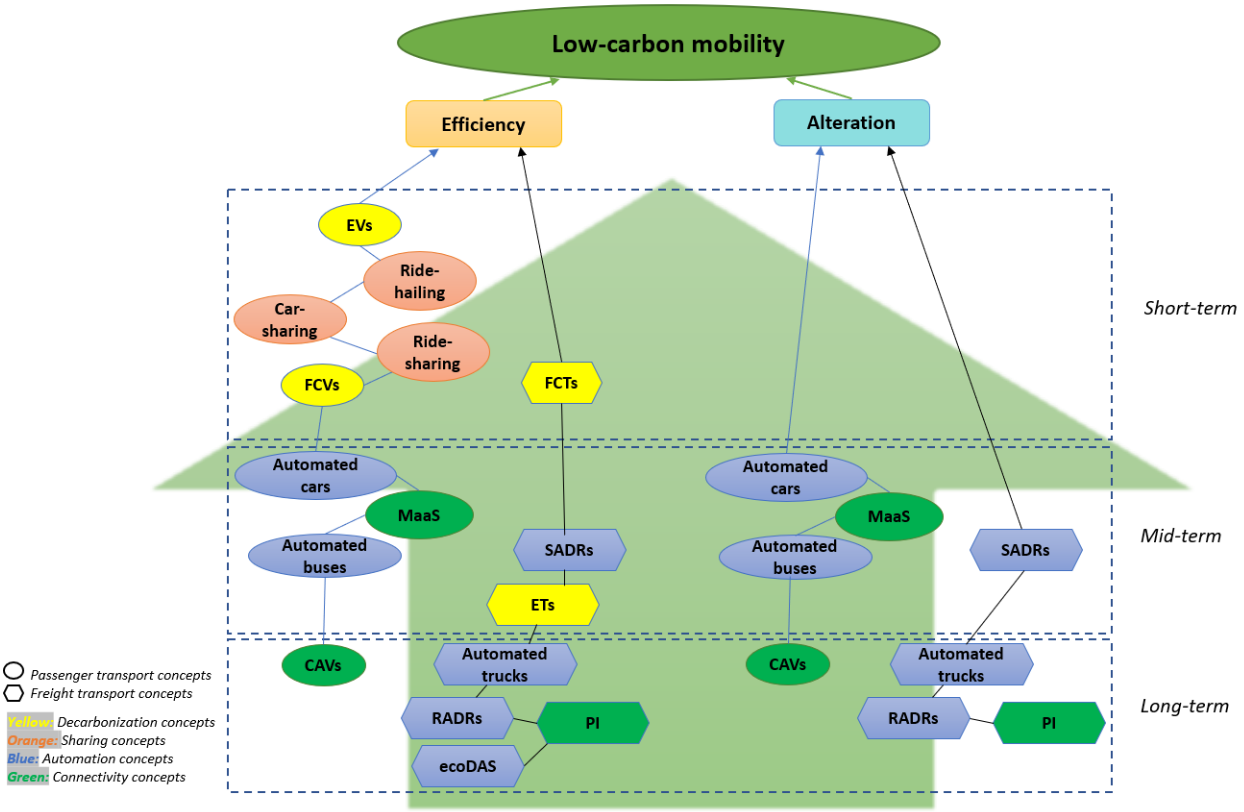

Figure 2: Visions and technological pathways to achieve the low-carbon target for road transport

5. Conclusions

This paper reviews a broad range of mobility concepts for both passenger and freight transport. The focus is laid at their advantages and disadvantages, as well as their technology maturity level. Among ACDS concepts, car-sharing, ride-sharing, ride-hailing and EVs are the most mature ones. This paper also discusses visions and technological pathways towards carbon neutral mobility for road transport. It is important to note that the study is limited to technological advancements, without presenting aspects of transformative pathways. Technological advancements alone will not be able to reach the targets, if suitable systems for them are lacking and the majority of users does not accept them. Moreover, even though road transport holds a significant share of global CO_2 emissions, it is solely a part of the mobility system. In order to achieve carbon neutrality in the whole transportation sector, efforts are required from the other mobility segments as well.

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