



Assessing Charging Infrastructure Opportunities for Battery Electric Medium Duty Vehicles in Austria

A Master's Thesis submitted for the degree of
“Master of Business Administration”

supervised by
Dr. Bernhard Scherzinger, MBA

Mag.iur. Stefan Richter

00310248

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Affidavit

I, **MAG.IUR. STEFAN RICHTER**, hereby declare

1. that I am the sole author of the present Master's Thesis, "ASSESSING CHARGING INFRASTRUCTURE OPPORTUNITIES FOR BATTERY ELECTRIC MEDIUM DUTY VEHICLES IN AUSTRIA", 87 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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Signature

For Elisabeth and Paul - you are my energy

I. Abstract

In the preface of a changing world aiming at the reduction of GHG emissions, this master thesis analyses the potential for charging infrastructure for battery-electric medium-duty vehicles (MDV) in Austria. By conducting a thorough analysis of national statistics and international literature, this thesis corroborates the hypothesis that current and future developments in the electrification of freight vehicles offers multiple opportunities to roll-out charging infrastructure for MDV in Austria. An interview with a renowned expert in commercial vehicle charging solutions substantiates the rightfulness of this finding.

The existing regulatory background in Austria and future implications of EU policies require increasing efforts in fields of transport to meet the joint environmental goals until 2030 and beyond. Therefore, an electrification of MDV offers remarkable potential to turn regulations and laws into positive business models due to the novelty of electric powertrains.

Although manufacturers offer only limited product lines, the prospects to electrify the powertrain of MDV show that even today, prototypes and first early productions can keep up with diesel or gasoline powered pendants. In a holistic analysis of the entire lifecycle and under assumptions on the battery life, today's vehicles are already close to overtake conventional MDV in terms of TCO calculations and real-life applications. Considering this, the projected developments in battery prices and capacities show a very promising future for BEV in commercial fleets, as the existing restrictions in load capacities due to heavy battery weight could be compensated by higher battery efficiency.

On the contrary, the MDV segment in general constitutes a niche existence in Austria. Therefore, the overall potential for charging infrastructure is bound to the development of N2 vehicles and requires synergies with heavy duty vehicles. Conductive plug in solutions (mainly CCS) at a capacity of 150 kW will remain the predominant standard for commercial vehicles in Europe for the upcoming years, while different fuels or alternative charging solutions might impose a competitive threat only in a later, more mature stage in time.

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IV. List of abbreviations

AbgKlassV	Verordnung des Bundesministers für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, mit der Bestimmungen über die Durchführung der besonderen Kennzeichnung von Fahrzeugen betreffend die Zuordnung zu den Abgasklassen festgelegt werden (IG-L - Abgasklassen-Kennzeichnungsverordnung – AbgKlassV), StF: BGBl. II Nr. 120/2012 [German for: Regulation on Exhaust Emission Class Labelling]
AC	alternating current
AnSchG	Bundesgesetz über Sicherheit und Gesundheitsschutz bei der Arbeit (ArbeitnehmerInnenschutzgesetz – ASchG), StF: BGBl. Nr. 450/1994 idF BGBl. Nr. 457/1995 [German for: Austrian Labour Protection Act]
approx.	approximately
BEV	battery electric vehicle
bn	billion
CCS	Combined Charging System
CNG	compressed natural gas
dB	decibel
DC	direct current
ESD	Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020 (Effort Sharing Decision)
esp.	especially
et.al.	et alii [Latin for: and others]
EU	European Union
f	following
FAME	Fatty Acid Methyl Esters
FQD	Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the

	specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC (Fuels Quality Directive)
GHG	greenhouse gas
GKV 2018	Verordnung der Bundesministerin für Arbeit, Soziales, Gesundheit und Konsumentenschutz über Grenzwerte für Arbeitsstoffe sowie über krebserzeugende und fortpflanzungsgefährdende (reproduktionstoxische) Arbeitsstoffe (Grenzwerteverordnung 2018 – GKV 2018), StF: BGBl. II Nr. 253/2001 [German for: Austrian Limit Value Regulation]
GVW	gross vehicle weight
HPC	high power charging
IEA	International Energy Agency
IG-L	Bundesgesetz zum Schutz vor Immissionen durch Luftschadstoffe (Immissionsschutzgesetz – Luft, IG-L), StF: BGBl. I Nr. 115/1997 [German for: Austrian Law on Air Pollution]
KDV	Verordnung des Bundesministeriums für Handel, Gewerbe und Industrie vom 30. November 1967 über die Durchführung des Kraftfahrzeuggesetzes 1967 (Kraftfahrzeuggesetz-Durchführungsverordnung 1967 – KDV. 1967), StF: BGBl. Nr. 399/1967 [German for: Regulation to Execute the Austrian Road Traffic Code]
KFG	Bundesgesetz vom 23. Juni 1967 über das Kraftfahrwesen (Kraftfahrzeuggesetz 1967 – KFG. 1967) [German for: Austrian Road Traffic Code]
km	kilometer
km/h	kilometer per hour
KSG	Bundesgesetz zur Einhaltung von Höchstmengen von Treibhausgasemissionen und zur Erarbeitung von wirksamen Maßnahmen zum Klimaschutz (Klimaschutzgesetz – KSG), StF: BGBl. I Nr. 106/2011, [German for: Austrian Climate Protection Law]
KVO	Verordnung des Bundesministers für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft über die Qualität von Kraftstoffen und die nachhaltige Verwendung von Biokraftstoffen (Kraftstoffverordnung 2012), StF: BGBl. II Nr. 398/2012 [German for: Austrian Fuel Regulation]
kW	kilowatt

kWh	kilowatt hour
l	liter
lbs	pounds
Li-Ion	lithium-ion
Li-S	lithium-sulfur
LNG	liquified natural gas
MDV	medium duty vehicle
mn	million
MoeStG	Bundesgesetz, mit dem die Mineralölsteuer an das Gemeinschaftsrecht angepasst wird (Mineralölsteuergesetz 1995), StF: BGBl. Nr. 630/1994 [German for: Austrian Act on Mineral Oil Tax]
MPW	maximum permissible weight
NST	Standard goods classification for transport statistics
NUTS	Nomenclature des unités territoriales statistiques [French for: Nomenclature of territorial units for statistics]
MW	megawatt
MWh	megawatt hour
OECD	The Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
PHEV	plug-in hybrid electric vehicle
PJ	petajoule
RED	Directive 2009/28/EC of the European Parliament and the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Renewable Energy Directive)
SEK	Swedish krona
SoC	state of charge
StVO 1960	Bundesgesetz vom 6. Juli 1960, mit dem Vorschriften über die Straßenpolizei erlassen werden (Straßenverkehrsordnung 1960 – StVO. 1960), StF: BGBl. Nr. 159/1960 [German for: Austrian Road Traffic Regulations from 1960]
TCO	total cost of ownership
tkm	ton kilometers
V	volt
WEM	with existing measures
Wh	watt-hour

1 Introduction

1.1 Trends in electric mobility

More than 80% of transport services in Austria are being conducted within less than 80km range. (Statistik Austria, 2018c, p. 37) During the initial research for this master thesis it was this specific statement by *Statistik Austria* that convincingly showed the potential of electrification of medium-duty vehicles (MDV). Most people entering the fields of electric mobility argue first with their range anxiety. (Botsford & Szczepanek, 2009, p. 7) What will happen if one runs out of battery in the middle of nowhere? But most people don't see the already existing charging infrastructure with up to 150 kW charging output and still fear they could lack a chance to refuel their vehicles. (Tsakalidis, Thiel, Europäische Kommission, & Gemeinsame Forschungsstelle, 2018, p. 14f)

In an environment where every Euro cent and every minute count, people know very well about the capacity and the restrictions of their logistics infrastructure. It is a proven fact that electric vehicles – although of a higher cost price – show significantly lower operating costs compared to conventional petrol or diesel cars. It's their lack of most mechanical parts like combustion engines, fluids, transmissions and clutches that makes electric vehicles less prone to technical or mechanical issues. (Wu, Inderbitzin, & Bening, 2015)

In passenger mobility, the infrastructure situation in Austria is rather developed. SMATRICS, the leading Austrian provider for electric mobility charging solutions, currently offers a charging point approx. every 60km. (SMATRICS GmbH&Co KG, 2019) And other providers are emerging, leading to an increasing competition for charging solutions for passenger cars. In March 2018, 3,596 public charging points were being registered in Austria.

(AustriaTech – Gesellschaft des Bundes für technologienpolitische Maßnahmen GmbH, 2018) In medium duty use cases, on the contrary, hardly any charging solutions are being offered although the hardware basis is roughly the same. The relatively low demand for electric light, medium and heavy duty vehicles might be the reason why no charging solutions have been established so far. From the supply side, OEM start offering attractive solutions for electric trucks. But whereas European manufacturers slowly start to ramp up their prototype production (Carey, 2018) (mostly accompanied by EU research projects like LEEFF, Megawatt or similar), Chinese manufacturers can already look back to hundreds of delivered vehicles in Asia.

In academia, several articles have been published on charging infrastructure for city centers or passenger cars. (Madina, Zamora, & Zabala, 2016) Highly sophisticated models analyzed the driving behavior of private individuals and tried to design a pattern where infrastructure would need to be established to form a sustainable charging network. (Micari, Polimeni, Napoli, Andaloro, & Antonucci, 2017) In addition, some studies focused on charging

solutions for delivery vans (class N1) or even for more hypothetical use cases in areas of heavy duty trucks (class N3). (Giordano, Fischbeck, & Matthews, 2017) But hardly anybody even analyzed the missing chain in logistics. MDV form an incremental part of the supply chain, linking interurban heavy duty traffic with local, last mile distribution. Especially for the retail business, MDV are crucial to serve the supply chain.

1.2 Increasing demand in road freight

On a global perspective, road freight vehicles account for more than 40% of all road transport related CO₂ emissions. Compared to global CO₂ emissions in a whole, heavy duty trucks produce 7% of the world's CO₂ emissions from energy production and use. Since the year 2000, CO₂ emissions from road freight have been rising by 2.8% yearly, out of which 90% of the increase has been caused by developing countries. (International Energy Agency, 2017, p. 18f)

The *European Commission* (2018b, p. 1) forecasts that without any additional action on the emission of road freight vehicles, their CO₂ emission would grow by another 9% in the period 2010 to 2030.

For Austria, hardly any reliable forecast for the further development of road freight exists. In 2009, the Austrian Federal Ministry of Transport, Innovation and Technology conducted a study on the development of freight in Austria. According to the pessimistic scenario 1, the road freight movements in Austria will have increase significantly (more than 100% increase in transit, +40% in bilateral transport and +28% in domestic traffic) in 2025 compared to values in 2005, resulting in 55,953 mn tkm per year. The rather optimistic scenario 2 ended up in 47,026 mn tkm/year, anyhow resulting in more than a 33% road freight increase compared to 2005. (TRAFICO et al., 2009, pp. 41–43) Although the economic crisis might have influenced the actual values of freight movement, this study still shows a strong trend towards increasing transport volumes.

1.3 Vehicle classification

In order to determine the further classification of vehicles and to assess the market potential specifically, the following chart shall illustrate the current vehicle categories in Austria:

Class M			Class N		
M1	M2	M3	N1	N2	N3
Cars < 8 seats	Busses > 8 seats < 5,000 kg	Busses > 8 seats > 5,000 kg	Vans < 3,500 kg	Medium trucks > 3,500 kg < 12,000 kg	Heavy trucks > 12,000 kg

Table 1: Overview passenger and commercial vehicle classes; Source: own illustration, based on §3 KFG

Although the scope of this work is Austria, several international aspects need to be considered, too. Therefore, the U.S. classifications 3 to 6 need to be considered besides the Austrian Class N2:

Light Duty	Medium Duty				Heavy Duty
	Class 3	Class 4	Class 5	Class 6	
< 10,001 lbs (4,536 kg)	10,001 – 14,000 lbs (4,536 – 6,350 kg)	14,001 – 16,000 lbs (6,351 – 7,257 kg)	16,001 – 19,500 lbs (7,258 – 8,845 kg)	19,501 – 26,000 lbs (8,846 – 11,793 kg)	< 26,001 lbs (11,794 kg)

Table 2: U.S. Vehicle Weight Classes & Categories; Source: (Alternative Fuels Data Center, 2019)

This thesis will use the term “heavy duty (vehicles)” (HDV) generally for class N vehicles. If reference to specific sub-classes is needed, the terms N1, N2 or N3 are used respectively. As the following analysis will focus on N2 classified medium duty vehicles, the term MDV or N2 will be used solely for class N2. Other vehicle classes will be covered solely to differentiate particularities for MDV compared to other vehicle types.

1.4 Research questions

Deriving from these remarkable trends in electrification of medium duty vehicles, the following research question shall be answered by this thesis:

What is the overall domestic demand in Austria for medium duty vehicle charging solutions?

This central research question will be clustered into the following sub-set of further research questions which will serve to structure the paper:

What are the major regulatory indications in Austria and in the European Union which will influence the utilization of MDV class N2?

Are OEM currently able to deal with demand and what are the technical specifications of electric MDV on the market?

What is the overall market potential in Austria for delivery and transport services utilizing MDV in the category N2?

What are the competing charging technologies on the market and what could be disrupting forces?

What are the classic driving patterns of MDV in urban Austrian areas and what does this mean for charging infrastructure?

What is the absolute and relative demand for electric MDV and how does this influence the distribution of chargers?

What would be the preferred location, density, technology and set-up for MDV chargers?

1.5 Objective of the master thesis

This master thesis aims to evaluate the overall potential of charging infrastructure for electric MDV. As battery-electric vehicles represent the most relevant and complex use-case, any other vehicle classifications like plug-in hybrids, battery-hydrogen combinations or others will not be reflected in this analysis. Final objective of this paper is the assessment of the overall demand for electric chargers based on the fleet projections of MDV. For that cause, the total addressable market will form a profound base to assess the actual customer demand by fleet operators and logistic companies. Based on that information, economic and technological opportunities are being assessed and benchmarked against competition in tradition fuels and alternative renewable energy sources. Finally, a recommended set-up of chargers will be identified.

2 Regulatory background

As mobility and road transport in particular are topics of high interest and also high environmental impact, EU and national regulations strongly impact the future of these sectors. Studies show that the EU transport policy advanced from rather economical and technical based views more to smart, integrated and green attributes. Instead of trying to execute behavioral policies, the EU regulations post 2010 focus more on innovation technology. (Aditjandra, 2018, p. 197f) This shift might also bring a substantial promotion for electric powertrains in MDV through the following European and Austrian regulations.

2.1 EU policies

Jean-Claude Juncker, President of the European Commission, introduced the Third Mobility Package “Europe on the Move” in May 2018 in order to complete the triad of initiative packages and to increase the European position regarding innovation, digitalization and decarbonization. Besides initiatives on Connected & Automated Mobility and Safe Mobility, clean transport actions should enable the European Union to comply with its commitments under the Paris Agreement. One of the key initiatives in low-emission mobility was the introduction of the first ever CO₂ emissions standards for heavy-duty vehicles. (European Commission, 2018a)

2.1.1 CO₂ limits for heavy duty vehicles

Whereas the CO₂ emissions of passenger cars had been regulated already back in 2009 (European Parliament, 2009), the European Commission so far lacked a proposal to limit the

carbon emissions from trucks. This comes rather surprising, as trucks, buses and coaches contribute to about a quarter of CO₂ emissions to the overall road transport emissions in the EU. (European Commission, 2018b, p. 1)

In May 2018, the European Commission published a proposal to reduce the CO₂ emissions of new heavy duty vehicles in the EU in a stepwise approach until the year 2030. For the years 2025 onwards, the proposal foresees a reduction of average CO₂ emissions of 15% compared to the benchmark of emissions in 2019. From 2030 onwards, the Commission proposal requires an indicative reduction target of at least 30% compared to 2019 values. The proposal also introduced incentives for zero- and low-emission vehicles. Interestingly, the draft regulation solely focuses on trucks and tractors of categories N2 and N3 with an axle set-up of 6x2 or a 4x2 configuration with a technically permissible maximum laden mass exceeding 16 tons. It is important to mention that this definition excludes vehicles in the categories M2 (busses) and M3 (coaches) as well as category N vehicles outside the above mentioned criteria. This means that only MDV with a 6x2 axis configuration fall under the new CO₂ emission targets. The specific regulations for zero- and low-emission vehicles, in contrast, are applicable for all category N vehicles and therefore include all MDV. (European Commission, 2018b, pp. 10, 21)

For zero- and low-emission vehicles, defined as heavy-duty vehicles without an internal combustion engine or with an internal combustion engine that emits less than 1 g CO₂/kWh or less than 1 g CO₂/km, the Commission foresees some sort of super-credits, as those vehicles in the fleet of a manufacturer count as two vehicles reducing the overall fleet emissions. The accountability of those vehicles is being capped by a maximum of 3% reduction for the manufacturer's overall fleet. (European Commission, 2018b, pp. 22–23)

To sum up, only 6x2 axis MDV will be affected by the future emission targets for road freight vehicles. But as OEM will be charged with high excess premiums from 2025 onwards (6,800 €/gCO₂/tkm) (European Commission, 2018b, p. 24), the introduction of zero- and low-emission vehicles in form of BEV and PHEV will be a very promising option to compensate for higher-emission vehicles being sold in other categories.

Besides some minor changes compared to the proposal by the European Commission, the *European Parliament* approved the proposal in April 2019. (European Parliament, 2019)

2.1.2 Other pollution limits and urban centers

In contrast to CO₂ requirements, other pollutants like particulate matter (PM), nitrogen oxides (NO_x), unburnt hydrocarbons (HC) and carbon monoxide (CO) have been regulated since decades, leading to remarkable improvements in air quality all around Europe. Mainly the introduction of EURO classes for the type approval of both passenger and commercial vehicles has brought an emission classification system to identify the grade of pollution from vehicle classes. (European Parliament, 2009) From 2013 onwards, all new HDV sold, registered or put into service within the Community have to comply with the latest EURO VI norms. (European Commission, 2011, para. 5) But not only emission thresholds, also testing procedures are being constantly developed to assess the real world emissions of on-road vehicles, especially in the previously not tested warm-up phase of engines. (European Commission, 2016) As Juncker's aim is to also improve the air quality in Europe, one might expect further burden on the emission of these pollutants from internal combustion engines.

2.1.3 Fuel Quality Directive

The European Commission does not solely tackle vehicles to reduce exhaust emissions. Also the CO₂ intensity of transport fuels were evaluated and considered as a remarkable contribution to the EU greenhouse gas emissions. Besides reporting the life-cycle greenhouse gas emissions of fuels, the FQD required suppliers to gradually reduce GHG emissions directly from their fuels and energy supplied by up to 10% until 2020 (compared to 2010 levels). According to Art. 7a FQD, this shall be reached by reducing 6% obtained through the use of biofuels, alternative fuels and reductions in flaring and venting at production sites, 2% by purchasing credits under the Clean Development Mechanism of the Kyoto Protocol and finally another 2% through the use of environmentally friendly carbon capture and storage technologies and electric vehicles.

Austria transposed the FQD by publishing the KVO, introducing a 5.75% substitution target based on the energy content of diesel and gasoline fuels. According to §11 KVO, electricity from renewable sources can be counted towards the substitution target and can be transferred from electricity providers to obliged parties.

2.1.4 Renewable Energy Directive

The RED sets mandatory national targets for each EU country's share of renewable energy sources in its entire energy mix, specifically accounting for renewables in transport. According to Art. 3, for the calculation of the electricity from renewable energy sources consumed by electric road vehicles, that consumption shall be considered to be 2,5 times the energy content of the input of electricity from renewable energy sources.

Austria reported the national targets within the National Renewable Energy Action Plan 2010, striving to increase the 2005 renewable share of 24.4% to a 34% ratio until 2020. (Austrian Federal Ministry of Economy, Family and Youth, 2010, p. 1)

To achieve this target, the ministry listed several measures specifically for electric mobility: Law on the taxation of mineral oils; Acceleration of a gradual, comprehensive introduction of electromobility in Austria; Austrian Action Programme for Mobility Management. (Austrian Federal Ministry of Economy, Family and Youth, 2010, p. 14)

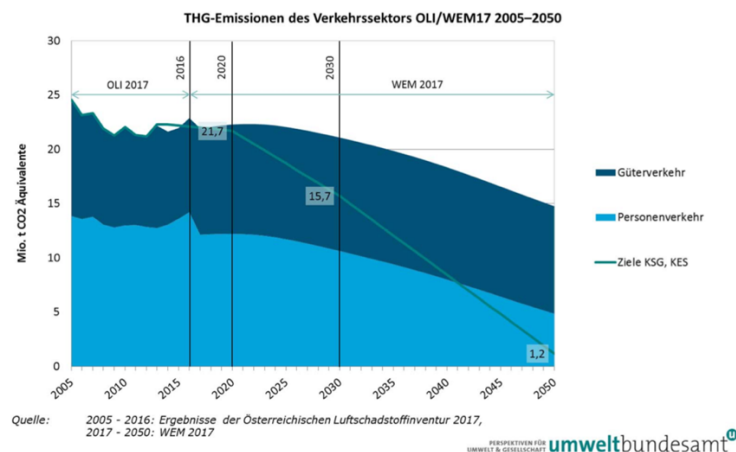
2.2 National laws and regulations

Besides the transition of EU law into national regulations, Austria policymakers also had decided in the past to initiate specific laws and provisions governing the usage of heavy duty vehicles. In the following section, a selection of specific regulations in direct correlation with electric powertrains should highlight potential national administrative burdens which could be avoided or even exploited by utilizing zero emission vehicles.

2.2.1 Austrian Climate Protection Law and #mission2030

Austria transposed the goals set by the EU ESD to establish binding national targets for GHG emissions by introducing the KSG in 2011, setting a 16% CO₂ reduction goal compared to 2005 values by 2020. Furthermore, the law foresees a legally binding pathway from 2013 onwards to reach an emission ceiling of 21.7 mn t CO₂ equivalent until 2020. With the #mission2030, the Austrian government introduced a comprehensive roadmap to reach a transport sector free of any carbon emissions by 2050. To obtain this objective, an interim goal of 15.7 mn t CO₂ equivalent has been set until 2030, reducing the overall transport emissions by 7.2 mn t CO₂ equivalent compared to 2016 levels.

A projection of the overall #mission2030 objective of a carbon neutral transport sector in comparison with the impact of existing measures (WEM scenario) shows the tremendous efforts required to reach this goal: (Heinfellner et al., 2018, p. 10f)



Caption 1: GHG emission in transport 2005-2050; Source: (Lichtblau, 2018, p. 24)

2.2.2 Environment labels

Already in 1997, Austria decided to introduce dedicated zones to prevent environmental damage caused by air pollutants. §§ 14 and 14a IG-L allow to establish speed limit zones and temporal or local driving bans for all or specific motor vehicles. To execute these regulations properly, the respective regulations (§14a IG-L, §4 AbgKlassV) implemented an environmental labelling of motor vehicles depending on their emission classification. When putting a vehicle on the market, the OEM is required to place the respective labelling



*Caption 3: Environmental zones in Austria;
Source: Green-Zones GmbH (2019)*

badge on the windshield, where it remains unless the engine is being modified or changed. Currently, only commercial vehicles of classes N1, N2 and N3 are covered. For the cause of environmental protection, EURO 0 to EURO 2 trucks are not allowed to enter the specific

environmental zones. Unfortunately, the respective restrictions are based on federal state regulations and differ accordingly. For very specific use cases, exemptions from the restrictions to enter or cross the restricted zones can be issued. (§14 (2) IG-L) In case of infringements of these restrictions, penalties of up to € 2,180 can be inflicted. (§30 (1) lit. 4 IG-L)

2.2.3 City bans

Alongside discussion about emission limits and diesel measurement manipulation, several cities throughout Europe announce to ban diesel or even combustion engines from their city centers in the upcoming years. Elisabeth Köstinger, Austrian Minister for Environment, admittedly rejected to discuss any bans on diesel, but other countries like Germany, Great Britain or Italy already introduced similar regulations and even had them approved by judicial rulings. (Özdemir, 2018) As 94.6% of LDV and 99.7% of HDV in Austria ran on Diesel in 2017 (Bundessparte Transport und Verkehr, Wirtschaftskammer Österreich, 2018, p. 60), a city ban could cause tremendous difficulties or even harms for companies operating in logistics.

2.2.4 Diesel tax privilege

In Austria, gasoline and diesel are taxed at different levels. Whereas the tax for one liter of gasoline is € 0.482, diesel is only taxed with € 0.397 of mineral oil tax (§ 3 MoeStG). Although frequently discussed, any initiatives to cancel this privilege on diesel has been strictly rejected by Austrian politicians. One of the major reasons for keeping the lower tax



*Caption 2:
Example of
Austrian IG-L
labelling badge
for Euro 6/VI
vehicles. Source:
Green Zones
GmbH (2019)*

regime for diesel is the pleasant effect of “fuel tourism”, i.e. a preference particularly by freight companies to fuel up their vehicles cheaper in Austria than in the neighboring countries. Although there are no proven figures of the actual amount of that phenomena, experts estimate that 20 to 29% of mineral oil tax revenue is being generated through non-Austrian customers, resulting in a yearly tax yield of more than € 830 mn (out of total revenues of € 4.2 bn). (Kummer, Dubrovnik, & Geske, 2016, p. 2)

Hence, an adjustment to mineral oil price levels to neighboring countries is very unlikely, as the Austrian government would need to transfer a high tax burden to Austrian tax payers. Consequently, one might not expect to see any indirect incentives out of the mineral oil tax regime, although it would have high impacts on the diesel-dominated freight industry.

2.2.5 Night, weekend and holiday driving bans

On Saturdays between 3 p.m. and 12 p.m. and on Sundays all day, vehicles above 7.5 t of laden weight or trucks with trailers and a laden weight above 3.5 t each are restricted to drive on public roads (§ 42 StVO). There are multiple exemptions esp. for the delivery of perishable food, livestock, emergency services or other services not to be delayed (§ 42 (3) and (3a) StVO).

For the nighttime (10 p.m. to 5 a.m.), vehicles above 7.5 t of laden weight are not allowed to be operated, except vehicles for military or road patrol services or if these vehicles emit not more than 77 or 80 dB of noise (depending on engine performance) and hence are classified as low-noise according to §8 (4) KDV. These vehicles are allowed to drive in those night times but are restricted to drive not faster than 60 km/h (§ 42 (6) to (9) StVO).

Regarding off-peak delivery, Volvo conducted a study together with the KTH Royal Institute of Technology to find out that night and early morning deliveries were 31% and 60% higher respectively. This means that especially for urban applications, off-peak deliveries could show remarkable efficiencies and additional commercial potential. (Pernestal Brenden et al., 2014)

2.2.6 Labor law

According to Annex Section C subsection 7 GKV 2018, diesel exhaust is being classified as a carcinogenic substance group. Consequently, workforce must not be exposed to diesel exhaust gases if any equivalent work result can be achieved with non-carcinogenic emissions. This is the reason why HDV are prohibited to drive directly into workshops or factory buildings, but instead need to unload at loading docks outside the building where goods are being further processed by low- or zero-emission forklift vehicles (e.g. based on CNG, LNG, hydrogen or electric batteries).

2.3 Conclusions

The pathway of both the European Commission as well as of the Austrian government is clear: Austria's transport sector needs to become carbon neutral by 2050 in order to fulfil the climate targets. Therefore, multiple actions need to be introduced to enable a stepwise reduction of GHG emissions in transport. But also other pollutants could be reduced significantly if delivery trucks would turn electric. And finally, electric powertrains could significantly support the decarbonization of fuels and the transposition of the RED, too.

But electric vehicles would not solely help reducing exhaust emissions, they also show new economic possibilities for their owners. The regulations mentioned above already indicate a broad range of restrictions or limitations regarding the exhaust or sound emissions of HDV. Whereas comprehensive exceptions for weekend driving restrictions already exist even for high-polluting vehicles, night-time deliveries are restricted to low-noise vehicles only. If city centers should decide to introduce both noise or exhaust gas restrictions or even combine both, electric trucks could be the preferred solution for deliveries. In the unlikely case that the Austrian government should refrain from the tax privilege of diesel, a whole chain of arguments for diesel engines in freight vehicles would break away, causing a remarkable competitive advantage of electric trucks in a TCO perspective. And even for transit traffic, benefits for zero emission vehicles are emerging: The German politics also brought up a strong signal for e-mobility in May 2018 by excluding electric trucks from highway tolls. (Hockenos, 2018)

Therefore, the utilization of electric trucks could show a remarkable upside potential for commercial freight. As some Austrian laws already foresee exemptions for electric vehicles (emission labelling, sound emissions), other fields still lack a clear distinction between vehicles with combustion engine and electric powertrains. This offers a huge potential for policymakers to incentivize electric trucks by amending existing regulations. Even new areas of application (see labor law restrictions) could occur, as trucks could close ranks with labor force.

3 Fleet analysis

After having analyzed the regulatory and legal requirements and preconditions for the future of road freight, the subsequent step questions if manufacturers already offer electrified powertrains in their MDV portfolio. In order to evaluate the present and future potential for charging infrastructure targeting electric trucks, the actual offering of OEM and their future product pipeline need to be summarized.

3.1 Current market for electric MDV and OEM pipelines

Not only the academic discussions, but also the product range of battery-electric MDV on the market is still very limited. Even the technical information being offered is very fragmented (esp. missing information on charging capacity, plug types and energy consumption), which might indicate a very early stage of public product communication. The following table illustrates a first product overview on MDV solutions globally available, making no claims of being complete as the approaching CO₂ targets for trucks will impose manufacturers to come up with low and zero emission solutions rather quickly:

OEM	Series	Max. weight (t)	Battery capacity (kWh)	Range (km)	Energy consumption (kWh/km)	Charging power (kW)	Source
Mitsubishi	eCanter	7.5	82.8	120	0.69	n/a	(Mitsubishi Truck and Bus Corporation, 2019)
BYD	T5	7.3	145	250	n/a	40AC/ 150DC	(BYD USA, 2019)
BYD	T7	11.8	221	200	0.88	100AC/ 150 DC	(BYD, 2018; BYD USA, 2019)
Freightliner	eM2 106	12	325	370	0.88	260DC	(Daimler AG, 2018)
Emoss	EMS 10	10	60-120	50-150	n/a	n/a	(Emoss Mobile Systems BV, 2019)
Emoss	EMS 12	12	120-200	150-200	n/a	n/a	(Emoss Mobile Systems BV, 2019)
Thor	UPS prototype	4.7	n/a	96	n/a	n/a	(Adler, 2018)

Table 3: Exemplary overview on electric MDV product range; Source: Own illustration, for data see section "Source"

Although the samples mentioned above might not be representative due to the low number of products on the market, they still give a good first example where the technical developments of electric MDV will head to. With a median range of 175 km and hardly any trucks being offered with a range below 100 km, the first models on the market show a promising coverage for multiple cases. But as already announced by the European Commission, testing standards will be assessed also for medium and heavy duty application (see chapter 2.1.2), potentially leading to an inconvenient decrease in range data if new testing cycles should be applied to commercial vehicles. (Taefi, Stütz, & Fink, 2017, p. 272)

3.2 Total cost of ownership

For freight industry, both regulatory burden and environmental concerns are important, but not determinant. It is mainly cost per tkm and utilization that count, as every non-delivered good or any parking or non-driving vehicle costs money and decreases competitiveness.

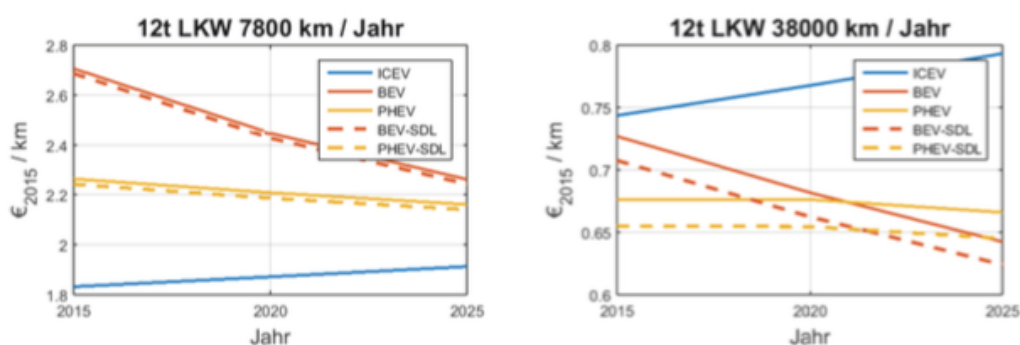
Therefore, a positive TCO case compared to conventional combustion engine trucks is key to evaluate the future potential of electric powertrains in this segment.

As a fully-fledged TCO analysis would include all national cost factors for Austria (e.g. electricity prices, tax incentives, road pricing, CO₂ costs etc.) and the scope of this thesis won't allow such an in-depth analysis, analogies to other studies in countries like Switzerland, Finland or the United States shall indicate if there is also a cost benefit of electric MDV in the near future.

Already in 2013, *Davis/Figliozzi (2013)* analyzed the lifetime costs of urban delivery trucks in the United States classifications 3, 4 and 5. It is specifically interesting that this study was based on electric MDV models with a much lower battery capacity (two models with 80 kWh and one with 360 kWh) compared to current models on the market. The model of this study operated on three different route instances based on five parameters (number of customers, service area, depot to service area distance, customer service time and customer demand weight). For these 243 route combinations in total, cost for the customer were calculated, declaring the one truck type as most feasible which can serve these routes at the lowest costs. The study claims that the cost efficiency of battery-electric MDV benefits from additional customers served, an increase in energy costs or longer distances being travelled. Although these numerous differing scenarios showed a very diverse picture, the overall outcome of the study states that under the precondition of falling battery prices and rising energy costs, electric MDV are more cost-efficient than diesel powered trucks. For the study's existing environment, a combination of high travel distances, low speeds, numerous and frequent customer stops, energy expenditures, tax incentives or a planning horizon beyond ten years would have been the precondition for a cost advantage. Especially the assumption of high distances comes as a surprise but considering the relatively high purchase prices of electric trucks and their low energy prices, the advantage in comparison with low purchase price vehicles running on more expensive diesel is higher the higher the actual mileage is. In other words, battery-electric MDV have significantly lower marginal costs. Anyhow, actual battery capacities do show some restrictions for battery-electric MDV in terms of overall range.

A similar result on the competitiveness of electric MDV is being achieved by *Feng/Figliozzi (2013, p. 145)* who specifically claim a high utilization of 60 miles per day or 16,000 miles annually per truck as key for the competitiveness towards diesel engines. Even at a 12,000 mile utilization competitiveness can be reached under the precondition of a 9% to 27% price decrease (or discount) on the purchase costs for the electric MDV. *Lee/Thomas (2017, p. 3319)* underline the economic benefits of electric MDV, but similar to other study authors

emphasize that the competitiveness can be shown in urban environments only. As *Liimatainen/Vliet/Aplyn* (2019, p. 805) rightfully summarize, “these studies conclude that even with an electric truck purchasing price three times that of a diesel truck, electric trucks are competitive if annual mileage is high enough and battery lifetime matches the vehicle lifetime. Furthermore, the benefits of electric trucks depend on the drive cycle (low payload weight, low speeds and frequent start/stop favor electric) and charging infrastructure costs.” *Arndt/Döge/Marker* (2016, p. 157) came to the very same result when they did a TCO calculation for electric MDV with two different mileage scenarios, resulting in an early break-even for a 12 t MDV running at 38,000 km/a, but clearly missed a break-even for the very same model with a runtime of only 7,800 km/a:



Caption 4: TCO calculation per kilometer within komDRIVE scenario (excerpt); Source: *Arndt/Döge/Marker* (2016, p. 157)

Rightfully, *Taefi/Stütz/Fink* (2017, p. 281ff) state that the TCO calculation and the assumption of a higher cost-efficiency at a higher mileage is strongly depending on the BEV being used and the specific profile of the freight company, potentially confuting this hypothesis. Finally, special transport requirements such as heating or cooling of freight are most likely reducing range or are increasing electricity consumption, ultimately influencing the TCO calculation. (*Margaritis, Anagnostopoulou, Tromaras, & Boile, 2016, p. 9*)

As already stated, while most of the cost indicators are influenced nationally or locally (e.g. energy prices, regulatory environment, incentives, etc.), one very decisive factor for TCO analysis of battery-electric MDV is the battery price levels, as powerpacks form an essential part of the vehicle price and therefore determine the cost performance of the MDV. All the studies cited above come to the conclusion that the replacement of aged batteries constitutes – besides the high vehicle purchase prices – an important cost factor for the electric MDV and the price to change a battery pack significantly influences the TCO calculation.¹

¹ See (*Taefi, Stütz, & Fink, 2017, p. 273*) with further references

3.3 Battery capacity and battery price development

In general, the battery can be considered as one of the main elements of any electric vehicle. When it comes to battery-electric MDV, the battery plays an even more important role, as it not only influences the maximum range of the truck, but also influences both loading volume and payload – two very central aspects for the transport industry.

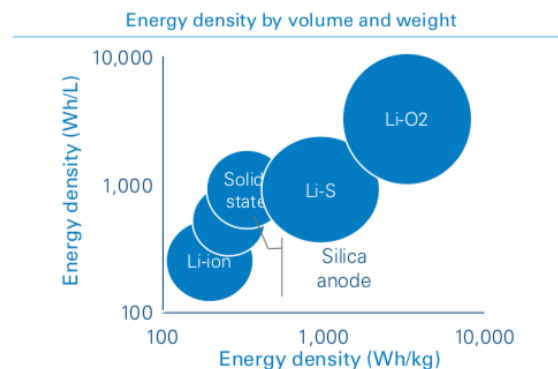
When assessing the capacity of a battery, both gravimetric and volumetric energy density can be evaluated. While the gravimetric density of a battery is measured in Wh/kg, the volumetric density is stated in Wh/l. Although any deeper analysis of the arrangement of cells within a battery pack would exceed the scope of this analysis, the energy density achieved both through alignment of cells within the pack and through chemical optimization is crucial parameter. The gravimetric density influences the payload of the vehicle; therefore the aim is to increase the battery density to reduce the deadweight of the MDV. EU regulations foresee that a higher vehicle weight should not be counted as part of the effective load of the vehicle in order to promote the use of alternative powertrains (European Parliament, 2015, para. 6), nevertheless the battery weight can be seen as a limiting factor for the vehicles. But besides the load weight, it's also the load volume that counts, as voluminous batteries would take up precious room in the vehicle which could be used for loading freight instead. But as *Mareev/Becker/Sauer* (2018, p. 3) claim in their study, payload might be a primary parameter compared to volume, as trucks which are loaded to a volume over 90% only utilize about 70% of their available payload on average.

Liimatainen/Vliet/Aplyn (2019, p. 808) even calculated in their four scenarios for full electrification of trucks that a 5% GVW increase in Finland would be sufficient to reach full electrification, whereas in Switzerland a 10% GVW increase would be required to support the electrification efforts. A similar assumption has been made by *Çabukoglu et.al.* (2018, p. 111) as they replaced the fuel tank volume with batteries. As this would have led to excessive weight increase, they capped the additional weight of the batteries with 5% of the original vehicle's MPW.

Considering the current levels of battery density, namely 125 Wh/kg and 200 Wh/l respectively, the required weight and volume for the actual range and usage of the vehicle can be calculated. In the case of the Freightliner eM2 106, the MDV with the highest battery capacity in chapter 3.1, this would mean a battery weight of 2.6 t and a required volume of 1,625 l for its 325 kWh battery. No wonder that the battery is considered as the second heaviest component in an MDV (following the vehicle body), limiting the maximum payload of a battery-electric MDV at most 23% compared to a conventional diesel truck. (Mareev et

al., 2018, p. 14) For the future, *Liimatainen/Vliet/Aplyn* (2019, p. 807) see an improvement in gravimetric battery density to 240 Wh/kg in their improved vehicle scenario, which would impressively decrease the battery weight in our example by 48% to 1,354 kg.

The future development of battery density is highly depending on three fields of technological enhancements: silica anodes, advances cathodes and solid-state electrolytes. In current technology Li-ion batteries, graphite is being used as the anode material; if the graphite can be replaced by pure silica anodes, an increase in energy density by approx. 40% can be expected. Anyhow, there are still issues in the lifecycle expectation for those kinds of batteries to overcome. Secondly, advanced-cathode chemistries like lithium nickel manganese oxide (LNMO) could further increase the energy capacity, but currently still faces issues at higher voltages required esp. for BEV. And finally, solid-state electrolytes could replace existing solutions by one thin, ion-conducting membrane. Solid-state batteries are currently treated as the most promising technology with potential to disrupt existing Li-ion solutions by increasing energy density by 40%, allowing the use of 5 V which further increases the energy density by 10% and solving many more technical and safety issues of existing battery generations. Leading battery manufacturing companies like Samsung, Toyota and Bosch already claimed to introduce solid-state batteries before 2020. (Arthur D Little, 2018, pp. 10–12)

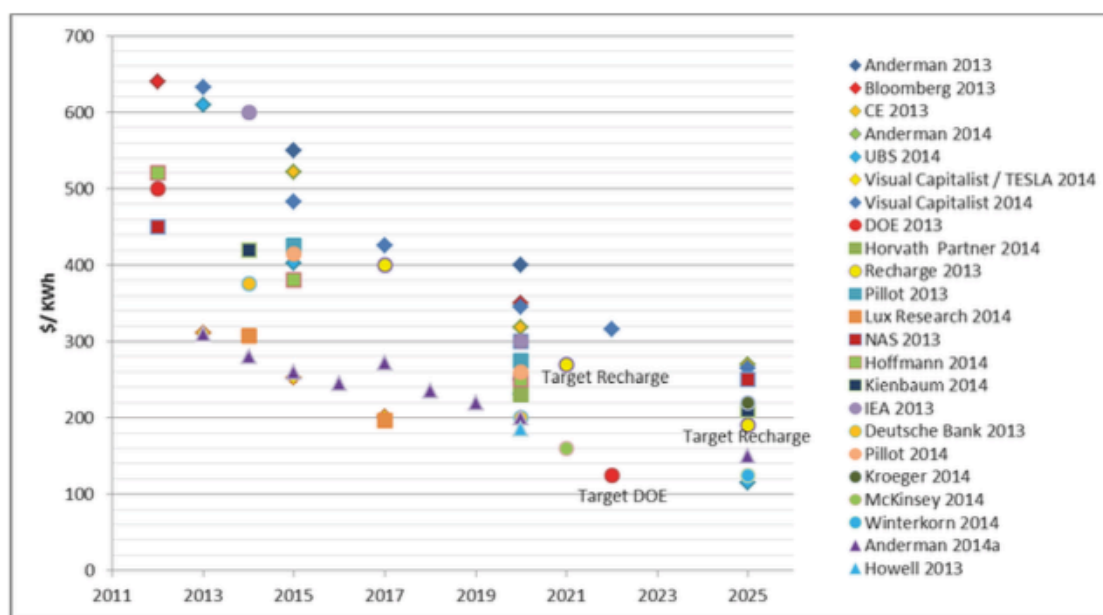


Caption 5: Selected major battery technologies and their energy density by volume and weight; Source: Arthur D Little (2018, p. 11)

As the illustration of *Arthur D Little* (2018, p. 11) shows, the deployment of solid state batteries mainly enhances the volumetric energy density, leading to result beyond the 1,000 Wh/l, while the gravimetric energy density could slightly be improved. The next big, for the needs of electric MDV specifically important step comes with the development of Li-S batteries which are expected to show a significantly higher gravimetric energy density around 1,000 Wh/kg. Li-S batteries have already been produced by existing companies for some time, nevertheless existing technology suffers cycling issues. Ultimately, due to the

deployment of solid-state electrolytes, these problems might be solved, and completely new fields of battery quality and density could be discovered.

On the cost side, several studies on the past, current and future price development of batterie packs for electric vehicles do exist. Therefore it might be rather challenging to find an objective projection especially on future developments. The most reliable study has been conducted by Technical University Berlin, as this paper from 2016 conducted a secondary study based on three different types of studies: findings of battery research programs, studies by consulting companies and statements or indications by leading automotive managers:



Caption 6: Overview on studies related to BEV lithium-ion battery price developments.
Source: Arndt/Döge/Marker (2016, p. 174)

Based on this outlook, *Arndt/Döge/Marker* (2016, p. 179) projected an average price development and come to the result that battery prices will decrease to USD 250/kWh in 2020 and to USD 190 in 2025. Compared to 2013 figures, this means a price reduction of 45% and 60% respectively. More current figures published by *Statista* (2019) for 2018 show an even more dramatic decrease, resulting in current global lithium-ion battery pack prices of USD 231/kWh already in 2018. Considering these actual figures for 2018, the price band of *Arndt/Döge/Marker* might be too broad, as their upper value of USD 270 already has been undercut in 2018. Therefore, the lower edge of their band around USD 110 to 200/kWh might be the value to look out for in the near future. A combination of materials containing lithium and manganese to produce high-performance cathodes or anodes containing silicon (composite) alloys as well as lithium metal cells are considered promising future

technological developments to further decrease battery prices to the target value of USD 125/kWh.

3.4 Conclusions

The current market for battery-electric MDV is very limited, offering only a couple of BEV options compared to classic combustion engine or hybrid models. This might surprise, as recent studies show that under specific circumstances electric MDV show a strong TCO result and can outperform diesel vehicles over time. For urban areas and delivery routes above a certain threshold including multiple stops at customers and considering heavy traffic, electric MDV are already a promising alternative for certain use cases.

For the implementation of electric powertrains in the entire spectrum of MDV, an increase of the vehicles' MPW is essential in the short to medium term. *Çabukoglu et.al. (2018, p. 117)* state that the potential for electrification would be practically zero for cell densities below 800 Wh/kg if regulators won't allow a weight increase respectively. Most of the authors of existing studies assumed a weight increase of 5% (either as their main scenario or as a cap for their calculations), therefore a regulatory weight increase in that area should be introduced to increase the chance of MDV electrification. A scenario without any mass limitation more than doubled the potential below any battery densities below 480 Wh/kg. If road safety and other technical requirements therefore allow, a raise in MPW for electric MDV of 5% and more would increase the chance to electrify the existing fleet most.

The future of electric powertrains in trucking industry is highly depending on the technological developments, above all the price and energy density developments of battery packs and cells. Mainly driven by passenger BEV, niche products like battery-electric MDV could strongly benefit from windfall effects by learning curves and economy of scale in battery development and application led by consumer product batteries. In questions of battery capacity, it is mainly the gravimetric density which counts for the industry, as improvements in the weight could increase the range and will increase the available payload. Any regulatory developments in allowing an increase of vehicle GVW would strongly support the dissemination of electric vehicles in freight industry. With a projected capacity increase and a price decrease in the area of 50 to 100%, the potential to electrify trucks might be boosted tremendously until 2025 or 2030.

As soon as OEM are putting more research and efforts into developing dedicated platforms for electric powertrains, the volumetric distribution on battery packs within the vehicle will be no further challenge. But as later analysis will further show in detail, an improvement in

battery density is not the only driving force in electrification. Without numerous technological improvements, electrification of MDV powertrains will stay a niche product for urban applications for a longer time.

4 Market segmentation and demand

In order to evaluate the future market potential for MDV charging infrastructure, the freight streams in Austria need to be analyzed. As soon as the specific user groups are being identified, the total addressable market (TAM) will give a first view on the maximum potential of this market segment. A further distillation will also include behavioral aspects and an analysis of the willingness of freight companies to be first movers into electric powertrains.

4.1 Total addressable market

In short, as of today the total addressable market for charging infrastructure aiming at electric MDV is practically zero. Whereas 1,755 electric N1 vehicles have been registered in Austria by end of 2017, only one medium or heavy duty electric truck has been added to the fleet in the past years, reflecting the negligible relevance of electrified MDV.

(Bundesministerium für Verkehr, Innovation und Technologie, 2018) Therefore, the following market segmentation and the demand analysis can't be based on historical data but needs to be built up on assumptions based on existing studies on the future developments in the MDV sector. As the scope of this research does not allow a fully-fledged bottom-up study based on tracking vehicles, conducting representative studies or drawing from existing movement figures, the following analysis needs to rely on a top-down approach, analyzing the overall freight potential for MDV in Austria and the suitable use cases for battery-electric vehicles before assessing the potential to electrify MDV.

The current freight behavior in Austria and existing MDV stocks form the basis which will be refined by specific use cases for electric trucks like distance travelled, payload limitations or applications in urban areas.

4.2 Distance and transport volume

4.2.1 Road freight in general

Austrian official statistics on road freight and transport distinguish between domestic traffic, cross-border receipt or shipping, transit traffic and other foreign freight. As analyzed in chapter 3, most likely electric MDV will not be intended for long-haul transportation or other transit freight due to range and capacity restrictions. Therefore, the further analysis will concentrate on all domestic movements of goods.

In 2017, in general more than 509 mn t of goods had be transported on Austrian roads. To further distinguish between the providers of these transport volumes, statistics are split

between vehicles registered in Austria and other vehicles registered abroad. The vast majority of freight, namely 360 mn t, has been inland transport conducted by vehicles registered in Austria. In contrast to that, transit goods by non-Austrian vehicles summed up to only 52.9 mn t, ranking second in the road freight statistics. The inbound (37.2 mn t) and outbound (31.3 mn t) cross-border transport of goods by foreign vehicles ranked third; any other volumes, mainly cross-border freight by Austrian vehicles, are negligible. (Statistik Austria, 2018c, p. 22f) Although Austria is often considered as the most prominent transit country in Europe (Verkehrsclub Österreich, 2018), these figures show that by far the most freight activities are being carried out within the national borders, i.e. starting and ending at a destination in Austria.

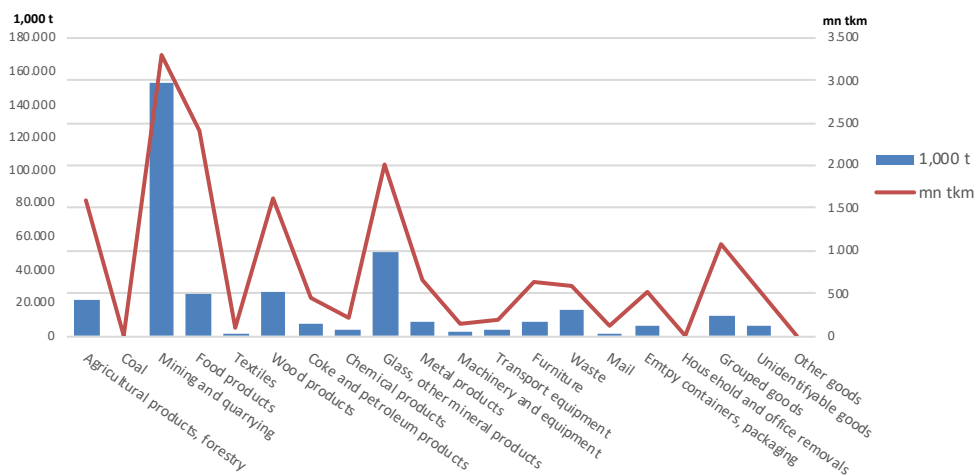
In contrast to volumes, an analysis of transport distances shows a different picture: Whereas 75% of the volume in Austria is being delivered by Austrian vehicles, only 44% of the mileage is being conducted under Austrian license plate. This means that 18.4 bn km of driving distance fall upon national and 23.3 bn km upon non-Austrian vessels, mainly representing the typical characteristics of transit freight at high mileage with relatively low volumes. (Statistik Austria, 2018c, p. 26) Hence, the further analysis will concentrate on vehicles registered in Austria for two main reasons: First of all, vessels registered in Austria are easier to measure, to evaluate and finally to steer with the help of regulatory measures or (tax) incentives. As long as no specific road pricing initiatives will be conducted for electric MDV, it could be mainly purchase subsidies, vehicle-related tax regimes or zone with limited access for combustion engines and exemptions for zero-emission vessels which could support the deployment of battery-electric MDV. (Mirhedayatian & Yan, 2018, p. 33) Secondly, the mentioned driving behavior indicates that foreign vehicles mainly conduct transit or inbound/outbound cross-border deliveries, whereas Austrian vehicles are used for inland transport. Considering the range of electric MDV and their economically preferred driving pattern stated in chapter 3.2, the following analysis will concentrate on domestic registered vehicles, only.

A breakdown of the actual distance bands shows that the majority (60.2%) of transport services except transit routes has been conducted at a mileage below 50 km. Interestingly, the share of Austrian vehicles decreases with increasing mileage, reflecting that the majority of cross-border transport services are being taken over by non-Austrian vehicles. Whereas 99.3% of transported goods in a range up to 49 km were shipped by vehicles registered in Austria, only 75.1 % were transported by Austrian vessels at a range of 500 km and beyond. The generic breakdown of inland freight services results in an average transportation distance of 45 km and an average transport volume of 11.9 t per shipment. (Statistik Austria,

2018b) A deeper look into the mileage of Austrian-only vehicles shows an even more surprising picture: in 2017, 184.2 mn t of goods or 48.1% of the overall shipped volume by Austrian vessels had been transported at a distance below 20 km. Considering further volumes in a range of up to 80 km, this results in 317.9 mn t or 88% of the transport volume of Austrian vehicles. (Statistik Austria, 2018c, p. 37f) Another interesting consequence of this mileage distribution is the fact that the shift of transport capacities from road to rail could hardly be executed as short distances below 50km are difficult to handle by train. (Statistik Austria, 2018c, p. 31) This gives another indication that the freight potential for road transport will increase in future, potentially increasing the need for low- to zero-carbon solutions for trucks and MDV specifically.

4.2.2 Freight by commodity

The NST 2007 category “Mining and quarrying” is leading the statistic both in freight volume and haulage transported in Austria. The high amount of tkm is most probably deriving from the rather high weight of transported goods in comparison to other segments. The category “Glass and other mineral products” ranks second and shows a relatively higher ratio of tkm, indicating a higher mileage compared to other segments. “Wood products” and “Food products” ranked third, where again high haulage (esp. for food products) suggest a high mileage proportion compared to the weight.



Caption 7: Inland road freight transport of European companies - freight volume and haulage according to NST 2007 categories 2017 - Source: own calculations based on Statistik Austria²

4.2.3 MDV transport and driving behavior

Unfortunately, no specific breakdown of statistics specifically for MDV exist in Austria. In contrast to that, a German study by TU Berlin conducted research also on 12 t trucks as a representative example for MDV. Whereas the official German statistics stated a daily

² Statistik Austria (2018a) offers a different category segmentation for Austrian companies (NST/R); to ensure consistent use of terminology, European terminology was used

driving range for MDV of more than 100 km, the komDRIVE study by *Arndt/Döge/Marker* (2016, pp. 126–129) came to the result that the average medium-duty vessel drives 24 km a day, ranging between 10 to 60 km in particular cases. The researcher also concluded that the evaluated MDV were strictly differentiated by their area of application, namely mere urban usage and overland transport. This is also reflected in the relatively high frequency of measured speed intervals at 50 km/h, which could have been hardly reached in urban environments only. According to the komDRIVE study, another characteristic attribute of MDV is the strongly alternating phases of activity where some of the assessed vehicles had been operated at 100% utilization in the testing cycle, whereas other vessels showed 0% activity and were essentially not moved. *Arndt/Döge/Marker* derive this effect from the relatively high loading times for specific vehicles, which occur at very different points in time during the route of an MDV vehicle. Finally, the operation time shows another interesting picture: Whereas the first test vehicles started operation around 3 a.m., the last tours were registered around 12 a.m., showing no tour in the afternoon or evening hours.

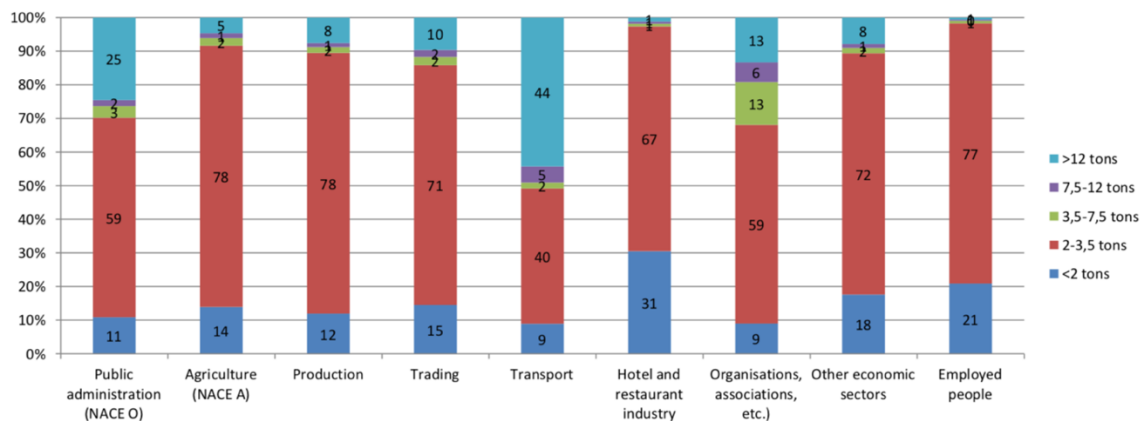
Contrary to the Austrian or German statistics, the Swiss road pricing system is based on a fee per mileage not only for highways, but for all road kilometers being driven by HDV in order to collect the road tax “LSVA”. This leads to a very detailed driving profile and reliable data on the specific freight patterns. (Çabukoglu et al., 2018, p. 110)

4.3 Existing vehicle fleet and registrations

In Austria, MDV are considered to be rather a side issue compared to the dominating N1 vehicles and larger N3 vessels. By April 2019, 10,748 MDV were registered in Austria, representing only 0.2% of all vehicles incl. trailers. (Statistik Austria, 2019c) Interestingly, in 2017 about 68% of transport services in Austria have been conducted with vehicles not older than 4 years. 30.4% of vessels in operation are between 4 and 7 years old, whereas 31.6% of trucks are older than 7 years. (Statistik Austria, 2018c, p. 32)

Whereas *Statistik Austria* publicly offers no diversified data about the specific segments, *Klaunberg et.al.* (2016, p. 207) claimed to have access to a deeper segmentation of MDV into economic sectors in Austria based on figures as of December 31, 2012. According to their analysis, the majority of MDV was registered for trading (3,819 vehicles), followed by transport (2,617 vehicles) and production (2,431 vehicles). “Other economic sectors” ranked fourth but lacked specific validity as this seems to have acted as a sort of catch-all element. A further analysis of the distribution of vehicle MPW incl. HDV above 12 t payload showed an interesting distribution in these sector categories. Although MDV represent a minority by

numbers of vehicles registered, they provide a remarkable percentage of MPW especially in the sector “Organisations, associations, etc.” (19%) and even in transport business (7%):



Caption 8: Distribution of vehicle PMW in % in the Austrian sector categories; Source: Klauenberg et al. (2016, p. 207)

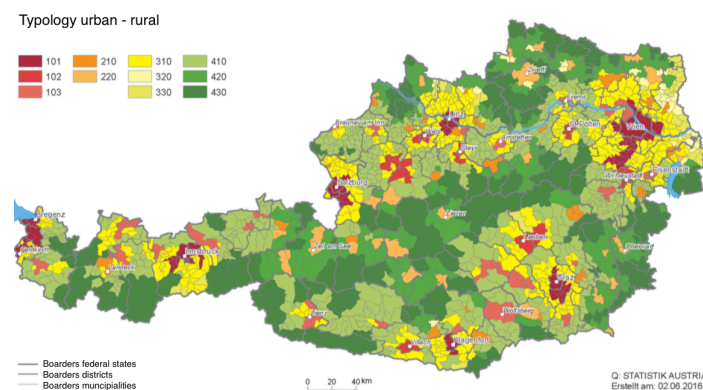
4.4 Urban areas

One of the key findings in chapter 3 identified urban areas as the first and most important application fields for battery-electric MDV. The restrictions in terms of range and the TCO calculation compared to conventional diesel engines suggested a high utilization with multiple stops and heavy traffic surroundings. Therefore, it seems obvious to identify and assess Austria’s urban areas in order to find the prior field of application.

To find these potential business regions, it is crucial to identify the key cities and major towns in Austria first. In general, there are three international and one Austrian approach in identifying urban areas. The Regional Typology developed by the OECD offers a three-step approach: First, the method identifies local units as rural (population density < 150 inhabitants/km²). Second, it aggregates these local units into NUTS 3 regions³ and classifies them as “predominantly urban”, “intermediate” and “predominantly rural”. Finally, a third step accounts for especially dense centers and adjusts their classification. (OECD, 2011, p. 3) Alternatively, the European Commission applies an Urban-Rural Typology by classifying 1 km² grid cells into urban centers, urban clusters and rural grid cells, depending on the population density and the combined population levels of bordering clusters. (Eurostat, 2019d) Deriving from workforce statistics, the European Commission also uses the Degree of Urbanisation (DEGURBA) methodology to distinguish between cities (densely populated areas), towns and suburbs (intermediate density areas) and rural areas (thinly populated areas). (Eurostat, 2019a)

³ For general information on NUTS classifications, see (Eurostat, 2019c)

On a national level, unfortunately no standardized definition for urban areas is in place. *Statistics Austria* (2016) developed a classification of types of areas, combining the existing urban region structure with a more diverse picture of rural areas. By using 500m grid cells, urban areas with outstanding demographic potential ($\geq 300/\text{km}^2$ or $> 25,000$) and high population (eight connected grid cells = 2 km^2 need to show demographic potential of $\geq 2,750$) are being categorized as core zones. These urban areas are be further divided into one metropolitan area (Vienna), six large urban regions with more than 100,000 citizens in its core zone⁴, nine medium-sized urban regions between 30,000 and 100,000 citizens in its core zone⁵ and 26 small urban regions with less than 30,000 citizens in its core zone⁶.



Caption 9: Urban-Rural-Typology; Source: Statistik Austria (2016, p. 13)

These potential areas might be ranked, starting with operations in highly populated areas (see 101) and potentially expanding to less populated cities and towns (see 102, 103). Altogether, the three core urban areas represent almost 4.5 million citizens or more than 50% of the total Austrian population.

For the application of electric MDV, these urban areas and their outer zones or satellite cities might be the preferred area, as these regions show two very promising criteria: firstly, these urban areas are well connected to transit networks by road, rail or air and can easily provide goods which can be further distributed by electric MDV. Secondly, these areas show a remarkable potential not only in their direct urban zones, but also in their surrounding areas. The core area Linz, for example, had been home to approx.. 250,000 people in 2013; in contrast to that, almost 200,000 people had lived in its surrounding zones, showing the

⁴ Graz, Linz, Bregenz-Dornbirn-Feldkirch, Salzburg, Innsbruck, and Klagenfurt

⁵ Wels, Wiener Neustadt, Villach, Sankt Pölten, Vöcklabruck, Steyr, Gmunden, Obersteiermark - Bruck an der Mur/Kapfenberg, Obersteiermark – Leoben

⁶ Eisenstadt, Telfs, St. Veit an der Glan, Spittal an der Drau, Wolfsberg, Krems an der Donau, Amstetten, Enns, Stockerau, Ternitz, Neunkirchen, Klosterneuburg, Braunau, Imst, Ried, Leibnitz, Weststeiermark – Voitsberg, Weiz, Aichfeld-Murboden – Judenburg, Aichfeld-Murboden – Knittelfeld, Wörgl, Kufstein, Lienz, Reutte, Schwaz, Bludenz

enormous potential of the urban areas in combination with a higher travelling distance which needs to be covered. (Statistik Austria, 2013)

4.5 Potential of MDV fleet electrification

Due to the fact that official Austrian statistics on MDV driving patterns and purpose of the specific routes are limited, the further focus of this research is to find any bottom-up analysis of freight behavior. Unfortunately, the literature on this very specific topic is even more limited. Center of existing research is the project SELECT (Suitable Electromobility for Commercial Transport), a joint initiative of researchers from Austria, Denmark and Germany and co-funded by the EU under the ERA-NET Electromobility+ scheme. The authors analyzed the Austrian and German potential to electrify commercial transport (also including commercially registered passenger vehicles). In a three-stage process to assess general information on logistics, *Klaueberg et.al.* (2016, p. 205) first evaluated the daily mileage per economic sector based on statistical data. Secondly, they conducted a survey on fleet decision-making in companies. Unfortunately, the authors focused solely on SME⁷, leaving out a small, but remarkable group of 34 larger enterprises active in land transport and defined by more than 250 employees, which employed in total more than 38,000 people and contributed almost EURO 19 bn in revenues in 2017. (Statistik Austria, 2018c, p. 73) In addition, the survey focused mainly on commercially used passenger cars and light duty vehicles and vans with payload up to 3.5 t, whereas heavy duty vehicles played a subordinate role. And thirdly, the authors conducted a GPS tracking analysis focusing again on vehicles below 3.5 t of payload. Accordingly, the study identifies the highest potential in electrifying vehicles below 3.5 t payload in the sectors production and trading. Furthermore, only one third of the interviewed companies would have been able to conduct their daily business with BEV offering a driving range of 100 km. (Klaueberg et al., 2016, pp. 205, 214f) Again it needs to be criticized that the study did include vehicles below 3.5 t of payload, as these vehicles offer a completely different usage perspective. Unsurprisingly, the authors identified potential for nursing services, as this segment requires a specific vehicle range and almost no loading capacity. To compare these use cases with vehicles offering a payload of up to 12 t seems to be far too broadly defined.

A Swiss study on the potential for MDV electrification shows a clear picture: With existing technological projections, i.e. 240 Wh/kg cell density without battery swapping options and at 50 kW overnight charging solutions, 10% of the Swiss fleet of MDV vehicles or 558 vessels could be electrified under current usage. This very disillusioning picture doesn't get better

⁷ Assuming that *Klaueberg et.al.* followed the official SME definition of the EU: (European Commission, 2003)

looking at the entire fleet, as in total only 12% or 6500 vessels of the Swiss commercial freight fleet would be electrifiable. Even more devastating is the environmental effect, leading to only 2.1% GHG reduction mainly attributed to the highest potential for electrification in the area of low performance vehicles, which – in relation to higher polluting vehicles – only disproportionately contribute to the overall emissions. Subsequently, Çabukoglu et.al. (2018, pp. 115–120) evaluated the impact of increasing the battery density to 2,000 Wh/kg, which showed a remarkable, but not game-changing increase of potential for electrification to 70% of the Swiss fleet. This relatively low result considering a rather high battery density derives from the limited overnight charging capacity of 50 kW in the initial scenario, leading to the impracticable result that vehicles couldn't be charged sufficiently and in time for the specific use cases.

To further evaluate the future potential for electrification of commercial vehicles, the authors of the study created three different scenarios, assuming different technological implications. Unfortunately, the study heavily relied on battery swapping, which might become a feasible option in the future, but needs to be considered as a competitive technology for conventional conductive charging solutions. Anyhow, the results of the scenarios show a clear indication of the impact of enhanced battery density; an increase of allowed battery swaps per day, in contrast, leads to a minimal increase of potential for electrification from 93.3% in Case B (420 Wh/kg battery density, 3 swaps allowed, 50 kW overnight charging power) to 93.4% in Case C (240 Wh/kg battery density, 6 swaps allowed, 50 kW overnight charging power). Considering the projected battery density developments as stated in chapter 3.3, an enhancement of battery density (also pushed by the developments in passenger car electrification) might be more feasible in terms of infrastructure costs for battery swapping facilities as well as additional technological requirements for vehicles. Although Çabukoglu et.al. (2018, p. 121) see battery swapping stations as a prerequisite for the full electrification of Swiss commercial vehicles, they have to admit the enormous number of approx. 130 swapping stations across the country, hosting and charging at least 100 batteries each and – in peak times – swapping batteries of a weight of up to 1 t within under five minutes. Consequently, the authors of this study call the technical requirement “enormous”.

A more comparative attempt had been chosen by Liimatainen et.al. (2019, pp. 806–807) by assessing the electrification potential for electric trucks in Switzerland and Sweden. The authors conducted a bottom-up analysis utilizing the data sets of continuous road freight surveys reported to the EU: They translated the total weight of the specific heavy duty vehicles into diesel consumption and further into electricity consumption. Finally, they

divided the converted diesel energy consumption by 2.5 to take into account the higher efficiency of electric motors compared to diesel engines.

The scope of this work would not allow a similar analysis of (confidential) data material as *Liimatainen et.al.* did. Anyhow, a comparison of fundamental data of the two analyzed countries Switzerland and Finland with the freight and vehicle registration data of Austria allows to draw specific conclusions of the comparability of the study results with Austrian preconditions. The Swiss transport industry shows a similar transport behavior in the compared categories. The overall transport volume as well as MDV and HDV vehicle registrations and transport capacities differ approx. by 25%, presumably reflecting a more service orientated Swiss economy. The most striking difference between Austrian and Swiss freight is the total haulage, where Switzerland proves to be a much weaker transit country compared to the Austrian corridors. As both countries are located in the Alps, a similar topography can be assumed without further analysis. Therefore, it deems legitimate to apply the Swiss study results to Austrian requirements and basic data.

In contrast to that, the Finnish transport industry shows a much more differentiated picture. Both total haulage and domestic transport volumes in Austria are higher but reflecting the transit nature of Austria in the much higher domestic transport volumes compared to the total haulage. In any other category, Finland overtakes the Austrian numbers - partially by far. This illustrates that Austria moves a higher volume of goods at a similar haulage, reflecting the higher mileage in the specific transport segments and representing almost the double tonnage of Austria in distance classes above 300 km. (Eurostat, 2019b)

	Switzerland	%AT	Austria	%AT	Finland
Total transport volume (mn t)	284.6	75.6%	376.4	74.1%	279.0
Domestic transport volumes (mn t)	274.0	78.3%	350.0	78.5%	274.6
Total haulage (bn tkm)	9.9	39.1%	25.3	97.2%	24.6
MDV registrations (number of vehicles)	8,300	71.7%	11,576	536.5%	62,103
MDV freight capacities (3.5 to 12 t, in thousand t)	27	67.5%	40	305.0%	122
HDV registrations (number of vehicles)	33,600	81.9%	41,006	204.1%	83,676
HDV freight capacities (12+ t, in thousand t)	413	87.3%	473	236.6%	1,119

Table 4: Comparison of 2016 key freight data in MDV and HDV segments in Switzerland, Finland and Austria; Source: own calculation, based on Eurostat (2019b)

Liimatainen et.al. (2019, pp. 807–811) created four scenarios to reflect the potential for electrification, depending on the technological developments and on the ultimate goal of full electrification:

Specifications of the electrification scenarios.

Scenario	Current technology	Improved vehicles	Improved vehicles and charging	Towards full electrification
Battery capacity (kWh rigid/articulated)	150/400	250/600	250/600	350/800
Gravimetric density of batteries (Wh/kg)	120	240	240	360
Overnight (8 h) charging power (kW)	50	50	150	150
On-road (2 h) recharging power (kW)	50	150	250	400

Table 5: Specification of electrification scenarios; Source: *Liimatainen et.al.* (2019, p. 807)

The results of these scenarios show a clear differentiation between Switzerland and Finland. Although both countries show an electrification potential of around 50% of their trips, the high share of long-haul, heavy duty truck freights in Finland shows a much weaker sensitivity of the potential towards improvements in technology. Even in a scenario for full electrification (see above), only 81% of trips, 61% of the mileage and 50% of CO² emissions can be reached in Finland, whereas Switzerland lands at 93%, 86% and 82%, respectively. Specifically for MDV, even the scenario for current technology looks rather promising (esp. when compared to the HDV scenario) but shows restrictions for full electrification for Finland particularly in regard to haulage. Interestingly, the sensitivity analysis shows that the model reacts much more positive to increasing use in urban environments than it reacts negatively to hilly environments – a combination which favors the environment in Austria. Finally, the study concluded that the freight of specific commodities which are more likely constrained by volume than by weight are more beneficial for the use of electric trucks. *Liimatainen et.al.* (2019, p. 811) exemplarily mention textiles, glass and other non-metallic products, machinery and equipment or empty containers and packaging in combination of being transported by MDV as specifically suitable to be transported by electric powertrains. Anyhow, Finland showed a stronger sensitivity to specific commodities than Switzerland.

Although a direct interference to the Austrian situation would be illegitimate, the results of this study show some indications for the domestic market. Austria is positioned in a similar freight environment as Switzerland. As this study focuses on vehicles registered in Austria only, the amount of transit traffic in both countries does not influence the assessment. Solely the fact that total haulage is much lower in Switzerland compared to Austria could influence the evaluation. But as this high haulage in Austria mainly derives from a higher transport volume, this would bring some negative implications for the potential for electrification, as a higher loading weight would limit battery-electric MDV most.

4.5.1 Special purpose vehicles

In general, the MDV classification also offers potential use cases for special purpose vehicles in forms of fire brigades, construction industry, dustcarts or mobile cranes. But these types of vehicles most likely need additional energy to operate their coachwork (e.g. water pumps, hydraulics, etc.), which would require more battery capacity to supply these consumers, too. (Schiller, Maier, & Büchle, 2016, p. 26) In addition, these vehicles are most likely considered as operating in common interest, which would most probably imply exemptions from emissions restrictions or city bans. Existing regulations like § 42 (3) and (3a) StVO exclude special purpose vehicles from e.g. night or weekend driving bans, so presumably also future restrictions esp. in urban environments will most probably bring specific rules for certain areas of application.

4.6 User acceptance

Although the survey of *Klaunberg et.al.* (2016, p. 210f) might not be representative due to the low response rate and the strong focus on SME, the results regarding user willingness to procure electric vehicles are clear: The majority of the responding Austrian companies (55%) was willing to procure a BEV in future and 3 to 4 out of 10 were in the process of evaluating to implement electric vehicles. Two thirds of the responsible fleet managers considered electric mobility not as a temporary trend. The intrinsic motivation more related from environmental aspects than from cost considerations, however 7 out of 10 companies in Austria agreed governmental subsidies are not mandatory to operate a BEV economically. Unfortunately, only a minority of the respondents would have been willing to pay more to procure a battery-electric vehicle. Considering the purchase price projections in combination with battery price developments and the findings that electric trucks will remain more costly than conventional combustion engine cars, this shows the lack of communication of TCO calculations as well as the cost sensitivity of companies.

The publication “Electric Fleets in Urban Logistics”, published as part of the EU funded ENCLOSE project, shows a rather generic, but clearer picture on the BEV acceptance of European companies and drivers. On the vehicle performance, characteristics like the good acceleration, low sound emissions, the automatic gear box or the speed of the vehicles were underlined. On the contrary, it is the smaller load capacity, the lifespan of the battery or simply a higher truck bed due to the required battery space which was mentioned as downside of BEV. On the very personal working environment perception, drivers praised the comfort to drive the vehicles, their operational reliability or the emission free operation. Unfortunately, still various negative aspects like technical errors, heating problems, lack of

drivers' knowledge and training or spare parts and repairs prevail. (AustriaTech – Gesellschaft des Bundes für technologische Maßnahmen GmbH, 2014, pp. 20–21)

The research by *Quak et.al.* (2016, p. 1513) completes this picture by interviewing logistic operators during the FREVUE study. Their major concerns were the business needs, high CAPEX, available infrastructure and the limited number of vehicles on the market. The vehicles tried out within the FREVUE study convinced several operators to invest more into BEV, showing a strong need to prove the practicability of electric trucks in reality.

Unsurprisingly, it's mainly the business case which is being considered by freight operators who are confronted with the question which vehicle type to procure.

4.7 Deduction to a Total Addressable Market

To now deduct the previous chapters to the TAM for battery-electric MDV, some assumptions need to be taken into account. The first assumption is the actual scope of the analysis. As currently no electric MDV is registered in Austria, the assessment needs to be future orientated. Considering the scope of both the European policy programs as well as the #mission2030, a full decarbonization of the entire transport sector is foreseen no later than 2050. Therefore, the evaluation of the future potential will be orientated within that timeframe.

Secondly, the electrification until 2050 includes a pathway of registering new vehicles with electric powertrain. If the entire fleet needs to be electric until 2050, the average lifespan of an MDV needs to be considered to calculate the year in which the last MDV based on a combustion engine needs to be registered. Austria does not offer official tables for the depreciation of fixed assets but allows actual values for usage to determine the depreciation; alternatively, the Austrian ministry permits the use of German list for that purpose.

(Bundesministerium für Finanzen, 2019) According to German legislation, trucks can be written off over nine years. (Bundesministerium der Finanzen, 2000) Therefore, the last MDV with combustion engine needs to be registered around 2040 in order to reach the target of full electrification until 2050.⁸ As chapter 2.1.1 showed, first CO₂ limits for specific kinds of MDV will be executed in 2025, which might indicate the first year of actual mass demand for electrified N2 vehicles.

⁸ Although the actual usage of vehicles by the actual holder might be longer, the assumption shall be that vehicles written off will be replaced by electrical ones due to economic reasons.

Unfortunately, there are no reliable projections for the future implications of freight behavior developments on vehicle registrations and vehicle class distributions available in Austria. Therefore, another assumption needs to be made on the development of vehicle registrations depending on the economic development and interlinked with the freight volumes and distances. As history showed, the actual stock of registered commercial vehicles almost constantly declined by 3% from 2012 to 2018, resulting in 10,899 vehicles registered end of 2018 and potentially indicating that N2 vehicles are on a downturn in general. (Statistik Austria, 2019a) These figures are further surprising considering the constant positive growth of Austria's GDP over this period (Statistik Austria, 2019b), usually leading to stronger freight activities and increasing stocks of freight vehicles registered.

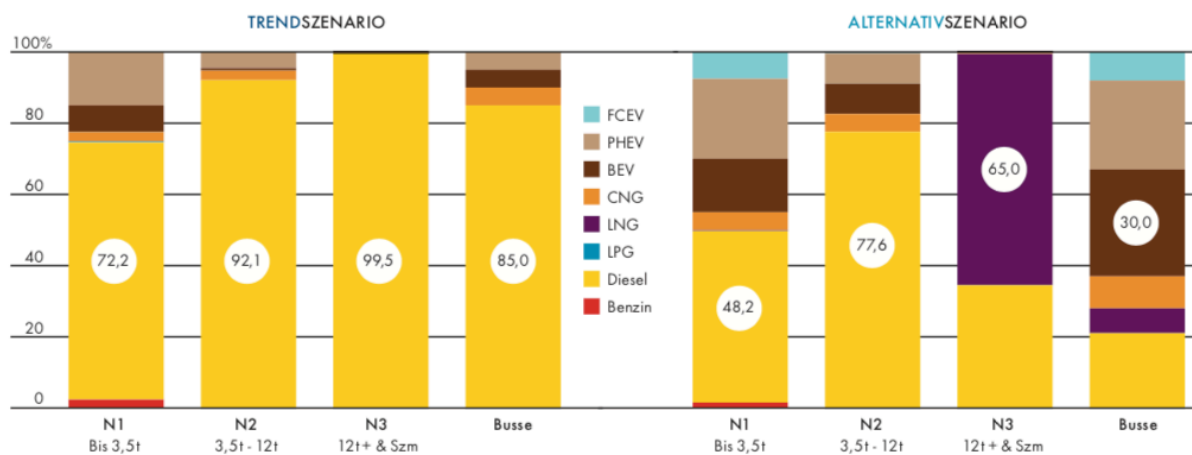
This constant downturn of N2 vehicles hasn't been explained by literature yet. Anyhow, this constant decline in registration numbers leads to the hypothesis that N2 will continue declining in the upcoming years, which can't be proven. In an expert interview, Mag. Franz Weinberger, Chairman of the Commercial Vehicle Committee in the Federation of Austrian Industries, concluded the following:

“Every commercial vehicle is being configured according to its very specific deployment area. In Austria, the MDV segment is mainly used for very specific use cases like retail distribution services, municipal vehicles or fire brigades. In general, the customers do not actively take his or her invest decisions orientated alongside vehicle classifications, but rather orientates the procurement decision based on the actual payload available and the routing requirements. The development of MDV registration has been stable over the last years and currently we see no economical or regulatory indicators which could change that trend. Regarding electrification, I do see no sustainable market impulse for the MDV segment. Only the transition period could bring a higher demand for electrified commercial vehicles, but apart from that, we expect vehicles only be exchanged out of replacement investments.” (Weinberger, 2019)

These assumptions lead to the result that a mass electrification of MDV will most likely take place between 2025 and 2050, leaving only 15 years for a full electrification of N2 powertrains. For the sake of this analysis, namely the demand assessment of charging infrastructure, a linear projection of electric MDV sold in the period 2025 to 2040 might be the best available estimate. Therefore, 500 to 700 newly registered N2 vehicles with electric powertrain could be expected yearly until reaching full electrification. As this figure ignores any other technologies like plug-in hybrids, gas-powered powertrains or hydrogen vehicles, these new registrations can be seen as the absolute maximum of electric vehicles being

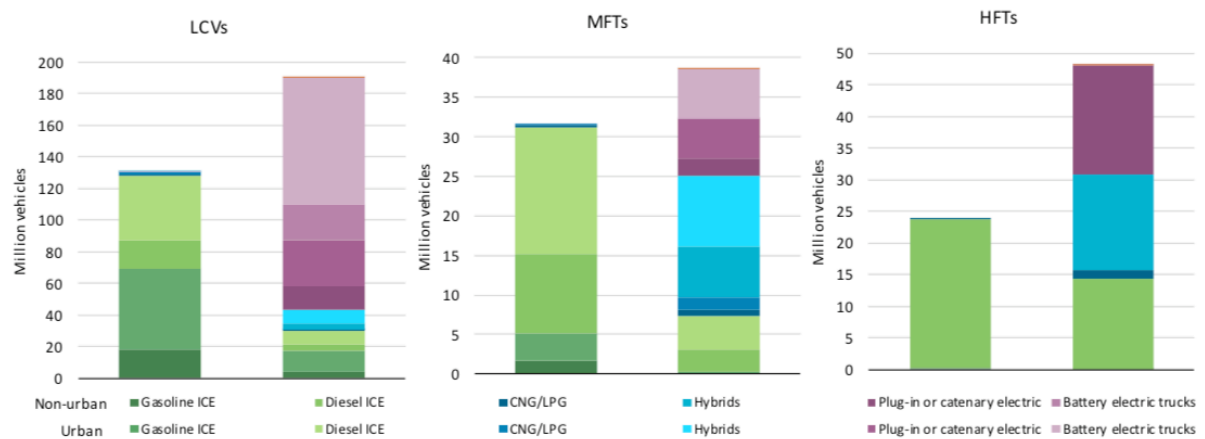
registered, probably reflecting a future scenario where policy changes require a more radical change to zero emission vehicles.

Shell (Adolf et al., 2016, p. 63f) conducted a two-scenario study on trends in commercial vehicle development, showing a more pessimistic picture for electrification of vehicles on the German market. Whereas the trend scenario rests upon existing developments, the alternative scenario reflects a stronger uptake of alternative powertrains and fuels. The result for MDV shows a more pessimistic outcome: More than 92% of N2 vehicles in the trend scenario will be based on diesel engines in 2040. PHEV will represent 5% of new vehicles, whereas BEV constitute a negligible minority. In the alternative scenario, in contrast, show a stronger picture of vehicles with electric powertrains (BEV and PHEV), jointly representing 17% of new registrations. Anyhow, the analysis of Shell shows a more pessimistic outlook for the electrification of N2 vehicles.



Caption 10: New vehicle registrations by powertrain 2040: Trend and alternative scenario; Source: Adolf et al. (2016, p. 63)

In contrast to that, a comprehensive study undertaken by the OECD together with IEA came to a much more optimistic result for the electrification potential in European commercial vehicles. In their optimistic Modern Truck scenario, by 2050, 40% of MDV are assumed to be operated by hybrid powertrains and 35% of N2 vehicles are based on plug-in or catenary enabled electric vehicle platforms. (OECD/IEA, 2017, pp. 123–124)



Caption 11: Vehicle stocks and fleet technology shares in the Modern Truck Scenario, 2015-50; Source: OECD/IEA (2017, p. 123)

Combining the outcome of this study with the assumption that the new registrations and the overall stock of MDV remains stable throughout the years until 2040, the share of electric MDV in new registrations will be around three vehicles per year. This leads to the conclusion that only a tremendous change in policies and customer perception will lead to a more rapid adoption of BEV in the N2 category. If this rethinking won't come, electric MDV will remain even a stronger niche product than its pedant with combustion engine.

4.8 Conclusions

Due to the lacking historical data and the missing detailed statistics on MDV driving and freight behavior, a comprehensive derivation of a market segmentation for electric MDV in Austria is rather vague and needs to be based on a number of assumptions and analogies. Anyhow, existing data on freight behavior shows relatively short trip distances of inland freight. An overwhelmingly high number of trips (almost 50%) are operated in a range of up to 20km, while in total 88% of the inland trips in Austria are operated at less than 80km. Considering the stated values in chapter 3.1, range anxiety can't be the reason for not choosing an electric MDV. In general, an average transportation distance of 45 km and an average transport volume of 11.9 t per shipment are not only ideal for MDV capacities in general but would ideally fit into the range and loading capacity of battery-electric MDV. With this data in mind, one might wonder why the N2 classification is this strongly underrepresented in Austria. One answer could be the loading volume, which might be exceeded with lighter goods even before the MPW is reached.

The analysis of transported commodities shows a clear majority of heavy weight goods in the category Mining and Quarrying, which would potentially exceed the loading capacities of battery-electric vehicles. Anyhow, these heavy goods are characterized by relatively short

freight distances which could be a turning point for electrified vehicles in operation. The segment Glass and other Minerals offers similar possibilities, as these cargoes usually weigh less. Even more promising perspectives offer the categories Wood and Food Products, as these freight activities are usually executed around urban nodes, potentially offering the infrastructure required for BEV.

The clustering of urban nodes and centers in Austria identified several agglomerations suitable for electric logistics. As numerous studies and projections showed that battery-electric MDV at current and near-future technology levels fit best into urban environments, these urban zones with their catchment areas offer the right demand in logistic services while being centralized enough to stay within the range of BEV. Urban centers are predestined for special purpose electric vehicles such as waste collection, road sweepers or fire brigades. Unfortunately, present battery technology is not capable yet to offer both the necessary range for the vehicles and sufficient power for the special purpose equipment like water pumps or hydraulic devices. Therefore, use cases in this segment are very rare and concentrate more on HDV which offer higher battery capacities.

Surprisingly, user acceptance both of companies and drivers seems to be a rather secondary obstacle for the electrification of MDV. People appear to be fascinated by modern technology and environmental aspects add some urge in changing the existing combustion engine powertrains. Anyhow, technological vulnerability needs to be resolved and the reliability of battery-electric MDV at all life situations and weather conditions needs to be safeguarded to leverage BEV in logistics.

Finally, the very limited stock of MDV and the negative trend in new registrations in this category can be reducible to a limited demand for vehicles in this freight category. The pace of electrification of medium-duty commercial trucks can hardly be predicted, as several scenarios could be calculated depending on criteria like regulatory environment, oil price development, vehicle and battery price trends or user acceptance. Taking into account both the most radical (linear uptake of battery-electric MDV until full electrification in 2040) and rather conservative outlooks (BEV strongly competing against alternative powertrains), the potential for new registrations of electric N2 vehicles range from a dozen to several hundred vehicles per year. Anyhow, the deployment of charging infrastructure will need to follow actual trends instead of installing chargers heavily in advance.

5 Competitive technology

The previous analysis of the market potential to electrify MDV showed that a fast, disruptive emerge of BEV in medium duty commercial appliances is rather unlikely. The scenarios analyzed showed rather a long path towards a decarbonization of transport services, shaped by a coexistence of combustion engine cars besides emerging low to zero carbon solutions like biofuels, natural gas (CNG), LPG and hydrogen.

5.1 Current and predicted fossil fuel demand

In general, 1,67 mn t of gasoline and 6.95 mn t of diesel had been used for energetic reasons in Austria in the year 2017. This constitutes a reduction in gasoline consumption of 1.2% and an increase of consumed diesel fuels by 2.9% compared to 2016 values.

(Bundesministerium für Wissenschaft, Forschung und Wirtschaft, 2018) This shows a strong dominance of diesel-powered mobility in Austria, which on the one hand side might be attributed to the strong representation of diesel vehicles in commercial road transport; on the other side, the tax privilege on diesel fuels mentioned in chapter 2.2.4 can be seen as the dominant reason for the strong diesel consumption in Austria.

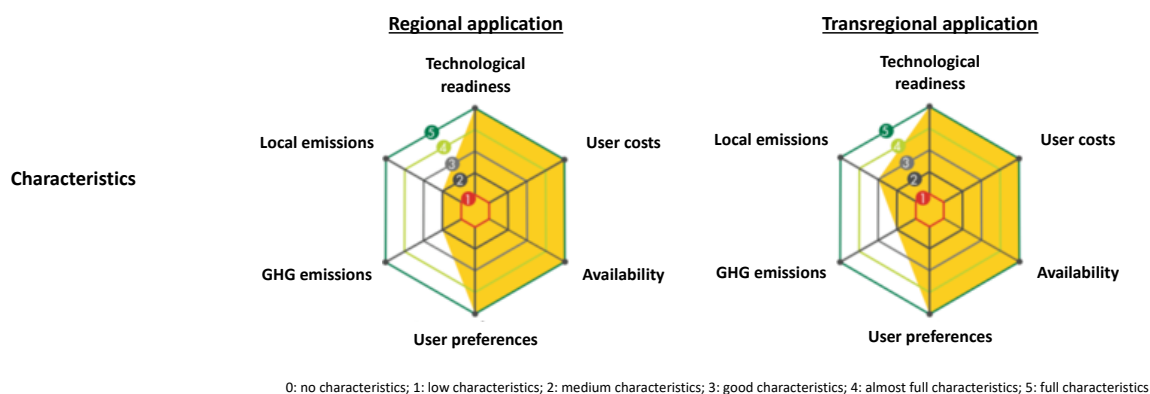
For the future perspective of diesel and gasoline market share in the energetic end use, the energy scenario for Austria by *Baumann et.al.* (2016, pp. 37–40) shows a remarkable reduction of total energy demand in transport until 2030. While the transport sector had been the dominating energy consumer in the 2012 baseline, it shows a total reduction in consumption by 1.9% annually, resulting in 22% of the overall energy consumption until the end of the scenario. The transport sector will even overtake the industrial consumption in 2030, which will consume 46% of end energy use. Anyhow, diesel and gasoline will remain the dominant energy source even in 2030, resulting in a share of 60% of total consumption. On a sectoral view, road transport will contribute most to the reduction in energy use by declining by 2.7% annually, whereas the sectors aviation, rail and shipping will annually increase by 1.9 to 2.3% on average. In road transport specifically, a remarkable technological shift of technologies can be observed in this scenario. The share of gasoline will decrease from 23% in 2012 to 11.5% in 2030, whereas electricity in transport will grow to almost 10% until 2030. Anyhow, these relative figures remain rather humble compared to the absolute share of diesel. In 2030, diesel consumption will constitute almost 77% of total energy consumption in road transport.

In contrast to the Austrian predictions on the total energy consumption, *Adolf et.al.* (2016, pp. 70–71) see a slight increase to 853 PJ in road freight energy consumption specifically for commercial vehicles until 2030 before consumption decreases again due to efficiency gains

until 2040. In the conservative Trend Scenario, the study sees a marginal decrease in diesel consumption from 99.7% in 2014 to 99.1% in 2040, claiming that diesel will remain by far the dominant energy source in road transport. On the other hand, the more progressive Alternative Scenario shows a constant reduction in energy demand by 13%, resulting from almost a halving of diesel demand compared to 2014 (58% of total demand), being compensated by CNG and LNG covering another 41% of the demand. In that scenario, electricity and hydrogen demand together will amount to only 8 PJ or 1.2% of the energy demand. This reflects not only the modest uptake of electric powertrains in freight industry, but also shows the higher efficiency of existing powertrains.

In order to provide an overview on the advantages and disadvantages of the respective competition technologies as alternative to electrification, the following summaries will outline the current market implications and key characteristics of the specific applications:

Diesel powertrain	
Market penetration	Predominant technology for all commercial vehicles, broadly available
Application	All commercial vehicles (trucks, busses, other vehicles)
Efficiency potential until 2040	Engine/powertrain: 7-14%; hybridization: 5-20%; waste heat utilization: 5%
Costs	Low for powertrain due to technological readiness and high quantity; diesel price depending on oil prices and tax regimes



Caption 12: Status and characteristics of diesel powertrain; Source: own illustration based on Adolf et al. (2016, p. 41)

This illustration of the diesel powertrain shows that although the diesel engine can be considered as a mature technology, there is still remarkable potential to improve the efficiency by applying engine or powertrain upgrades or by introducing hybridization or waste heat usage. Due to the cost benefit, diesel engines will remain a strong competitor for alternative technologies in the upcoming years. (Adolf et al., 2016, pp. 34–41)

5.2 Alternative technologies

After having concluded that diesel might play a significant role even in the distant future until 2040 and beyond, alternative technologies shall be evaluated.

5.2.1 Biofuels

The expression biofuel is being used as some sort of umbrella term for the usage of bio based liquid fuels in mobility. The IEA classifies biofuels as “liquid and gaseous fuels produced from biomass – organic matter derived from plants or animals” (International Energy Agency, 2011, p. 8). Furthermore, the literature distinguishes between conventional and advanced biofuels. The former include ethanol based on sugar and starch or conventional biodiesel based on raw vegetable oils extracted from soybean, canola, palm oil or sunflower, as well as fuels based on animal fats and used cooking oil (also referred to as FAME). The latter consist of cellulosic ethanol (a product of sugar fermentation) or advanced biodiesel, which can be further differentiated between hydrotreated vegetable oil (HVO) and Biomass-to-liquids (BtL). (International Energy Agency, 2011, pp. 13–14)

According to national law (KVO) which derives from European legislation (FQD, RED), a specific proportion of biofuels needs to be co-blended to fossil based diesel and gasoline. Whereas the most common form of biofuel usage is the co-blending of specific amounts to fossil fuel products like diesel or gasoline, the product itself might be also applicable for a pure, 100% biofuel application. In 2017, 435,138 t of biodiesel and 23,838 t of HVO were co-blended to Austrian fossil fuel based diesel, whereas 31,052 t of biodiesel and 56 t of HVO were sold in a pure form. On the gasoline side, 80,352 t of sustainable bio ethanol were co-blended into fuels in Austria in 2017. In total, the overall co-blending quota reached 6.1% and therefore overachieved the legal target of 5.75%. (Bundesministerium für Nachhaltigkeit und Tourismus, 2018, pp. 5–6)

From an environmental perspective, biofuels could be a direct competition to BEV, as their application are allowable to reduce GHG emissions according to EU regulations. Anyhow, co-blended or purely used biofuels are still used in an internal combustion engine and produce local emissions. From several other perspectives mentioned in chapter 2, biofuels won't offer any advantages towards conventional fossil fuels.

5.2.2 Natural gas

Currently two forms of natural gas in transport do exist: gas in compressed (CNG) or liquified (LNG) form. Whereas CNG consist mainly of methane (CH₄) and is being filled into vehicles in a compressed state, LNG as a liquid fuel offers a far higher energy density. LNG is being produced by cooling down natural gas below -162 °C, where the gas has only a six-

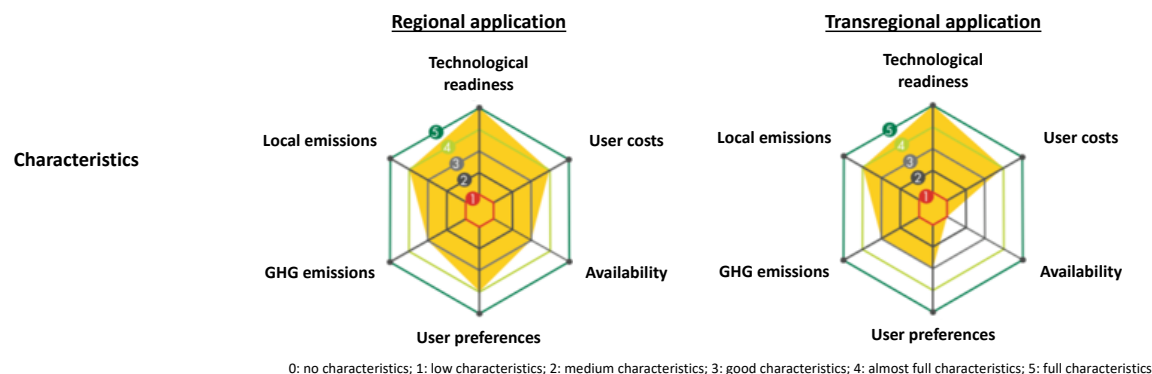
hundredth of its original volume without being under pressure. Tanks for vehicles are designed to keep the extremely low temperature without additional cooling required. Due to the high energy density, ranges of around 1,000 km can be offered in LNG trucks.

In Austria, altogether 157 public CNG filling stations do exist, a figure which does not include additional filling stations in private hand or located at company grounds. (Fachverband Gas Wärme, 2019b) The number of LNG filling stations is much lower, offering only a first test site in the Enns harbor in Upper Austria since September 2017. In addition, biogas can contribute an additional aspect to CNG or LNG, as it might be produced from biogas plants or even from so-called power-to-gas stations which convert (preferably) renewable electricity in an electrolysis process into hydrogen and in a next step into biogas. Even for this technology, first test sites have been erected in Austria.

In contrast to CNG or LNG, liquified petroleum gas (LPG) is not being produced from natural gas but is being extracted from a byproduct of the refining process in fuels refineries. In contrast to natural gas, LPG offers some disadvantages in handling (as it is heavier than air, the entry into underground carparks is prohibited) and does not allow the co-blending of bio components. History showed some applications in public bus fleets in Austria, but LPG always remained a niche product. (Fachverband Gas Wärme, 2019a)

As natural gas features a lower carbon fraction, it offers a lower GHG emissions than diesel or gasoline. Unfortunately, the degree of efficiency of natural gas powered combustion engines is also lower and especially for LNG, more energy is needed to produce, liquify and transport the gas. But if efficiency of the engines could be increased and if sufficient filling stations can be built, LNG offers a promising alternative to diesel and gasoline and constitutes a serious competitor for electrified powertrains. Especially the dual-fuel technology where natural gas can be used in diesel engines under co-blending of minor quantities of diesel seem to be very promising to increase the engine efficiency. (Adolf et al., 2016, pp. 43–47) Anyhow, OEM might be reluctant to invest into another technology to be further developed, and energy companies might be cautious if the high investments to build up the required infrastructure would pay off.

Natural gas powertrain	
Market penetration	Niche product, limited vehicle availability; CNG nationwide available, LNG not
Application	On fixed routes, mainly light-duty vehicles, busses or distribution traffic; LNG with potential in transit
Efficiency potential until 2040	Engine optimization; introduction of dual-fuel for heavy duty trucks
Costs	Higher for powertrain due limited quantity; lower costs for gas (mainly due to tax regime)



Caption 13: Status and characteristics of natural gas powertrain; source: own illustration based on Adolf et al. (2016, p. 46)

5.2.3 Hydrogen

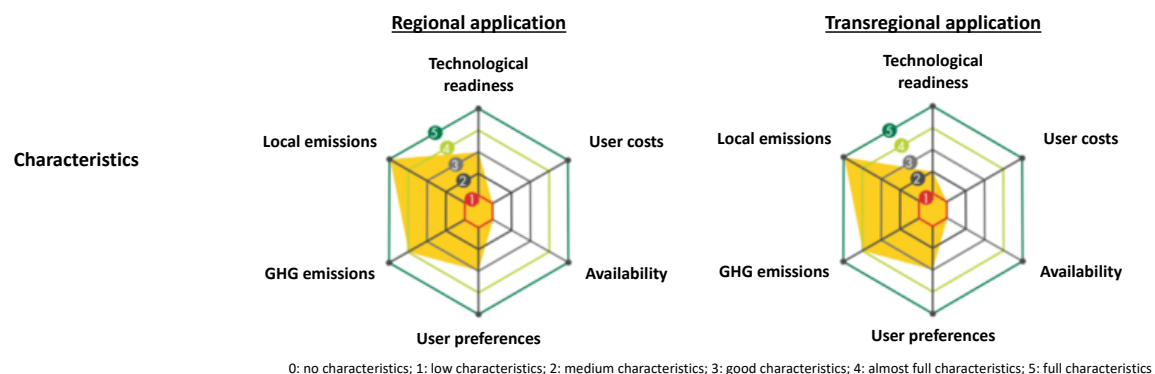
It is a commonly known hypothesis that the future powertrain distribution will distinguish between short- and long-distance driving vehicles and that the former will be covered by BEV while the latter can be achieved with fuel cell vehicles powered by hydrogen. (Kast, Morrison, Gangloff, Vijayagopal, & Marcinkoski, 2017, p. 183)

Analog to what has been discussed in chapter 3.3, the inclusion of a hydrogen powertrain faces similar issues as BEV, as components like the high-pressure hydrogen tanks, the fuel cell and a buffer battery require a specific volume and take a remarkable weight, both important aspects of range and loading capacities for a commercial vehicle. Therefore, *Kast et al.* (2017, pp. 5, 9) designed two tank layouts with 350 and 700 bar respectively to design different scenarios for differing range requirements. They come to the conclusion that HDV offer most possibilities to include the system components into the vehicle and therefore could provide long distance range of up to 1,000 miles (approx. 1,600 km) even at a pressure of 350 bar. Interestingly *Kast et al.* conclude that with increasing battery pack capacity, an even bigger portion of that battery capacity needs to be used to move the increased battery weight. In contrast to that, after the required system component of a fuel cell powertrain has been added, “an increase in vehicle range requires only slightly larger components, which has a relatively small impact on vehicle mass and cost” (Kast et al., 2017, p. 183). This is an interesting thought, but unfortunately neglects the increasing cell and power density of current and future battery packs. As pressure in a fuel cell tank might

reach its physical limits, the future predictions of battery density stated in chapter 3.3 offer promising developments in the next years.

Product offerings for hydrogen trucks are even thinner than for battery-electric MDV. As no hydrogen MDV has been announced yet, a U.S. based company named Nikola Corp. already introduced three versions of hydrogen HDV. The Nikola One offers 500 to 1,000 miles (800 to 1,600 km) of range and a payload capacity of 65,000 lbs (29.5 t). Whereas the Nikola Two offers similar specs with a smaller driver cabin, the Nikola Tre will be specifically designed for the European market and even offers a range of up to 1,200 miles (1,930 km). Anyhow, neither of these trucks has entered mass production and no MDV solution seems to be at hand. (Nikola Corporation, 2019)

Hydrogen powertrain	
Market penetration	Only passenger production vehicles; prototypes for busses; no trucks in Europe
Application	Applicable for all categories; size tanks for hydrogen might limit range or MPW
Efficiency potential until 2040	Efficiency of fuel cell at 60%, therefore room to improve powertrain and to reduce costs of fuel cell
Costs	Significantly higher cost due to costly fuel cell; cost of prototypes not comparable to production vehicles



Caption 14: Status and characteristics of hydrogen powertrain; source: own illustration based on Adolf et al. (2016, p. 53)

5.3 Conclusions

Depending on future developments especially in environmental policies and regulatory guidelines, the limited potential of alternative fuels (esp. biofuels) to reduce GHG emission might get OEM, freight companies and even governments into dire straits. Therefore, a pure reliance on internal combustion engine solutions might not be enough to reach the climate targets. Natural gas can be a promising alternative to diesel or gasoline as CNG and LNG emit up to 30% less GHG compare to conventional powertrains. (Adolf et al., 2016, pp. 45–46) Anyhow, the further expansion of filling station networks would be costly and might end in stranded costs if this kind of powertrain should be leapfrogged by alternative technologies.

And especially for urban city centers, the major field of application for MDV, zero emission zones could even prevent gas powered vehicles from entering these restricted areas.

Hydrogen might be a promising alternative to BEV, as it combines the convenient and fast re-filling logic which users of conventional vehicles are already used to with zero-emission quality of electric powertrains. Yet, vehicles come at tremendously high prices and most vehicle categories aren't even available yet. But if existing constraints like high conversion losses (more than 50% of energy is lost at the production of hydrogen) or infrastructure restrictions can be overcome, hydrogen might pose the biggest threat to BEV in commercial trucks – especially at high distances or in use cases where long charging duration might not be applicable. (Diermann, 2017)

6 Charging infrastructure

After having analyzed the demand side for charging solutions, the following chapter will analyze current and future technologies in charging infrastructure solutions to assess the applicability, infrastructure costs, energy demand and localization of the chargers. As already found out in previous chapters, the implementation of BEV for N2 applications highly depends on the available infrastructure to charge the vehicles, as current restrictions in battery and range can mostly be compensated through sophisticated application of chargers. Additionally, the existence of a comprehensive charging infrastructure also supports the psychological aspect of electric mobility, as range anxiety is also present amongst commercial drivers (see chapter 4.6 for details on user acceptance).

6.1 Charging technologies

In order to distinguish between the respective charging technologies and their fields of application, it might be indicated to further elaborate on the actual usage in operations first. While the prevalent solutions are based on charging the vehicle while parked or at least at stop (stationary), other, more recent technological developments focus more on transferring energy to the vehicle while moving (dynamic). To further differentiate between static and dynamic appliances in detail, the following analysis will differ between charging with direct contact between the charger and the vehicle (plug-in and conductive) and technologies where no direct physical connection is needed (inductive). (Bi et al., 2019, p. 54)

6.1.1 Stationary

6.1.1.1 *Conductive*

Conductive charging technology is being defined as a physical, wire-bound connection between the charging hardware and the vehicle. The technology is being classified by power

levels on the one hand side and the positioning of the charging unit (on-board or off-board). Regarding the charging power, AC level 1 delivers a maximum of 1.92 kW, whereas AC level 2 delivers up to 19.2 kW and DC level 3 a capacity of more than 19.2 kW. Level 1 and 2 AC chargers usually have the charger on-board of the BEV, high-power DC charging frequently have their charger off-board, which means that the inverter is being placed outside of the vehicle within the actual hardware of the charging station. (A. Khaligh & S. Dusmez, 2012, pp. 3475–3476) Hence, AC charging capacities are being reached by on-board vehicle chargers, whereas DC charging is mostly conducted by inverters outside the vehicle's system.

For future developments, *Meintz et al.* (2017, pp. 217–218) assume a constant advancement of charging capacity beyond 400 kW with a voltage of 800 to 1,000 V. As this might be a remarkable increase for passenger cars, for commercial vehicles (esp. in bus fleets) this constitutes only a modest increase in both capacity and voltage.

Although chapter 6.1.1.2 identifies plug-in conductive charging solutions as the current state of the art technology for mainstream vehicles, several start-ups and established companies carry out research on alternative interfaces to combine the high capacities and low losses of conductive charging with the convenience of automated connection between infrastructure and the vehicle. Matrix Charging by Easelink GmbH, just to mention one innovative example, offers a fully automated conductive charging technology. The start-up based in Graz/Austria installs a dedicated connector to the vehicle's underfloor, which can be also retrofitted to existing passenger cars. This connector communicates with the charging pad mounted to the ground to identify the vehicle and to start the charging process. When successfully identified, the connector initiates a vertical, unidirectional movement down to the charging pad to connect the vehicle with the charger. According to the manufacturer, this system is capable to deliver up to 22 kW AC and high-power DC (with no further specification) capacities at the convenience that the connector automatically finds its way to the charging pad. (Easelink GmbH, 2019)

6.1.1.2 Plug-in

As a sub-technology of conductive chargers, plug-in technology foresees a direct wired contact between the charger and the vehicle by standardized plugs. Naturally, plug-in systems do only exist in static application forms.

The major challenge for the plug-in technology is to find a common standard for the plug format. Although the CCS standards (an enhanced version of the previous Type 2 standard)

seems to be set in Europe, other standards like ChaDeMo, predominant at Japanese OEM, and the Chinese GB/T system do offer a remarkable competition for the European approach. Tesla as one of the leading manufacturers for M1 vehicles offers an own standard for its Superchargers, allowing only Tesla vehicles to charge with that plug type. (Steitz, 2018)

The initiative “CharIN”, backed by prestigious European OEM like BMW, Volkswagen or Daimler, strongly lobbies for CCS to become the leading standard plug-in charging technology. (CharIN e.V., 2018) While initially focusing on passenger cars, the initiative recently broadened its focus and now also supports the CCS plugs for MDV and HDV applications. Unsurprisingly, manufacturers from the U.S. and Asia expressed their doubts about this development. The outcome of this fight for the plug standards strongly depends on the industry acceptance as well as the standardization endeavors to find joint communication protocols and to involve all stakeholders. (Hurt, 2018)

6.1.1.3 Pantograph

Whereas pantograph (also known as catenary) solutions, i.e. current collectors which attach to a power source to draw energy, are mainly known in a dynamic way in existing rail, tramway or even trolleybus solutions, its static appliance is seldomly seen on European streets. In contrast to the dynamic solutions mentioned in chapter 6.1.2, the static appliance of pantographs mainly serves technical and practical reasons. On the one hand, compared to a conductive cable-based solution, an overhead pantograph can deliver a higher electrical capacity. On the other hand, the manual inserting of conductive plugs might be sometimes perceived as annoying and inefficient. (Zhao, Wang, Fulton, Jaller, & Burke, 2018, p. 16)

ABB, one of the leading providers for charging infrastructure in Europe, introduced its electric bus charging system named TOSA where catenary charging solutions are being deployed alongside the bus routes to charge en route at dedicated bus stops. The company introduced a field study in Geneva where the bus line 23 connecting the airport with rural Geneva was equipped with electric busses and catenary chargers with a capacity of 600 kW at 13 of the total 50 bus stops. (ABB Power Grids, 2019)

6.1.1.4 Wireless

Whereas any conductive charging solution requires a physical connection, inductive or wireless appliances can supply power without the need of any direct connection to the vehicle. In the general principle, power from the grid is being converted into high frequency AC by using AC/DC and DC/AC converters. The actual power transmission is happening between a transmitting coil usually mounted on or in the ground and a receiving coil

attached to the vehicle. As soon as the energy in form of high frequency AC has been transmitted, it is being converted to a more stable DC supply, which the onboard power management of the BEV is being able to operate with. (Panchal, Stegen, & Lu, 2018, p. 923)

Following the nature of wireless technology, the two systems (transmitting and receiving units) are separated by an air gap. The possible distance between the two system components is depending on the setup of the charging unit itself and the conditions of its surrounding, e.g. the thickness of the pavement or other factors. Generally speaking, the air gap between the two units is usually smaller than 0.4 m. To control and manage the energy flow, the wireless charging system usually operates on a communication link between the ground and the vehicle assembly to exchange information about the charging procedure, e.g. state of charge, power level, misalignment and ground clearance. Even more important, the method to pay for the charge needs to be communicated to the respective parties. (Machura & Li, 2019, pp. 211, 220)

In more specific, basically four different manifestations of wireless charging solutions are available: conventional inductive power transfer (IPT), capacitive wireless power transfer (CWPT), magnetic gear wireless power transfer (MGWPT) and resonant inductive power transfer (RIPT). *Panchal et.al. (2018)* illustrated the specifics and characteristics of these technologies in a comprehensive table:

WPT methods	Performance			Price	Size/ Volume	Complexity of design	Power Level	Suitability for WEVCS
	Efficiency	EMI	Frequency range (kHz)					
Inductive	Medium/High	Medium	10-50	Medium/High	Medium	Medium	Medium/High	High
Capacitive	Low/Medium	Medium	100-600	Low	Low	Medium	Low	Low/Medium
Permanent magnet	Low/Medium	High	0.05-0.500	High	High	High	Medium/Low	Low/Medium
Resonant inductive	Medium/High	Low	10-150	Medium/High	Medium	Medium	Medium/Low	High

Caption 15: Overview of different methods of Wireless Power Transfer for EVs; Source: Panchal et.al. (2018, p. 923)

Due to the larger air gap requirements and the high power levels required, capacitive wireless power transfer (CWPT) hasn't found a broad field of application in EV charging yet. Magnetic gear WPT (MGWPT) offers a different technology by applying two synchronized permanent magnets positioned side-by-side. When those gears are rotating, the primary magnet acts as a generator, whereas the second gear receives the power and delivers it further to the EV's battery. While still facing tremendous challenges in dynamic appliances due to synchronization issues, static application fields could be commercialized soon. Whereas the two aforementioned technologies are still in research phase, inductive power transfer (IPT) can be seen as current state of the art technology for wireless power

transmission. By further developing the traditional inductive technology, the resonant inductive power transfer (RIPT) uses compensation networks being added to both the primary and secondary windings in order to increase efficiency. (Panchal et al., 2018, pp. 923–926)

A major downside of wireless charging solutions for EV are the technical limitations in regard to charging power levels as well as in efficiency of the system. The Korean Institute of Advanced Technology (KAIST), one of the leading institutes for research on wireless charging, achieved a maximum efficiency of 91% at a charging power of 9.5 kW. At the maximum power of 22 kW, the efficiency was reduced significantly to only 71%, resulting in remarkable losses. In contrast to that, the Oak Ridge National Laboratory (ORNL) based in Tennessee/USA fitted a wireless charging system into a Toyota RAV4 and reached an efficiency of 95% at 20 kW. (Machura & Li, 2019)

Besides efficiency issues, wireless charging also offers constraints regarding health and safety, the high CAPEX, infrastructure development and maintenance of existing systems. In questions of health, there are mainly doubts about the electrical shocks deriving from malfunctions, the magnetic influence on human bodies and animals as well as the potential fire hazards from defective units which make additional safety precautions mandatory. Especially the fact that the transmitting units are being installed on the ground of parking lots or houses requires additional safety regulations and standards. People with health monitoring devices or pacemakers might suffer some severe health issues if they are near the charging pads or even inside the car while being charged wirelessly. (Panchal et al., 2018, pp. 928–930)

6.1.1.5 Battery swapping

As *Zhang et.al.* (2018) rightfully state, battery swapping systems bring some promising advantages compared to conventional charging stations. First and foremost, the swapping of batteries within minutes allow a much quicker processing of vehicles compared to conductive or inductive solutions. Furthermore, the presumably slower charging of batteries within a swapping system leads to a longer battery lifetime. And finally, the centralized charging systems supports grid operators to better balance the supply and demand curve over time, as a bundled solution can be tracked much easier than dislocated charging stations. If applying bi-directional charging (see chapter 6.1.3), such a swapping station could additionally function as a large buffer storage for the grid, potentially support volatile renewable energy sources feeding to the electricity grid. Unfortunately, the model developed

by *Zhang et.al.* (2018) solely focuses on taxi and bus operations, again constituting a different application compared to commercial freight vehicles in the classes N1 to N3.

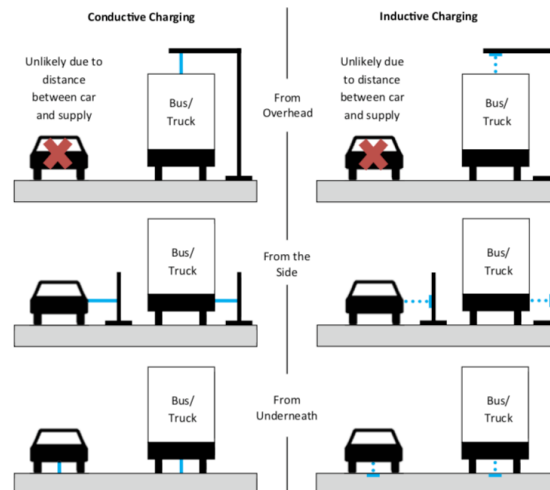
One very distinctive factor for the deployment of battery swapping systems is the fact that currently no standard for the implementation of batteries within BEV does exist. This means that the layout and the placement within the vehicle differ depending on the manufacturer, leading to tremendous difficulties in changing these batteries on the go. Furthermore, the exchange of batteries would necessarily lead to batteries in circulation which have a different age and therefore a different maximum capacity remaining. It would be most likely not acceptable for a BEV driver to conduct a battery swap at such a station if he or she would receive a battery with lower capacity and range than anticipated. Especially in commercial vehicle use cases, a different range after swapping the battery due to previous battery degradation wouldn't be acceptable. In a closed user group with active fleet and battery management, such an effect could be controlled. But battery charging stations will most likely be deployed in public space or at least will be accessible publicly, which would leave the received battery capacity to chance. (Chen, Yin, & Song, 2018, pp. 364–365)

6.1.2 Charging-while-driving (CWD)

Although not explicitly mentioned in chapter 4.6 as one of the major impediments for user acceptance of BEV in transport, the handling time imposes a central concern of logistic companies. Time is money, and each moving of cables and plugs and even the shortest high-power charging passage takes precious time and costs efficiency. Therefore, the current developments in enabling dynamic charging while driving, commonly described as CWD, constitutes a promising option especially for commercial vehicles. (Chen et al., 2018)

To current state of research, CWD can be either achieved by conductive solutions (e.g. overhead contact lines or conductor rails) or by inductive appliances (e.g. magnetic resonant coupling). (Chen et al., 2018, p. 352) While both technologies do show some differences, some aspects are applicable for both. First and foremost, the speed of the vehicle running over the dynamic charging lane is decisive for the capacity being taken from the vehicle. The slower the vehicle passes the charging lane, the more energy can be absorbed and stored in the battery. Furthermore, the higher the frequency of vehicles travelling over these charging lanes, the higher the utilization rate of the system is and therefore the faster the entire investment pays itself off. (Chen et al., 2018, p. 364) And finally, the way how to apply the energy is also decisive for the applicability. While power supply both from the side or from below the vehicle is theoretically appropriate for both passenger cars as well as commercial trucks, any application from above the vehicle (no matter if it's conductive or inductive)

would make sense solely for trucks, as the distance between passenger cars and the lanes optimized for truck heights would be too big for induction and technically too challenging to overcome for conductive pantographs on passenger cars. This is the reason why the majority of recent research projects focus on solutions from below the vehicle in order to broaden the field of applications. (Connolly, 2017, pp. 236–239)



Caption 16: Different concepts currently being investigated to electrify roads; Source: Connolly (2017, p. 238)

Another interesting aspect of CWD technology is the fact that the actual SoC of a vehicle can be hardly changed for a longer distance. While the active charging of a battery could be difficult especially on high-speed sections on motorways or highways due to the higher energy usage and a lower intake due to the shorter time of the vehicle remaining on the charging pad, at least a remarkable reduction of the SoC decrease or even a stabilization of the SoC while driving on those roads could be achieved. This could mean that battery capacities for BEV (especially those travelling longer distances) could be reduced significantly, as energy would only be drawn out of the battery when the vehicles does not run on such CWD lanes. Therefore, the initial cost of BEV as stated above could be reduced and the electrification could be executed more quickly. (Machura & Li, 2019, p. 226)

In comparison to stationary charging solutions, the CWD technology shows a much higher impact on the grid due to the usage of very short high-power charging pulses. Furthermore, a prediction of the charging behavior is much more difficult, as the usage of these charging lanes depend on route choices under multiple factors. Therefore, the prediction of grid impacts – a factor highly important to stabilize the overall grid in times of high demand – is much more difficult compared to static, conventional charging solutions. Due to the in- or on-road appliance of CWD solutions, any battery storage or buffering solutions to reduce the

burden on the grid could be difficult to implement, specifically in urban environments with limited space. Field tests in Greece combined stationary and on-road chargers at capacities of 3.6 or 11 kW and 30 kW respectively. The research showed that dynamic road charging moved the grid peaks from evening events more to morning hours. But the fact that most vehicles used the dynamic charging while stuck in the heavy traffic back home, an unwanted peak of 44% increase in grid demand occurred in the short period between 18:45 and 19:00 in the evening. (Machura & Li, 2019, pp. 225–226)

6.1.2.1 *Conductive charging lanes*

While static pantograph solutions are mainly considered as a more convenient alternative to the conventional plug-in technology at presumably higher capacities, dynamic conductive charging lanes are considered as a completely different concept especially for long-haul distances.

Although this analysis won't enumerate and evaluate the existing research projects on conductive charging lanes as they are numerous and complex enough for a study by itself, one might follow *Connolly et.al.* (2017, pp. 239–240) by highlighting the Elonroad project in Sweden. The strength of this conductive power rail technology from below the vehicle is the circumstance that it can be retrofitted to existing streets and highways on top instead of the need to cut existing asphalt. A narrow strip as transmitting unit connects to the receiving unit mounted below the vehicle with expected power transfer capability of up to 240 kW and efficiency of up to 97%. Elonroad itself states that the costs for the technology can be preliminarily calculated at EUR 0,6 mn/km (Elonroad, 2019) and announced that the company has been awarded to build the first urban electric road for bus appliance in Lund/Sweden with a public funding of SEK 83 mn and a total project budget of SEK 96 mn (Elonroad, 2019).

6.1.2.2 *Inductive charging lanes*

For inductive charging lanes, i.e. wireless charging of vehicles running over dedicated lanes or pads, a similar technology is being used compared to the static solutions described in chapter 6.1.1.4. Differing from static solutions, the two major challenges in applying dynamic induction is the relatively high air gap between the coils and the misalignment of the transmitting and receiving coils, both highly influencing the actual efficiency of the system. In more specific, the application of dynamic inductive charging lanes can be distinguished between centralized and individual power frequency schemes. Whereas in the centralized scheme one large coil of 5 to 10 m is being installed into the road, the individual power frequency scheme foresees several individual charging pads distributed across specified

roads. Technically, a major challenge would be to drive the vehicle exactly above the respective coil to increase efficiency and to maximize the power intake. According to *Panchal et.al.* (2018, p. 931) the appliance of self-driving or autonomous cars can help to increase the accuracy and efficiency of this technology. Anyhow, especially centralized or single-long-coil track structures show a rather low efficiency due to the fact that the entire track needs to be active during operation and because the receiver onboard the vehicle covers only a very small part of the transmitting coil. This efficiency could be improved with segmented solutions but would also require intelligent systems which identify and track vehicles approaching and passing the track. (Sun, Ma, & Tang, 2018)

From a cost perspective, a first estimation can be conducted based on the existing research projects and first field tests. The main cost driver is the length and diameter of the charging coil, which mainly implies the charging power levels available. In contrast to that, a higher power level reduces the number of charging pads required on the roads, as a higher amount of electricity can be delivered to the BEV and therefore a lower penetration in the road network would be required to deliver sufficient energy. *Limb et.al.* (2016, p. 3) assumed that the costs for inductive charging lanes can be separated into roadway retrofitting (50%), inductive charging electronics (40%) and electric grid power delivery infrastructure (10%). With that distribution, they come to a cost estimation of USD 2.4 mn lane⁻¹ mile⁻¹. In contrast to that, *Chen et.al.* (2018, p. 357) based their model on USD 200 per m of charging lane.

Interestingly, *Machura/Lee* (2019, p. 228) come to the conclusion that the reduction of the battery packs due to the en route charging via inductive charging lanes lead to 50 kWh packs instead of 100 kWh. In their example, this results in higher costs for the road charging infrastructure, but in total leads to 20% less costs compared to conventional stationary charging solutions. Surprisingly, this calculation is based on a real driving cycle of buses and requires 18 vehicles and charging pads with a maximum length of 372 m and a charging power level of 80 kW to maintain a SoC above 50%.

A final aspect is the question how to meter and invoice the energy consumed on these dynamic charging lanes and highways. A sophisticated authorization, metering and billing systems would need to be developed in order to pass on the infrastructure and electricity costs to the customers. (Bi et al., 2019, p. 55)

6.1.3 Bidirectional charging and V2G

All the technologies mentioned above do have one principle in common: Electricity is being unilaterally transferred from a power source to the vehicle and its battery. But especially in

the appliance of a single- or double-shift operation of commercial vehicles, the BEV are most likely being parked at the depot during the nighttime. In such a use case, the bidirectional energy flow of vehicles in form of V2G applications could be a promising technology to utilize the EV batteries to buffer load peaks during those times when the vehicles aren't used. Originally designed for conductive chargers, first testing of bidirectional wireless charging shows promising outcomes. For such an application, both the vehicle and the counterpart device on the ground need both transmitting and receiving coils in order to transfer the energy in both ways. Should this technology and the enhanced usage of conductive or inductive bidirectional charging become mainstream, the BEV acting as power banks outside of operating hours could impose both an additional business model for the freight company as well as a promising supplement to the volatile energy production out of renewable energy sources. (Koelch, 2018; Sun et al., 2018, pp. 495–496)

6.2 Cost comparison

Existing cost comparison models between different charging technologies for commercial vehicles focus mainly on urban bus fleets, as these might be the easiest research objects due to their pre-defined routes, their predictable operating hours and their profound data set in practice. Surprisingly, no study analyzed the deployment of static or dynamic pantograph solutions, as these appliances are already existing in Austria since centuries. Anyhow, *Chen et.al.* (2018) so far conducted the most comparable study in analyzing the cost competitiveness of conductive charging infrastructure, charging lanes and battery swapping stations in the use case of electric public transport systems. As MDV follow a similar, predictable driving routine and a comparable inner city route, some analogies could be taken from research on bus charging solutions.

As *Chen et.al.* (2018, pp. 351–353) rightfully state, due to a lack of existing solutions already applied in real-life conditions, no empirical data can be found for the actual operational and maintenance costs. Only capital costs for the entire charging infrastructure as well as for the bus fleet are being considered. Stationary charging facilities are provided at the bus depot, which leads to the assumption that every bus starts into a new day of operation with a fully charged battery. Furthermore, the study assumes 120 kW of electric power for the charging and swapping stations, whereas 80 kW are being assumed for the power lane. In questions of efficiency, the study calculated conservatively with 90% for charging stations and battery swapping and with 85% for charging lanes. This results in overall capital costs which are by far the lowest for the charging station. Surprisingly, the capital costs for the battery swapping stations are only slightly higher, whereas the charging lane shows the largest initial cost of almost USD 800,000. In contrast to this picture, the fleet costs for the charging station

solutions are by far the highest due to higher battery requirements and a larger fleet due to the longer charging duration. Of course charging lanes can minimize the fleet costs, as they solely target to hold the SoC during operation. The swapping technology shows the most balanced way to charge bus fleets in this model. (Chen et al., 2018, pp. 364–365)

Unfortunately, this model relates very specifically to busses, as it shows a direct correlation to the required battery size depending on the charging technology. In the case of an MDV appliance, the public charging infrastructure will be only one part in the overall TCO calculation for the vehicle, as usually commercial vehicles aren't bound to defined routes, but travel demand orientated on different routes. Usually, the investment in public charging infrastructure is not defrayed by the vehicle owner, but by the infrastructure proprietor. Of course infrastructure costs will most probably be reflected in the retail prices to charge the vehicle, but a direct cost correlation would lead to wrong assumptions.

Similar to what has already been said, the variables of service frequency, circulation length, operating hours and operating speed highly influence the sensitivity of this model. Especially with increasing operating speed, the competitive advantage of charging lanes dissipates and increases the cost advantage of swapping stations, which show their biggest advantage at operating speed above 30 mph. Charging stations are showing a positive sensitivity to low service frequency and a relatively short circulation. The study finally projected these results to worldwide bus rapid transit corridors in major cities to assess the most competitive technology for these applications. Only in Amsterdam, Los Angeles and Zaozhuang, three cities with relatively high operating speed (≥ 20 mph) and low service frequency (≤ 23 vehicles/h), battery swapping stations constituted the most competitive charging solution. Whereas no charging station solution was recommended for these cities, charging lane appliances dominated the other 35 cities. Anyhow, the comparison was based on peak operating hours, logically resulting in high service frequency and lower operating speed. As the authors rightfully acknowledge, an overall assessment throughout all operating periods (also off peak) would potentially reduce the enormous competitive advantage of charging lanes. (Chen et al., 2018, pp. 354–364)

Bi et al. (2019) expanded the cost assessment by additional economic factors like life-cycle GHG emissions and energy consumption. Whereas a break-even would be strongly supported by a monetarization of GHG emissions (assumed at USD 250/t of CO₂), the pure cost perspective of dynamic charging lanes would lead to an amortization above 20 years, presumably reaching a break-even as late as after 30 years after construction. Additional applications like road-side solar panels combined with battery storage bring additional CAPEX, but strongly support the GHG and energy reduction in the respective scenario.

Finally, the study backs the hypothesis that high-frequency roadways ($\geq 26,000$ vehicles/day), low speed (≤ 55 mph) and a short remaining service life for existing infrastructure (≤ 3 years) strongly support the application of dynamic charging lanes.

To round this picture up, the study by *Funke et.al.* (2019, pp. 897–898) concluded that an expansion of fast-charging stations is three to seven times lower than investing into higher battery capacity to enhance the BEV range. Although this model is based on passenger cars, similar conclusions can be drawn for commercial vehicles and trucks. Anyhow, the authors need to admit that comfort considerations similar to what has already been said on user expectation weren't considered in the research. So it might lead to a combination of fast-charging infrastructure combined with higher battery capacity not only for payload issues, but to fulfill the user or driver expectations in a commercial vehicle.

6.3 Capacity and energy demand

Strongly depending on the industry developments regarding battery capacity and range of future battery electric MDV as well as the required charging technology and the charging cycles, the capacity of chargers being deployed could range from slow AC chargers for overnight use cases up to HPC ranging to 150 kW and more. It is almost impossible to indicate the right charging levels for each application, as the daily routing and the energy demand for it define the requirements for the charging infrastructure.

The most adequate analysis has been conducted by *Liimatainen et al.* (2019, p. 807) by projecting the improved vehicle capacity to higher charging power required to charge during and after operating shifts. In their current technology scenario, both overnight and on-road charging takes place at 50 kW. The en route charging capacity improves to 150 kW in their improved vehicle scenario, whereas overnight and on-road charging in their improved vehicle and charging scenario end at 150 kW and 250 kW respectively. In their most advanced scenario (towards full electrification), vehicles are charged overnight at 150 kW and en route at 400 kW. Their calculations are based on the assumption of overnight charging of 8 h and on-road charging of 2 h cumulatively, with charging times estimated so that they would allow two 8 h work shifts incl. a 45 min charging break during each shift and a ½ h re-charging between the shifts. Interestingly, they also concluded that a 16–40% share in Finland and a 23–34% share in Switzerland (both countries in focus of their analysis) would be charged on-road, whereas the rest of the charging cycles would be conducted over night. Finally, the study comes to the result that pure overnight charging solutions would not be sufficient any longer as soon as vehicle battery capacities reach 400

to 800 kWh, resulting in a strong need for en route charging opportunities. (Liimatainen et al., 2019, p. 812)

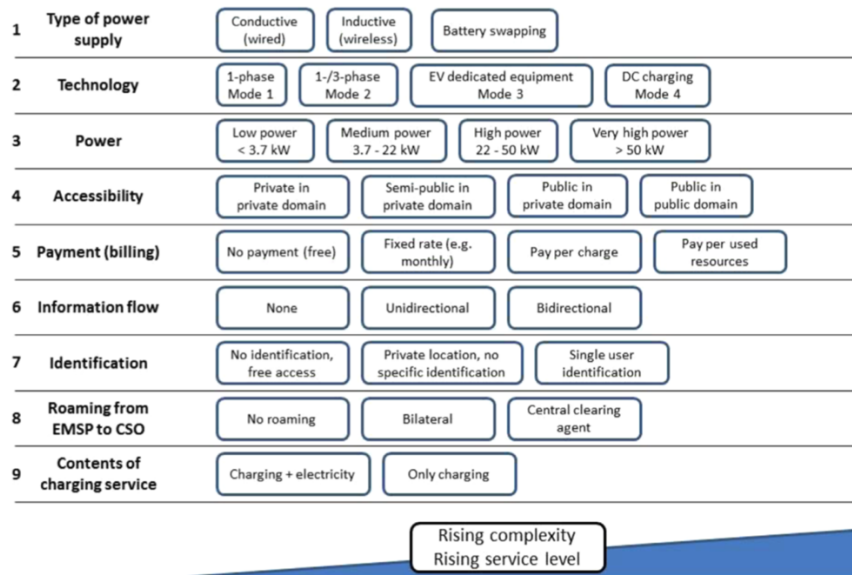
Based on the assumption that battery capacity levels will remain around 200 to 300 kWh in the upcoming years (following the current fleets capacities mentioned in chapter 3.1) and will increase to even higher levels of 400 to 800 kWh following new battery technologies (see chapter 3.3 and the discussion right above), the charging technology needs to stay flexible and scalable to follow the actual trends of battery capacity. For this application, manufacturers like the Italy based company Alpitronic offer modular charging hardware which can easily be upgraded by adding power stacks with a capacity of 75 kW charging power. With such a modular system, charging capacity from 75 kW to 300 kW and beyond and a range of 150 to 1,000 V can be offered while the existing hardware (casing, cables, etc.) doesn't need to change. (Alpitronic GmbH, 2019)

6.4 Location

Following on what has been analyzed in chapters 4.2.3 and 4.4, the primary field of application of MDV lies in urban environments. Therefore, the following location analysis concentrates on charging infrastructure models based on city logistics. Regarding nationwide charging opportunities for long-haul transportations, MDV will be a minor driving force compared to HDV. Therefore, the assumption is that MDV which are being used for long distances will follow the infrastructure intended for HDV, irrespectively if it will be based on stationary or dynamic charging solutions. This is also supported by the fact that conductive plug-in solutions, which are currently the predominant technology, are compatible for both MDV and HDV.

As already analyzed before, the major aim in infrastructure planning will be to find the ideal balance between the size of the battery and the number of charging stations deployed. Less charging stations means lower hardware, construction and grid costs, but leads to a higher battery capacity needed. The costs are therefore transferred from the infrastructure owner to the vehicle proprietor. On the other hand, a high amount of charging opportunities will presumably lead to lower battery capacities (only if user acceptance will allow such a reduction). But taken this into account, lower energy capacity will again lead to charging delays and a downtime of vehicles. Hence, a high-density network with smaller batteries on-board the BEV will urge the fleet operator to acquire additional vehicles to compensate for the standing time and to guarantee the service frequency. (Chen et al., 2018, p. 352)

In order to erect and operate a charging network – either for passenger cars or for electric MDV – the following caption lists the major charging alternatives by categories and evaluates them alongside the complexity and service level required:



Caption 17: Morphological box for the different charging alternatives for EVs; Source: Madina et.al. (2016, p. 286)

Although the scope of this research does neither allow any deeper analysis of these factors and specifically of charging network planning and distribution models, some indications should be analyzed regarding the distribution of charging stations for MDV. While many models are based on urban nodes, intersections, major highways or other criteria, the approach by *Arnhold et.al.* (2018, pp. 6–8) combines socio-economic, mobility, energy-related and spatial data to weigh these factors against each other’s and to assess the overall potential for charging infrastructure. In particular, this analytic hierarchy process (AHP) uses points of interest (e.g. supermarkets, hardware stores, parking spaces, etc.), sociodemographic aspects (e.g. land use category, income, etc.), electrical preconditions (e.g. grid access, but also expansion through demand-orientated planning), the required type of charging infrastructure and the respective traffic flow (e.g. loads, main arteries, etc.) to design and implement a planning tool for infrastructure development. Although the study showed an interesting coverage of charging stations and delivered a very promising model for charger distribution, the basic assumptions show room for improvement. First and foremost, *Arnhold et.al.* (2018, pp. 9–12) assumed that fast-charging stations will deliver at least 22 kW, which is by far too low for commercial vehicles and might be even too low for passenger cars. Secondly, their assumption to locate chargers also underground might be not only limited to passenger cars (due to the height restrictions for trucks) but could be

bound to AC infrastructure only due to regulatory issues in building DC infrastructure in parking garages. And finally, the study did not take into account any detailed grid requirements, which might make a mockery of the entire planning.

To answer the question about the optimum distribution of chargers for commercial freight activities, one must analyze and understand the freight behavior of the respective customers. Without any doubt, companies acting in logistics always aim to optimize their routes to minimize costs and to maximize output in form of goods being transported. Considering the exclusion of MDV transport for long haul freight, the respective groups of goods being transported mentioned in chapter 4.2.2 indicate how the transport routes are being designed and chapter 4.3 showed the distribution of N2 registration within the respective commercial categories. Combining these two factors, one can assume that MDV are mainly used to transport trade goods in urban environments. Hence, the so-called individual single-depot capacitated vehicle routing would apply, as each logistic company operates its own single depot where their MDV start operating and deliver goods to their clients on optimized routes before they return to this depot after having delivered their load. In contrast to that, multiple depots vehicle routing models are based on more than one depot with vehicles operating between these depots on more sophisticated routes. As the reduction of GHG emissions is more and more taking the center stage in logistics (esp. in urban environments), a collaboration in collecting and distributing goods at multiple hubs is getting even more important. (Muñoz-Villamizar, Montoya-Torres, & Faulin, 2017, pp. 41–42) Anyhow, as logistic companies operate in a very competitive environment and lots of trade companies in Austria own their dedicated fleets, an individual single depot model can be assumed at least for the first years of electrification, as the procurement of electric MDV will most likely be executed by large trade companies first. (Council für nachhaltige Logistik, 2019a)

If a company decides to implement charging solutions for its fleet at its depot, the dimensioning of the charging capacity and the number of chargers strongly depend on the turnover rate of goods transported and the utilization of the BEV. It makes a tremendous difference if a company operates its vehicles only at traditional working hours (8:00 to 5:00), or if a shift work model is implemented. In the former case, a low-capacity overnight charging opportunity – presumably even with an AC charger – could be sufficient to re-charge the vehicle within 12 hours. For such a case, Çabukoglu *et.al.* (2018, p. 112) concluded that a 50kW DC charger would be enough capacity for most vehicles. At higher utilization rates of the vehicles, a DC high-power charging will be inevitable to use short loading or unloading breaks to re-charge at the hub. Furthermore, if the battery capacity

should increase to levels mentioned in chapter 3.3, even chargers at 100 kW would be limiting some fleets at some application areas or charging behavior. This leads to the conclusion that in order to build up a sustainable charging infrastructure to serve even future vehicle generations, a capacity of 150 kW at least needs to be installed. (Çabukoglu et al., 2018, p. 116)

As currently neither reliable data nor comprehensive research on the ideal distribution of charging infrastructure for battery electric trucks exist, the EU funded research project megaWATT (Council für nachhaltige Logistik, 2019b) concentrates on the very specific question of how to implement EVs in the daily operations of large retail companies in Austria. Although still in a very early phase, the consortium already came to the first unofficial finding that a 100% charging solution at the logistic hub of a retail company would lead to an additional energy demand in the areas of MWh. The analysis of a dedicated hub of one of Austria's biggest retailers came to the result that the electrification of the 57 trucks in operation would result in 8.5 MW of additional current load, mainly deriving from a simultaneity factor of the assumed 150 kW charging stations re-charging the trucks at the end of the respective shifts. Assuming a consumption of 200 kWh per vehicle per charging session, this would result in an additional energy demand of 11.5 MWh per charging cycle.

Without anticipating the results of the megaWATT research program, the burden on the local electricity grid by electrifying entire logistic fleets and by installing chargers at the company's depot might bring remarkable load peaks and might even require a higher network level and a direct connection of the charging depot to the nearest high-voltage transformer station – both leading to enormous costs for the operator of the charging park. Therefore, an even distribution of the charging infrastructure within urban centers of for those companies which run a network of branches could be a preferable solution to avoid an accumulation of charging processes at one depot.

This so-called opportunity or destination charging can be further divided into path-based and tour based charging, both reflecting the en route charging of vehicles. The path-based distribution model focuses on a placement of public or semi-public chargers alongside major routes aiming to potentially capture a maximum of vehicles passing by. This method can easily be combined with offerings not only for MDV, but also for heavy-duty trucks, vans and even passenger cars. The major challenge in this constellation is to foresee a charging station layout which can service vehicles of all sizes and dimensions. In contrast to that, a tour-based approach for infrastructure planning focuses mainly on roundtrip or random trip constellations of transport companies. Logically, the distribution depending on the actual

vehicle routing requires a deep understanding of the freight behavior and a remarkable amount of data to calculate the positioning. The installation of these chargers could be done semi-public, which could mean that the charging infrastructure could be used not only by the freight company owning them, but also by third parties supplying the respective branch. Unfortunately, such a public service for any commercial vehicle could lead to an unintended blocking of such an infrastructure and unintended waiting time for the own fleet. (Deb, Tammi, Kalita, & Mahanta, 2018)

Besides the positioning of the chargers depending on the operations and the routing of the vehicle, *Deb et.al.* (2018, pp. 12–15) rightfully claim that also the availability of power grids, namely the respective distribution network, is crucial for the chargers installed. Although criteria like voltage stability, reliability and power losses are rather concerns of the grid operator than of the charging infrastructure owner, these aspects could be essential for the mass adoption of BEV followed by charging infrastructure rollout. Because in case of chargers reaching a critical mass for the grid, additional fees or even penalties could put additional burden to the economic viability of the charging business model. Therefore, the ideal approach to place charging infrastructure might be a combination of both logistics and grid aspects by considering the transport and distribution network simultaneously.

6.5 Conclusions

Whereas the vehicle development of electric MDV is still in the early stages of development, charging solutions for commercial vehicles already can draw remarkable experience from passenger car applications. At least in Europe, the conductive solution of charging a vehicle via CCS plugs seem to reach a common standard, which also effects commercial solutions. As infrastructure investors and developers can easily apply existing methods and standards, CCS conductive plugs will constitute the standard for charging MDV in the upcoming years.

Anyhow, important criteria like charging power, charger distribution or allocation and convenience aspects will challenge this technology. In the fields of stationary charging, technologies like catenary overhead chargers, originally deriving from public transport busses, could pose a substantial competition risk for conventional plug-in solutions as they offer higher capacities combined with a more attractive usability.

Although battery swapping stations never made their debut in real life applications for passenger car vehicles, a realization for commercial vehicles could be much more realistic. If the concerns about centralized charging hubs with a remarkable impact on the grid could be overcome, battery swapping could pose a very fast and reliable alternative to

conventional solutions. Anyhow, mutual agreements on different stages of battery age in use and on common standards for vehicle integration need to be found to lead to a minimum of user acceptance.

In case the electrification of the transport sector takes over on a broader scale, a rethinking of the transport behavior and the equipment of batteries could lead to completely new solutions in the field of CWD. If users accept lower battery capacities for low or last mile deliveries, any farther distances could be compensated by dynamic charging solutions. Already as of today, CWD technology in form of conductive or inductive solutions are almost cost competitive to stationary charging considering the lower costs for vehicle batteries. In terms of sole infrastructure costs, of course, costs for CWD still pose a much higher investment and confront the investor with higher regulatory burden compared to conventional solutions. But if users are willing to accept lower battery capacities and therefore benefit from lower vehicle prices, CWD could constitute an interesting alternative for long haul applications. For MDV in urban environments, any dynamic charging might be less attractive.

Regarding the further development of stationary charging solutions, the first wave of installation will most probably concentrate on depot solutions directly at the hub of the respective logistics operator. This would result in a constant development of stationary chargers in parallel to the electrification of MDV, leading to a couple of dozens of chargers per year. Whereas a fully continuous shift system would require high charging capacities, a single or even double shift operational model would be most suitable for first fleet replacements and charging solutions at capacities around 50 to 150 kW. Only if the battery capacities will not increase in accordance with current estimations, but longer distances need to be covered by electric MDV, the en route charging will become a viable option. Besides these range considerations, an early realization of decentral charging solutions at e.g. branches could be necessary to avoid grid peaks at centralized depot charging parks. Current research programs like megaWATT show that a full electrification of entire fleets would lead to a further expansion of chargers due to the massive grid access costs at the hubs.

In an expert interview with *Theo Schuller* (Schuller, 2019), Product Owner Charging Infrastructure at MAN Bus&Truck SE, this hypothesis was further strengthened. Schuller strongly confirmed that conductive charging solutions in form CCS plugs will remain the standard in Europe for the upcoming years. Asian OEM will bring their own formats like GB/T or ChaDeMo with their vehicles, but CCS seems to be set for Europe. The reason for

Schuller to stay with conductive solutions is mainly the efficiency and costs for this technology. While inductive solutions can be considered as luxury in the passenger car segment, in commercial appliance the wireless charging technologies will be mainly used for long haul appliances in HDV. In contrast, MDV are mainly used for city distribution of goods. As this kind of logistics can be planned rather thoroughly, capacities like 200 km of range for an MDV can be easily dispatched. The range is mainly following the legal environment, meaning that charging breaks are driven by mandatory resting periods (e.g. 45 minutes after four hours of driving). In future, when autonomous vehicles are in operation, this charging behavior will change, and vehicles will be able to operate 24 hours a day.

According to *Schuller*, inductive charging technologies are also strongly depending on the energy prices at hand. In the United States, a country with relatively low energy prices around USD 0,05 per kWh due to nuclear power dominance, efficiency losses of 15-20% can be accepted for convenience reasons. For Europe, losses in that amount would be much too high to be acceptable. *Schuller* referenced to failed experiments in Europe regarding inductive train technologies, which have never been put to practice and have been exported to China. So the costs per km to put inductive coils into the ground are much higher than overhead power line solutions, which is why this form of dynamic charging is being preferred over induction.

Schuller confirmed the hypothesis that the first charging solutions for MDV will be installed at hubs of logistic companies and big retailers to charge overnight or at loading stops and secondly, if the dissemination is big enough and to avoid higher grid peaks at those centralized hubs, the charging solutions could be de-centralized at retail outlets e.g. one big retailer sending his trucks to city centers to distribute trade goods charging in between when trucks are loading and unloading. For this appliance, 150 kW charging capacities will be absolutely sufficient for the upcoming 10-15 years to supply the power needed for one, two or even three shift operations. While capacities will stay the same, battery improvements will mainly lead to lower battery weight and higher loading capacities of the MDV. *Schuller* sees a strong potential for a further development of the connector, as higher charging capacities could be delivered by uncooled cables or even by two connectors delivering power to one vehicle simultaneously, whereas catenary solutions and CWD on highways will be mainly built for long haul operations of HDV. Finally, for the future potential for the electrification of MDV, *Schuller* believes in zero emission zones in megacities around the world, which will bring all vehicles operating in urban environments to electric powertrains. "Within the city, we will not see any combustion engines any more", he concluded.

7 Findings and outlook

As the previous analysis has shown, the potential to electrify MDV and to supply the needed infrastructure is remarkably high and results mainly from three drivers: regulatory and political tendencies, technological readiness and economic viability.

From a regulatory perspective, the increasing pressure on GHG reduction and sustainable environmental solutions will pose an increasing threat to existing powertrain solutions. On the pathway to a full decarbonization until 2050, the Austrian fleet of MDV vehicles will need to be constantly electrified, leading to a small to medium digit number of newly registered BEV per year. But the decarbonization of the transport sector does not only bring a burden, but also constitutes the potential for a major paradigm change in logistics. By overcoming existing regulatory frameworks like night and weekend driving bans or by allowing electric MDV to drive directly into factory and warehouse buildings, many different and additional fields of application could be found for electric MDV. In order to make electric trucks more attractive, the regulatory bodies in Austria, but mainly those in Europe need to re-think existing limits on MPW to compensate for the higher battery weight and to allow similar loading capacities for both conventional and electric vehicles.

From a technological perspective, the electrification of powertrains for MDV currently sees no major impediments to apply the technology in mass markets. Already existing models offer sufficient range and capacity, and charging rates of up to 150 kW offer fast re-charging in depots or en route. Although further research on the actual driving behavior of N2 vehicles in Austria would be needed for broader conclusions, the currently available MDV driving patterns in Austria already strongly fit the circumstances for an electrification. The major field of application for electric MDV will be urban areas, hence all agglomerations around urban nodes in Austria are the primary target area for charging infrastructure. Furthermore, the low average driving distances in the MDV segment as well as an average transport weight of less than 12 t are convincing indicators even for existing truck models at current battery capacities. Anyhow, one might question the *raison d'être* of MDV at all: The surprisingly low and even further decreasing numbers of new registrations in the N2 segment could be potentially explained by the growing demand for higher capacity vehicles as well as the increasing popularity of smaller, faster and easier to operate N1 vans. So future research and market analysis need to focus on the question if the MDV segment in Austria (and potentially in other countries) could be cannibalized by N3 trucks to transport heavier goods or by N1 vans to gain more flexibility. Anyhow, for the existing N2 fleet in Austria, the

category food and retail good transport, combined with applications in urban environment, was identified as the most promising area for electrified vehicles. Due to existing battery capacity restrictions, any special purpose applications are not suitable as the auxiliary equipment would use too much energy to be compensated by the system battery. Because of this very restricted field of application and the low market share of N2 vehicles, the overall potential for new registrations of electric MDV is limited to solely a low two digit number annually.

Although the technical feasibility of electric trucks has been shown in several field test over the last decades, the existing offerings are economically not competitive both in terms of prices and of range compared to conventional diesel powertrains. Especially for commercial usage, the battery density and the price developments are key for the future adoption. Only if battery-electric MDV are priced similarly to conventional vehicles and as soon as the TCO calculation shows clear advantages in maintenance and fuel costs, electric MDV will pose a direct competition to diesel engines. Because current calculations are strongly depending on future assumptions on battery changes and fuel price indications, which both can't be assessed due to the uncertainties in future developments. Until the commoditization – most likely depending on the passenger car developments – of electric powertrains, electric trucks will primarily remain an instrument for environmental conscious companies to shape their sustainability strategy.

The same situation can be assessed for the charging infrastructure itself. Strongly following the roll-out of electrified MDV, the charging infrastructure will most likely be implemented at transport depot where multiple vehicles are being operated at. The charging capacity of choice will be 150 kW, although modular solutions which can offer 75 kW but can easily be upgraded could be the hardware of choice for these infrastructure companies. For a second wave of electrification, the centralized charging of multiple vehicles at the same time (most likely overnight) would lead to remarkable peaks in the electricity consumption. To avoid excessive costs, fleet operators are well-advised to distribute their chargers evenly to their branches or subsidiary to avoid peaks. In order to do so, similarities to existing infrastructure planning methods deriving from passenger car charger distribution can be adopted to fulfill the need of commercial routes.

To conclude, the upcoming years will bring only limited demand for charging infrastructure aiming specifically at MDV. If the technology develops as projected and if vehicle manufacturers follow their communicated product release funnels, customers could be easily convinced of the advantages of electrified MDV. The further developments in charging

infrastructure technology, might it be stationary solutions or dynamic charging, will strongly depend on the question if an industry standard can be found amongst OEM. Otherwise, CCS plug-in solutions will remain the technology of choice at least for the next decade.

8 Annex

8.1 Annex 1: Interview on charging technologies for commercial vehicles

Transcript of the interview with Theo Schuller, Product Owner Charging Infrastructure at MAN Bus&Truck SE, on May 5th 2019

Stefan Richter: Mr. Schuller, thank you again for your willingness to participate in this expert interview for my master thesis assessing charging infrastructure opportunities for MDV in Austria. As just discussed, Mr. Schuller, this interview will be recorded electronically and will be transferred to a written form afterwards. After this, the electronic version will be deleted. Do you consent to record this interview electronically?

Theo Schuller: Yes, and I am not interested in any publication in this form. That means I want you to transfer it to text form and have a look at the text you use.

Richter: Absolutely, I will do so. As discussed, I write this master thesis on charging opportunities, so this considers the N2 segment by the European definition. Within this thesis, I have come to the technological assessment of charging infrastructure, assessing which technology is currently available and what will be future trends. In your current view, what is these days the most promising charging technology to charge electric MDV in Austria?

Schuller: Worldwide we have three standards: GB/T for China, ChaDeMo and CCS. It looks like CCS is going to be the main European standard. This means that OEM delivering vehicles from Asia might bring Asian standards, but mainly we will have CCS throughout Europe.

Richter: So the plug-in technology will be the dominant technology?

Schuller: Related to other technologies, the most efficient charging is being done via CCS. This means in commercial vehicles we will see no other technologies because the costs are much higher.

Richter: This brings me to the second question about the differentiation between stationary and dynamic charging solutions. In my thesis I have divided those two technologies,

whereas stationary charging can be further divided into conductive solutions like plug-in or other directly connected solutions, or into conductive solutions both stationary and dynamic (also known as CWD) which again can be conductive via rails or overhead catenary or pantograph solutions or inductive solutions where the chargers are embedded into the highway. What is your view on both stationary and dynamic charging of vehicles?

Schuller: Whenever the vehicle has a route which is known by the owner, he/she can plan this route and therefore the TCO of the vehicle including these routes, meaning the owner is capable to assess how expensive a technology is to move cargo from A to B. For the stationary technology, it is crucial to know where your A and B is and where you find stations in between to charge. This means that the planning of the route and the planning of the vehicle is giving the decision of what to use. Stationary charging with CCS will be the technology for MDV as delivery vehicles moving between hubs and inner cities e.g. delivering goods for supermarkets. MDV will not be used for long haul, but mainly for distribution transportation. The long haul segment, e.g. driving from Milan to Hamburg, might need dynamic solutions as N3 vehicles transport higher loads. The business case between dynamic charging and CCS is that even a vehicle that is dynamically charging needs to disconnect from the infrastructure and needs some buffer of energy to move on without rails. That means this long haul idea of using rails is ideal if the infrastructure is close to the destination. Right now, if you charge CCS and you know you have 200km to drive, you are sure you can make it. Electric vehicles will be dimensioned according to the laws, meaning if the law says today that you are allowed to drive four hours and you must take a break after four hours, this is exactly what the technology will deliver. A vehicle after four hours of drive needs a charging session, which should last the same amount of time as the break of the chargers (e.g. 45 minutes). This means our vans can be charged in 45 minutes, and our CNL trucks in Austria as well. If you imagine these vehicles have no drivers because they are autonomous, then you can forget these laws because the vehicle drives 24 hours.

Richter: Allow me to come back to inductive solutions. This would need also some adaptations to the vehicle. So would you see a readiness of current and future vehicles to be adapted to inductive stationary charging solutions as this could be the case for MDV?

Schuller: No. Inductive stationary charging is somehow like luxury. If you drive a luxury car you need a luxury charging solution where you don't need to put your hands on

anything at all. Passenger cars with induction yes, commercial vehicles no because on inductive technologies as you can see now on busses in the United States where they are already charging inductively as we speak, they have about 15-20% losses in energy. This is way too much for European purposes. If you have nuclear power at EUR 0,05/kWh, ok, but if you talk about European prices, this is not ok. So inductive charging is much too expensive. We already have made this experiment. In Germany we have developed a train technology and this train was never built in Europe because it's too expensive, so now you can see it in China it's TransRapid. So the costs per km to put the wiring in the surface below the vehicle are too high to make any sense. We see a much lower price for highways with wires from above than putting wires or copper under the surface. This is an experiment which brings costs which are too high.

Richter: Previously you were mentioning the charging capacity and I have also come to the preliminary conclusion in my thesis, based also on the megaWATT research project which is evaluating also the MAN trucks within the Austrian field tests, that the first charging solutions for MDV will be installed at hubs of logistic chains and companies and big retailers to charge overnight or at loading stops and secondly, if the dissemination is big enough and to avoid higher grid peaks at those centralized hubs, the charging solutions could be de-centralized at retail outlets e.g. one big retailer sending his trucks to city centers to distribute trade goods charging in between when trucks are loading and unloading.

Schuller: Exactly.

Richter: So you follow this view, this is great. Where do you see the perfect charging capacity? You were mentioning the CNL which to my information is using 150 kW capacity trucks. Do you see this as sufficient charging capacity for the upcoming years, or do you see it differently?

Schuller: Well, for these vehicles it's perfect when you see that the capacity is enough to drive one shift. If a driver is driving eight hours in one shift and he's charging 45 minutes before another driver gets the vehicle and drives the next shift means that you can use the vehicle in one, two or even three shifts. This is sufficient for the route he's driving. This means that today's technology is sufficient. What will get better and better is the technology of the battery itself, meaning that for the same route you might need lower mass in batteries, which means lower weight and higher load

capacity of the vehicle. Actually, these kind of vehicles with today's technology are going to get less weight and less costs. I believe that in the next 10 years, 150 kW will be sufficient.

Richter: This already brings me to my last question. If I can conclude, you are saying that conductive stationary solutions primarily at depots and hubs at 150 kW will be the charging technology for the upcoming 10 years. Do you see any indications for future technologies that would say would be crucial for any disruptive developments in terms of charging solutions? You were mentioning efficiency of induction which could be higher in your view, but what could be somehow developments in technology that could lead to different charging solutions?

Schuller: Actually, the three standards that I already named (GB/T, ChaDeMo and CCS) are already capable of delivering the solution for the next 10-15 years. So if you charge now with 150 kW, it would be normal in five years to talk about 300 kW and in ten years about 450 kW for commercial vehicles. So we are not talking about sports cars driving alongside the autobahn and want to charge fast as a luxury, but we are talking about a normal standard charging case. So all the busses at the bus depots will see this kind of evolution, and all trucks as well. What we see today in the standardization is sufficient in the next 10-15 years.

Richter: So it will be mainly an evolution in charging capacity than in different charging technologies?

Schuller: Yes, that's correct. The connector itself might have an evolution. We see that below 150 kW, there is no cooling required. We already see with 150 kW and cooling, you can upgrade to whatever the technology gives. We believe that if you have one charging connector, you might have a second one. The Chinese already show today: busses with two CCS connectors delivering the double amount of energy. The same companies that already developed pantographs are developing contactors for higher energy amounts. But we at MAN believe that the overnight charging is the better solution than charging on the way. So pantograph and highway charging are for long haul vehicles and not for distribution.

Richter: Great, thank you so much, this has answered my last question. Is there anything from your side you want to conclude?

Schuller: From my side I believe that we already have the technology which is capable to implement these kind of vehicles. I believe that we will have zero emission zones in megacities and this trend is going to bring all the vehicles to electric mobility. Within the city, we will not see any combustion engines any more.

Richter: Thank you so much, Mr. Schuller, for this interview and your time.

Schuller: Thank you.

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