Deliverable 1a: Analysis of the Available Types of Heavy-duty Vehicles

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1 Introduction

This document introduces the main classes of Internal Combustion Engines Heavy-Duty-Vehicles (ICE-HDVs) and collects the most relevant facts, studies and adopted policies to understand their current mobility and energy needs.

Chapter 2 introduces the HDV classification according to the European framework and clarifies the relevant classes of HDV in the scope of this work, which is their decarbonisation through direct (battery or fuel cell) or indirect (alternative fuels) electrification.

Chapter 3 goes more into detail on the description of ICE-HDVs and their eventual transformation into electric-propelled HDVs.

Paragraph 3.1 gives a preliminary estimation of the overall 'primary energy consumption' of all ICE-HDVs and the relative weight of each category. These estimates are drawn from the data published by several EU agencies committed to reporting on HDV data.

Paragraph 3.2 briefly touches on the expected trends for both people and goods transportation and compares the trend consistently observed over the last 10 years (increase in road transport for both people and goods) with the targets proposed by the European Union (EU) in the Smart Mobility Action Plan following the EU Green Deal.

Paragraph 3.3 describes all kinds of HDVs, with a focus on the features closely related to the present energy consumption and the principal use modes, which shall determine their charging needs and patterns when they shall become electric-propelled.

Finally, **Chapter 4** analyses the principal regulations and limitations related to certain classes of HDV, for which specific requirements exist.

2 Selected acronyms

ACEA	European Automobile Manufacturers' Association
APS	Announced Pledges Scenario
BEV	Battery Electric Vehicles
CAN	Controller Area Network
CECE	Committee of European Construction Equipment
CEMA	European Agricultural Machinery Association
EC	European Commission
EEA	European Environmental Agency
ERS	Electric Road Systems
EU	European Union
FCEV	Fuel Cell Electric Vehicle
GHG	Greenhouse Gases
GPS	Global Positioning System
GVW	Gross Vehicle Weight
HDVs	Heavy Duty Vehicles
IEA	International Energy Agency
ILUC	Indirect Land Use Change
ICE-HDVs	Internal Combustion Engines High-Duty-Vehicles
NREL	National Renewable Energy Laboratory
STEPS	Stated Policy Scenario
T&E	Transport & Environment
UNECE	United Nations Economic Commission for Europe
UniFe	Università degli Studi di Ferrara

3 Scope of the work and HDV selection

This work is ultimately devoted to understanding the consequences of HDV electrification for the power grid.

Electrification means the transition from ICE-HDVs to Battery/Fuel-Cell Electric-HDVs, or simply HDEVs.

Although almost every vehicle with a mass > 3.5 Tons can be legitimately considered an HDV, this analysis focuses on road transport HDVs, thus excluding passenger airplanes, air cargos and national/international maritime transportation. Nevertheless, some considerations will also be made on the electrification of railways and near shore/inland ferries when the recharging/refuelling infrastructure use cases are similar to those of HDEVs.

There are some strong reasons to focus mainly on road transport HDVs:

1. There are already market mature HDEVs for road transport applications;
2. Due to the high impact on Greenhouse Gases (GHG) emissions, there are several EU Regulations, Directives and adopted policies to foster the large-scale deployment of HDEVs; and
3. Road HDEVs will make use of the same public recharging/refuelling infrastructure, which shall therefore be interoperable and spread throughout the whole EU territory.

Examining the European framework, HDVs for road transport of people and goods are classified according to United Nations Economic Commission for Europe (UNECE) standards, which is implemented by **Regulation EU 2018/858** '*on the approval and market surveillance of motor vehicles, their trailers and of systems, components and separate technical units intended for such vehicles'*.

The Regulation describes 3 vehicle categories of relevance:

- Category M: motor vehicles designed and constructed primarily for the transporting of passengers and their luggage;
- Category N: motor vehicles designed and constructed primarily for transporting goods; and
- Category O: trailers.

Each of these categories is further subdivided into subcategories. Strict criteria apply regarding the energy consumption and GHG emissions of all road transport vehicles falling into this classification scheme, as prescribed by **Regulation EU 2018/956** '*on the monitoring and reporting of CO_2 emissions from and fuel consumption of new heavy-duty vehicles*'.

However, several classes of HDV are still missing from the list the vehicles above. For example, agricultural machineries and tractors, for which Regulation **EU 2018/858** says: 'This Regulation does not apply to the following vehicles: (a) agricultural or forestry vehicles, …'. Indeed, according to the EU policy frameworks, these vehicles belong to the agricultural sector, together with the targets for emission reduction and duly reporting on energy consumption. The same holds for cranes and work machines, which belong to the industrial and building sectors.

In principle, these kinds of HDV may also transition from ICE-HDV to HDEV, and make use of the public recharging/refuelling infrastructure, thus impacting the power grid, which is the scope of this work.

The table below summarises the relevant categories of HDVs for this study.

*Table 1. Classes of HDV with reference to the UNECE classification and their sector of application. The green cells (**M1, N2, N3**) identify the vehicles classes 'HDV for road transport' [Regulation 2018/858]. Trailers (**O3** and **O4**), marked in yellow, while lacking any propulsion engine, are classified as polluting HDVs because the final efficiency of any articulated truck is the combination of the truck + trailer efficiencies. Main vehicle names in grey indicate Light-Duty vehicles, which are not part of this study.*

Vehicle class	Description	EU reference sector	UNECE class.	UNECE specification	main vehicles
M	passengers transport motor veichles	Road Transport	M1	< 8 seats	passenger cars, SUVs, vans
			M2	> 8 seats, mass < 5 Tons	small buses
			M3	> 8 seats, mass > 5 Tons	buses and coaches
N	goods transport motor veichles		N1	mass < 3.5 Tons	light duty vehicles, pick up vans
			N2	3.5 Tons < mass < 12 Tons	large vans, rigid trucks
			N3	mass > 12 Tons	heavy trucks, articulated trucks
O	Trailers		O1	mass < 0.75 Tons	
			O2	0.75 Tons < mass < 3.5 Tons	
			O3	3.5 Tons < mass < 10 Tons	
			O4	mass > 10 Tons	
T, R, …	special purpose motor vehicles	Public work			Cleaning vehicles and garbage collectors
		Industry			Cranes and work machines
		Agriculture			Tractors and Agricultural machines
Train	non electrified trainlines	Rail Transport			diesel trains

4 Analysis of heavy-duty vehicles

4.1 Primary energy consumption

The selection in Table 1 highlights the relevant classes of HDVs, but does not note the size of each class in terms of number of vehicles, nor does it present figures related to the overall primary energy that may switch from ICE-HDVs to HDEVs in the coming years.

As almost all HDVs are still based on diesel combustion engines, it is possible to use the GHG emissions as a proxy for a rough estimate on the overall primary energy consumption and of the relative 'weight' of the different classes of HDV.

Data on GHG emissions related to the transport sector are reported by the European Environmental Agency (EEA) [1] for the year 2019, and HDVs are responsible for approximately 27% of the road transport emissions, as shown in Figure 1.

Data on GHG emissions of agricultural machineries, tractors and work machines are not accounted for under the 'Transport sector', and the competent authorities are the Committee of European Construction Equipment (CECE) [2] and the European Agricultural Machinery Association (CEMA) [3].

In [3], it is reported that GHG emissions of agricultural machineries and tractors accounted for approximately 1% of the total GHG emissions of the EU 27, which should correspond to roughly 3–5% of the transportation GHG emissions. In [4] it is reported that, in 2007, the combined share of GHG emissions from construction and agricultural machineries was between 5–6% of the total volume of GHG emissions of the transportation sector, which agrees with the above estimate.

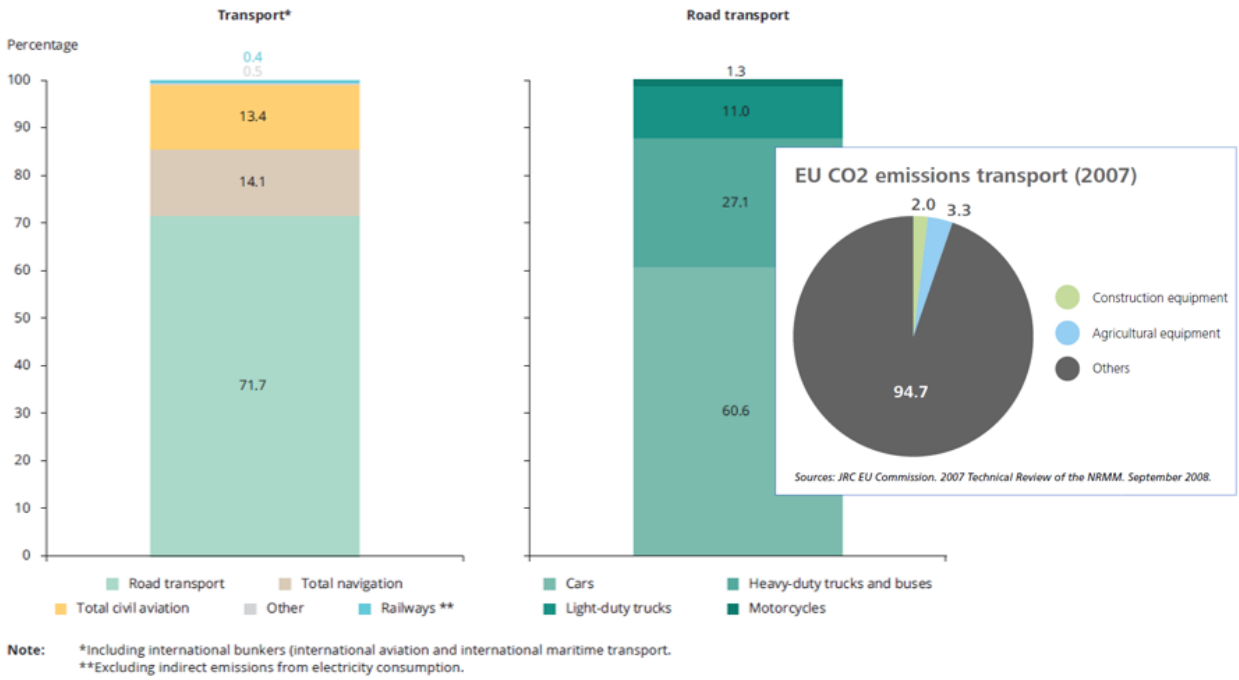

Figure 1. Share of GHG emissions in the transport sector (left) and GHG emissions related to the road transport only (right), figure from EEA [1]. In the light blue box is a pie-chart from [4] with the 2007 GHG emissions of agricultural and construction equipment compared to the transport sector.

Table 2 summarises the numbers discussed above, where the GHG emissions are compared relative to each other, as explained in the caption.

Table 2. Comparison of the GHG emissions for the different classes of HDV selected in the previous paragraph. The percentages are relative to the total GHG emissions of the HDV in this study. Data for trucks and buses are from [1]; data for industry and agriculture sectors are extrapolated from references [2] and [3] (data from 2007).

Vehicle class	EU sector	main vehicles	% GHG	EU reference bodies / committees
N	Road Transport	buses and coaches	77	EEA / ACEA
		large vans, rigid trucks		
		heavy trucks, articulated trucks		
T, R, ...	Industry	work machines and public work	7.5	CECE
	Agriculture	Tractors and Agricultural machines	14	CEMA
Train	Rail Transport	ICE diesel trains	1.5	EEA / UNIFE

4.2 Future trends in transport systems and HDV utilisation

The modal use of HDVs for goods transportation has steadily increased over the last two decades in addition to their overall carbon emissions, as shown in the figure below (green dotted line): despite a constant energy efficiency gain (brown line), inland freight transport demand increased both in absolute terms (red line) as well as relative to total inland freight transport (orange line).

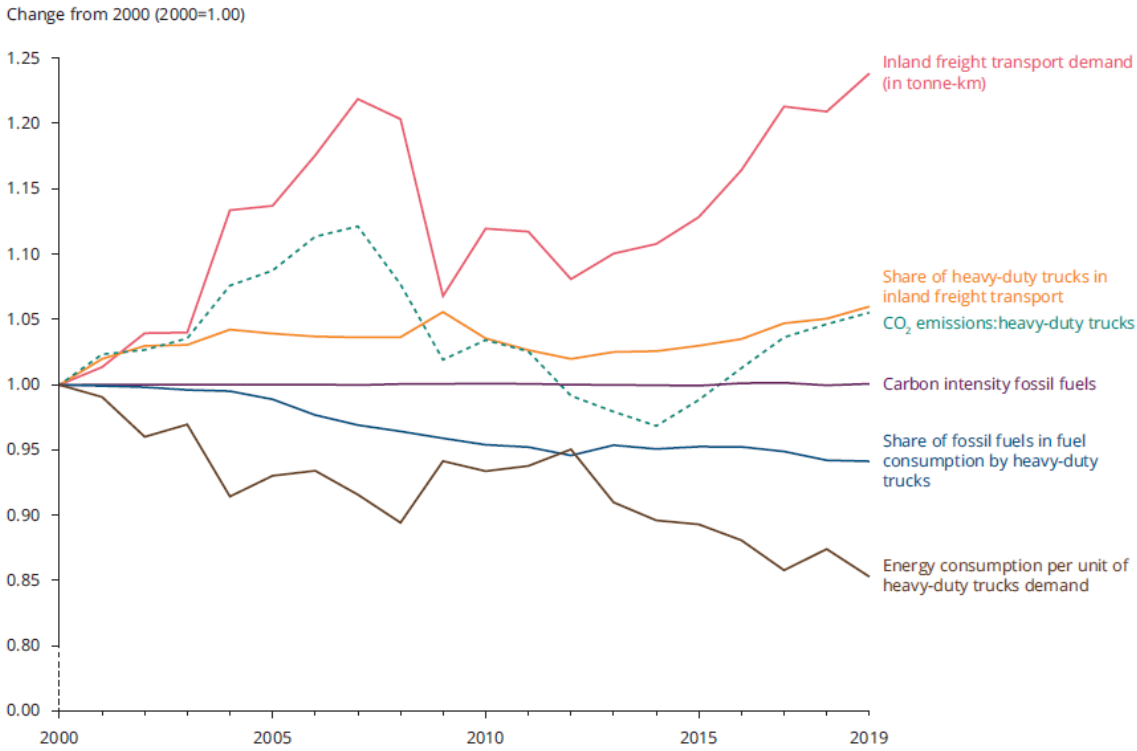

Figure 2. Share of Heavy-Duty trucks in inland freight transportation (orange line) and inland freight transport demand (red line) from 2000–2019. Figure taken from [1].

This trend is in contrast with the 'Mobility strategy and action plan' plan set out by the EU for decarbonising the transport sector by 2050 [5], which indicates specific targets to foster the modal shift from road transport towards rails and inland/short sea shipping.

The ambition is to double the traffic on high-speed rail by 2030 and to double rail freight traffic by 2050. The rationale behind these objectives is illustrated in the figure below, which illustrates the average GHG in gCO_2 per ton-km for freight transport in the EU27.

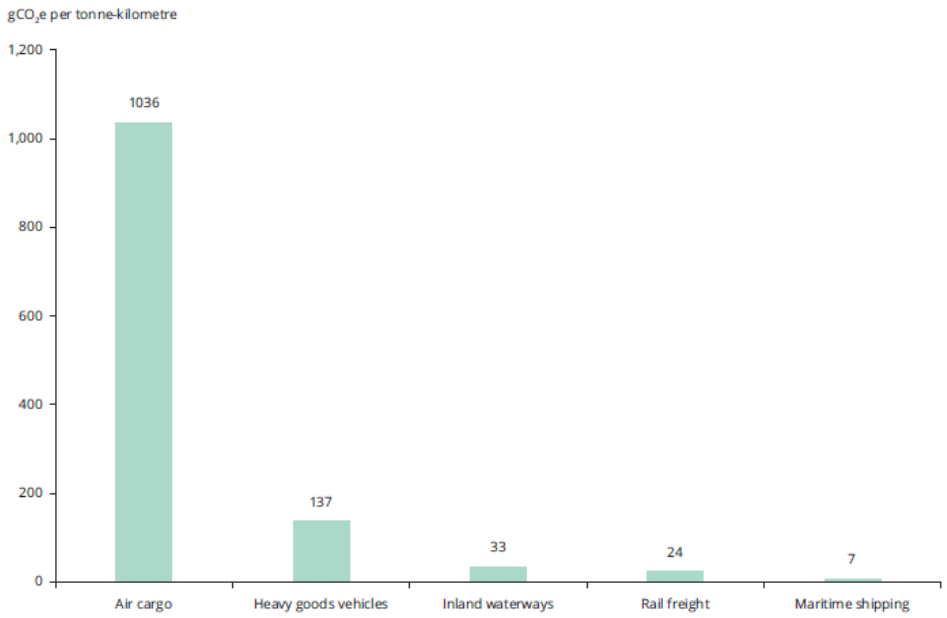

Figure 3. GHG emissions of HDV in the transport sector in the EU-27 in 2018. Average GHG emission (gCO_2 per ton-km), well to wheel, freight transport, data from [1].

Although the modal shift towards rail has a clearly huge decarbonisation potential, looking at the data also reported in [1] (see Figure 2), it emerges that road transport of goods and passengers is not only increasing in total volume but is also increasing in the relative modal share compared to railways and inland maritime transportation.

Thus, despite the efforts to promote other means of transportation and the stated objectives of shifting substantial amount of inland goods and people transportation from roads to railways[1], there are no signs suggesting that a significant modal shift away from road transport HDV is going to happen.

4.3 Available types of heavy-duty vehicles

Today, the vast majority of heavy-duty vehicles in operation across Europe run on diesel (97.8% of trucks; 94.5% number of buses) as it is the most convenient and capillary-diffused fuelling option for professional transport operators; until the 2022 energy crisis, it is also the most affordable option. So far, only negligible low- and zero-emission trucks are in operation.

The main available types of HDVs are introduced and defined in Table 3, whereas in Annex A their main features are presented in a tabular format. Data about stock of vehicles were downloaded from the Eurostat data portal for road transport [6]. It is specified that industrial machines are not included in the analysis as they are already highly electrified.
A more detailed description is then provided for trucks, buses and agricultural machines.

[1] EU Smart Mobility Strategy, see https://transport.ec.europa.eu/news/efficient-and-green-mobility-2021-12-14_en: [..] *TEN-T proposal is accompanied by an Action Plan on long-distance and cross-border rail that lays out a roadmap with further actions to help the EU meet its target of doubling high-speed rail traffic by 2030, and tripling it by 2050'.*

Table 3. Definition of considered HDVs types.

Type	Definition
Middle truck N2	Truck of weight 3.5 – 12 t, applied for local traffic and regional delivery
Heavy truck N3	Truck, tractor-trailer of weight > 12 t, applied for long distance or heavy distribution transportation
Urban bus	Bus for city and regional traffic
Intercity bus	Bus for intercity applications or scheduled services
Work machine	Truck used in construction sites and open-cast mines
Collection vehicle	Vehicle used for the collection, transportation or delivery of solid waste or recyclable materials
Cleaning vehicle	Road, sidewalk and sewer cleaning vehicle
Agricultural machine / tractor	Machinery used in farming or other agriculture work

4.3.1 Trucks

The European classification system defines trucks as 'motor vehicles with at least four wheels, used for the carriage of goods', with a mass of more than 3.5 tons. As reported in Table 4, trucks are classified either in the N2 category (exceeding 3.5 tons) or in the N3 (exceeding 12 tons), which is also referred to as heavy trucks or heavy commercial vehicles.

In this study, trucks are further classified into 4 sub-categories depending on the vehicle's weight, which is strictly related to the truck's application and use case. This distinction is also important as it affects the electrification potential and the recharging/refuelling requirements.

Table 4. Classification adopted for the truck segment.

Type	Definition	From [Tons]	To [Tons]	Usage
Rigid body	**Light-Medium duty (N2)**	3.5	7.5	Urban and regional delivery
	Medium duty (N2)	7.5	12	Regional delivery
	Heavy duty trucks/trailers N3	12	40	Long distance transportation, heavy distribution transportation
Articulated	**Traction units**	Designed to haul other road vehicles which are not power-driven (trailers)		Long distance transportation, heavy distribution transportation

Trucks carry 73.1% of all freight transported over land in the EU. They represent the most flexible and economic mode of transport for the vast majority of goods, and the only option for the final leg of the delivery chain. Most of our daily goods, from food to fuels, domestic/business/industry and material needs, depend on trucks at some point in the distribution chain.

Today, there are some 7.5 million trucks in circulation in Europe with an average age of 13.9[2] years old [7]. The vast majority of trucks, approximately 96.3% in operation across Europe, run on diesel as it is the most convenient and affordable energy carrier for professional transport operators. So far, only a negligible number of alternative fuel trucks are in operation, representing less than 1% of all trucks on the road today. Only 0.24% of trucks on EU roads have a zero-emission powertrain.

Alternatively powered vehicles (battery electric, plug-in hybrid, hybrid and low/zero emissions fuels) together represent 3.4% of new truck sales in the EU. The International Energy Agency (IEA) foresees that the share of electric trucks could rise from 7% to 17% of the sales by 2030, rising from 2% to 5% of the total truck stock in EU.

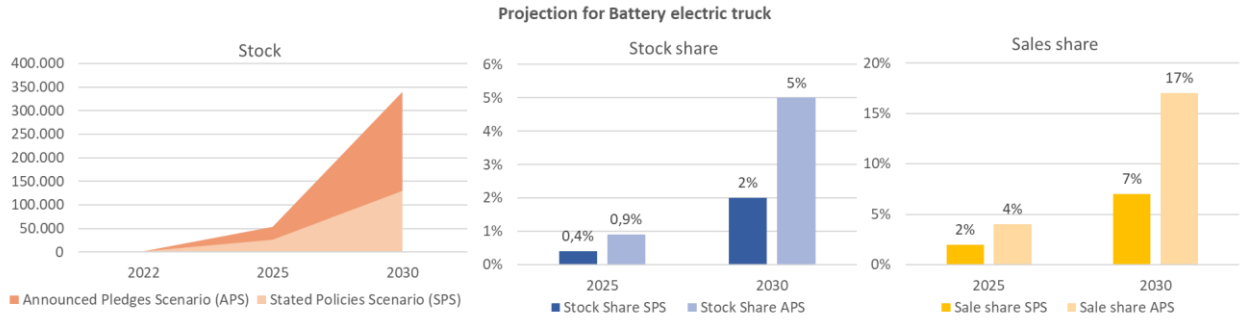

Figure 4. Projections for battery electric trucks according to IEA scenarios: Announced Pledges Scenario (APS) and Stated Policy Scenario (STEPS). APS is based on existing climate-focused policy pledges and announcements. STEPS in based on current policy plans and it does not take it for granted that governments will reach all announced goals.

Hydrogen-powered fuel-cell electric trucks are the second major zero-emission powertrain technology. As of 2022, only 52 fuel-cell trucks are in operation in Europe [8]. Nevertheless, several manufacturers have announced the start of series production of these vehicles from 2024 [9]. It is expected that hydrogen-powered trucks will become widely available during the second half of this decade (2025–2027). The European Automobile Manufacturers' Association (ACEA) estimates that at least 60,000 hydrogen-powered trucks will have to be in operation by 2030 [10].

The end-use of trucks varies mainly between long-haul and regional delivery. The following figures present typical driving profiles for both end-uses, released under the Fleet DNA project, which consists of high-resolution vehicle operation data that the National Renewable Energy Laboratory (NREL) collects from fleets around the country [11].

Figure 5 displays a representative driving cycle for regional haul. The profile covers a 450 km distance. The overall stop time is 1h and a half, however the longest stop time is roughly 10 minutes.

All the following driving cycles have been developed by NREL considering global positioning system (GPS) and controller area network (CAN) data. Data are then elaborated, filtrated and analysed to generate custom representative drive cycles using specialised statistical clustering methods.

[2] This data differs from the one reported in the Annex A which refers to the fleet turnover for the primary application. It usually happens that older vehicles are reused for less demanding duties.

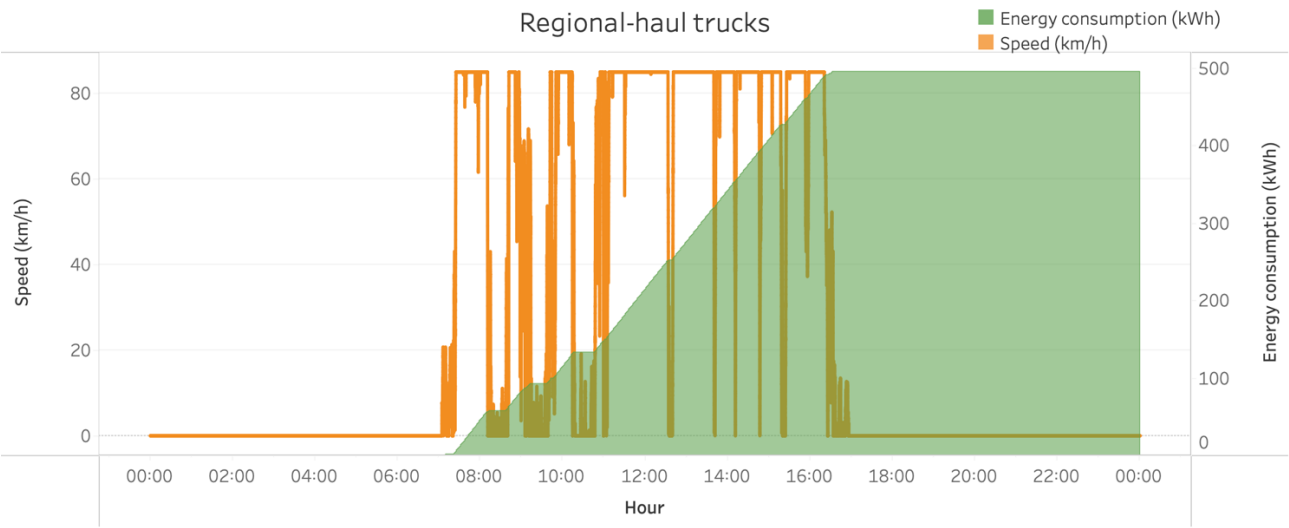

Figure 5. Regional truck representative daily driving cycle (RSE elaborations based on [12]).

Table 5. Parameters of the Regional truck representative driving cycle.

Time (minutes)	Distance (km)	Maximum Speed (km/h)	Average Driving Speed (km/h)	Stops
596	452	85	72	87

Figure 6 shows an example of a Representative Driving cycle for a long-haul truck. Over a distance of more than 900 km, the overall stop duration is 9 h, with one halfway stop of more than 100 minutes, and other stops range from 10 to 30 minutes. In this case, NREL driving cycles have been taken as reference, but it has been set a speed limit of 90 km/h to take into account European limits. Energy consumption has been calculated by using a simulation model [13] based on a feedback control on vehicle speed, setting the required torque to follow the representative driving cycles. The model considers main vehicle parameter (weight, tyre, frontal area) and motion resistance forces, i.e. tyre rolling resistance and air drag.

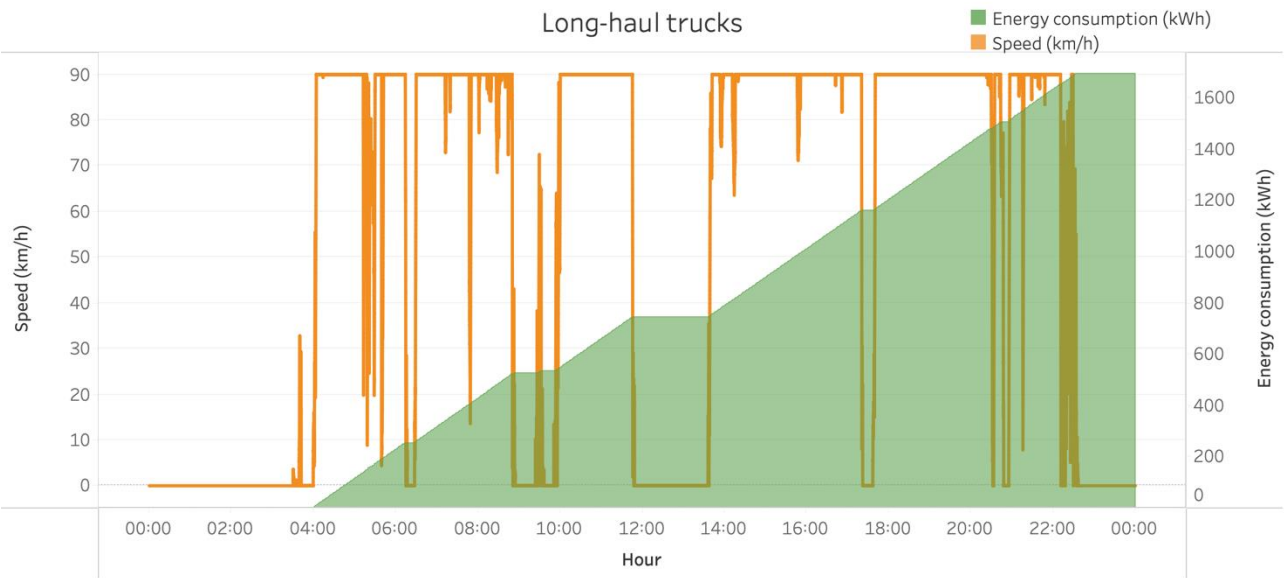

Figure 6. Long haul truck representative driving cycle (RSE elaborations based on [12]).

Table 6. Parameters of the Long-haul truck representative driving cycle.

Time (minutes)	Distance (km)	Maximum Speed (km/h)	Average Driving Speed (km/h)	Stops
1183	980	90	85	47

Driving profiles are crucial for deciding the technology of the future truck fleets. The presented driving profiles for long-haul trucks in [12] represents a very demanding use case, which is intended as an upper bound for the daily driving distances. Indeed, it is estimated [14] that 97% of truck drive up to 800 km per day, which is compatible with the announced ranges for the future generation of battery electric trucks.

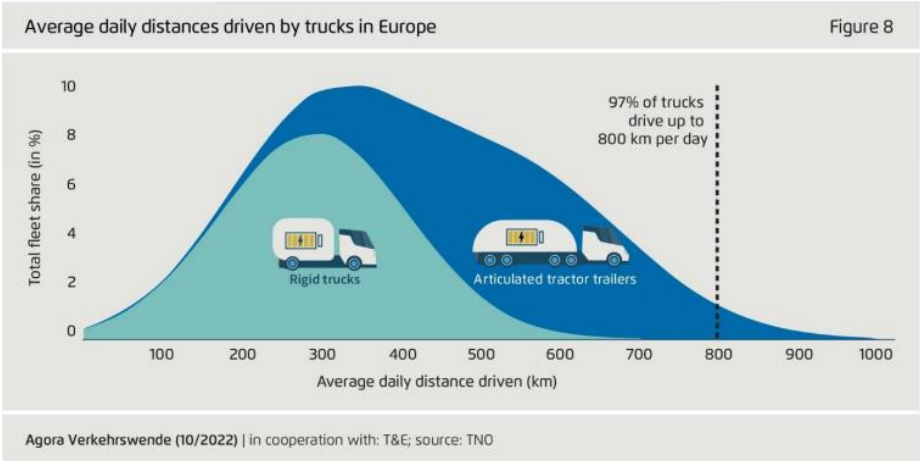

Figure 7. Average daily distances driven by truck in Europe [14].

4.3.2 Buses and coaches

The European classification system defines buses and coaches as 'vehicles having at least four wheels, designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver's seat'.

Buses are the most widely used form of public transport in the EU, serving cities as well as suburban and rural areas. Approximately 56% of all passenger journeys per year in the EU are made by urban and sub-urban buses [15].

With one bus capable of replacing 30 cars on the road, buses help ease traffic congestion. Moreover, they have the lowest carbon footprint per passenger of any form of motorised transport.

They are also the most cost-efficient and flexible form of public transport, requiring minimal investments to launch new lines or routes. Buses are also a safe transport mode, responsible for just 2% of road fatalities in the EU.

Today, approximately 692,200 buses [7] are in operation across the EU, almost half of which can be found in three countries alone: Poland, Italy and France [15]. Buses on EU roads are on average 12.8 years[3] old [7]. Only six countries in the EU have a bus fleet less than 10 years old.

Diesel buses account for 93.5% of the EU fleet [7]. Alternatively powered vehicles (battery electric, plug-in hybrid, hybrid and alternative fuels) together comprise 4.3% of all buses on the road today, with only 0.9%

[3] These data differ from those reported in Annex A which refers to the fleet turnover for the primary application. It usually happens that older vehicles are reused for less demanding duties.

being battery electric and 1.4% hybrid electric. However, significant shares of electric buses can be found in the Netherlands (12.4%) and Luxembourg (6.6%).

Zero emission buses continue to gain market share. Globally, in 2021 the registrations of electric buses increased 40% over the previous year. In the EU, 73% of all new buses are powered by diesel. Alternatively powered vehicles (battery electric, plug-in hybrid, hybrid and alternative fuels) together represent 27% of new bus sales in the EU.

Regarding future projections, the IEA foresees that the development of electric buses will accelerate in the next few years, rising from 11% to 25% of the stock by 2030, with up to 55% of sale share, depending on the policy scenario [8, 16].

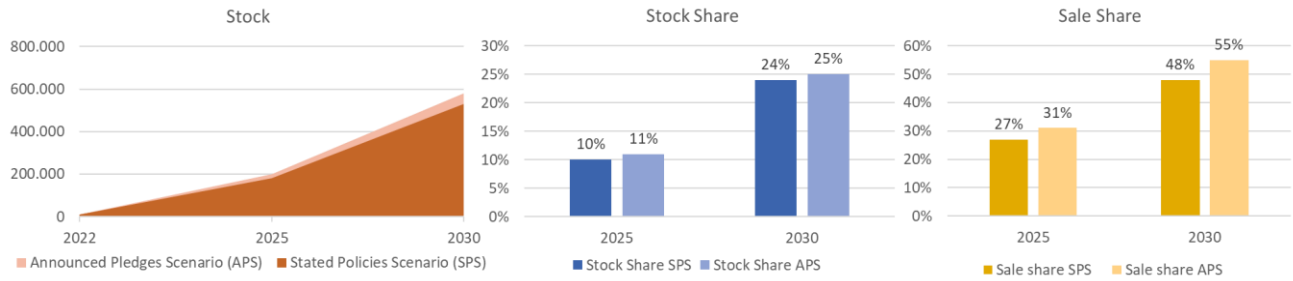

Figure 8. Projections for battery electric buses according to IEA Scenarios: Announced Pledges Scenario (APS) and Stated Policy Scenario (STEPS). APS is based on existing climate-focused policy pledges and announcements. STEPS in based on current policy plans and does not take it for granted that governments will reach all announced goals.

Hydrogen technology is also expected to play a major role in this segment. From the present stock of 188 [8], according to the municipal plan, the EU could reach 1200 hydrogen buses by 2025 [17]. Bloomberg projections suggest that in 2040, the share of new hydrogen vehicles could reach 6.3% [18].

Today, most of the electrification is limited to urban buses, whereas intercity buses have lower levels of electrification due to longer routes and therefore longer charging needs.

Under the UNECE standard, buses and coaches are classified as the 'M2' category (for those under 5 tons) or 'M3' (for those exceeding 5 tons). For the purpose of the present study, the M3 category is further divided into urban busses and extra urban busses. Specific details of each category are reported in the Table provided as Annex.

An example of a typical driving schedule simulating urban bus driving is captured in the Braunschweig City Driving Cycle (Figure 9) developed at the Technical University of Braunschweig, which has been frequently used in various research projects, as well as for some equipment certification programmes.

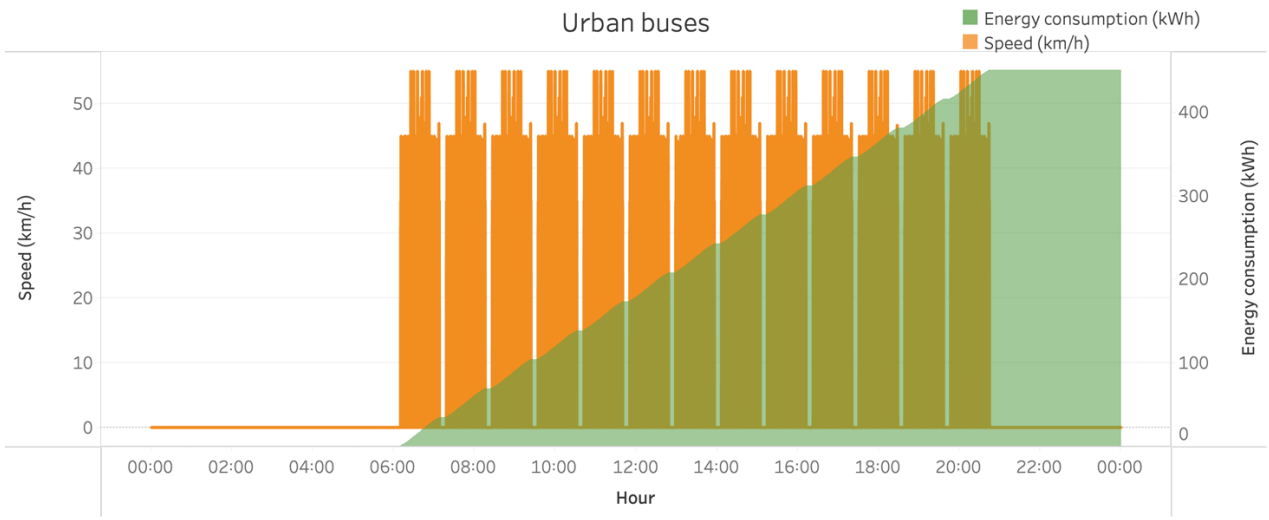

Figure 9. Braunschweig City Driving Cycle (RSE elaborations based on [12]).

Table 7. Parameters of the Braunschweig City Driving Cycle.

Time (minutes)	Distance (km)	Maximum Speed (km/h)	Average Driving Speed (km/h)	Stops
874	200	55	31	754

Figure 10 shows an example of a Representative Driving cycle for an extra urban transit bus, released under the Fleet DNA project which consists of high-resolution vehicle operation data that NREL collects from fleets around the country [11].

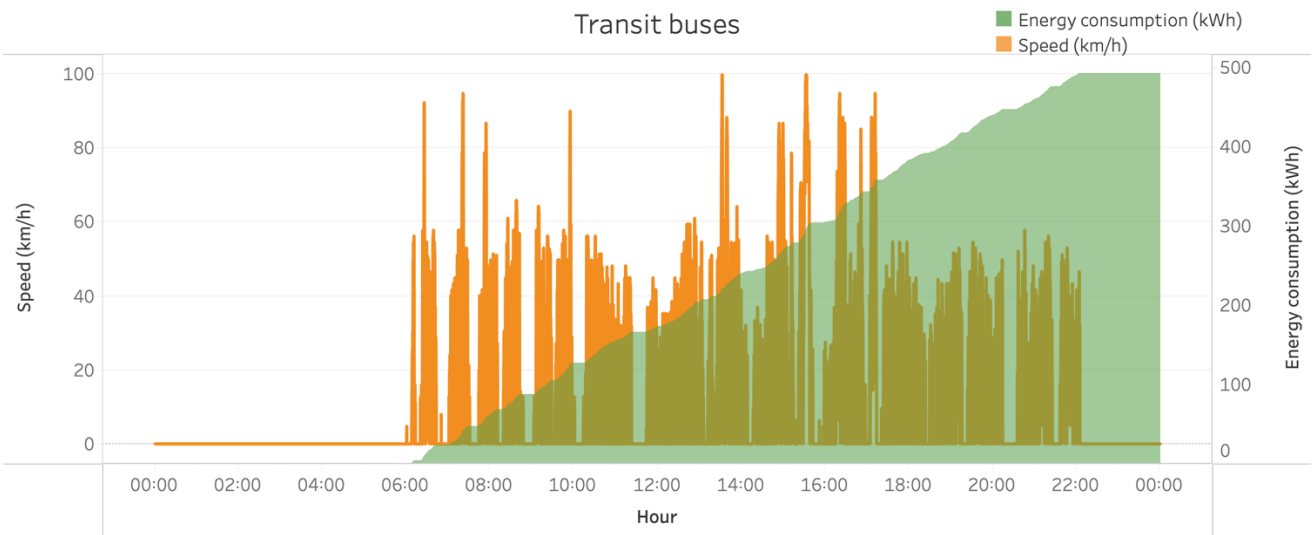

Figure 10. Transit bus representative driving profile (RSE elaborations based on [12]).

4.3.3 Work machineries, agricultural machineries and tractors

Regarding the decarbonisation strategies for work machines (building/construction industry) and tractors and machineries for the agriculture sector, two position papers were recently published by CEMA [3] and

CECE [2]. A joint position paper was also published [4] to stress the similarities in the two sectors and the common view on the best strategy to reduce carbon emissions while staying competitive in the market.

The CEMA position-paper on the decarbonisation potential in agriculture reports that [3]:

- *'The agriculture sector accounts for 10% of the total EU27 greenhouse gas (GHG) emissions (from crops, livestock and soils), and an additional ~1% of total EU27 GHG emissions can be attributed to agriculture from the combustion of fossil fuels during the normal course of operating agricultural machinery.'*
- *'One suitable solution in agriculture, for the coming decade, remains the internal combustion engine with the use of alternative fuels.'*
- *'European agriculture is not uniform; it diverges from region to region and from year to year.'*
- *'Reduction of energy consumption can only be obtained by measuring fuel efficiency over the entire crop or livestock production process.'*
- *'A corresponding exercise for agriculture would imply to refer not to the distance travelled, but to the tons of crop produced and harvested.'*
- *'Agricultural machineries are characterized by very long life-cycles of 25 to 30 years.'*

In addition, it is observed that agricultural machineries are not used uniformly throughout the year and have a limited mobility range, thus requiring a dedicated recharging / refuelling point at the site of operation, which is deemed technically very difficult (especially in the case of hydrogen storage) and economically unsustainable.

The CECE position paper on the role of construction equipment for decarbonising Europe [2] reports similar observations, stressing several times that overall process efficiency is far more relevant than reducing tailpipe emissions alone. They break down the factors contributing to CO_2 emissions in 4 classes, as illustrated below:

Figure 11. Key areas of intervention to reduce carbon emissions related to the use of work machines in the building sector.

Regarding the direct use of HDEV in the construction industry, the paper shows that the most suitable application is for full electric construction machines to be used at constructions sites located in urban areas and nearby an accessible electric connection, making it also possible to greatly reduce the battery pack required for operation.

The use of fuel cell or battery electric vehicles (BEVs) in remote areas is deemed unfeasible for economic and safety reasons. Figure 12 below reports a graphical representation of the likelihood for direct use of HDEVs in different scenarios typical for the construction industry:

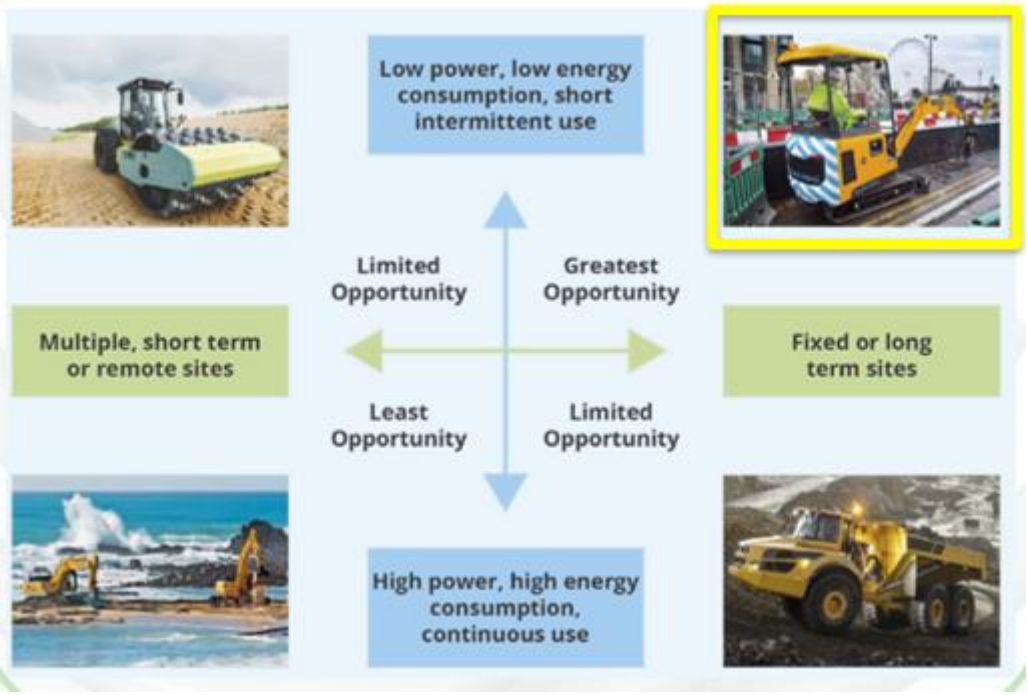

Figure 12. Taken from [2], the chances for use of direct electrified HDEV in the construction industry. The two relevant parameters for the assessment are: the daily power/energy consumption and the availability of a recharging/refuelling facility at the site of operation.

Summarising these two reports, the industry and agricultural sectors are committed to reducing their carbon emissions but reducing tailpipe emissions is not the priority for achieving their decarbonisation targets, whereas much can be achieved by focusing on overall operational efficiency rather than direct fleet electrification.

The agricultural and industry sectors are thus set to make use of biofuels and synthetic fuels, which makes it possible to reduce the capital investment costs for new machineries and does not require any new infrastructure.

The use of biofuels and synthetic fuels is under debate at European level:

- currently a 6% share of biofuels is used to dilute diesel fuel and decrease its GHG emission intensity.
- the environmental benefits of using biofuels over fossil fuels are difficult to quantify due to the complex chain for producing, transporting and pre-treating the feedstock. Final emissions are highly dependent on the type of feedstock from which they are produced.
- The EU has recognised that emissions related to the use of biofuels are also related to the Indirect Land Use Change (ILUC). The **ILUC Directive** (2015/1513) introduced the constraint that the share of energy from biofuels produced from crops grown on agricultural land is not to exceed 7% of the final consumption of energy in transport.
- the GHG emissions of fuels for transport (petrol/diesel) and for machineries and heating (gasoil) is regulated by the **Fuel Quality Directive** (EU, 2009), which does not mention Indirect Land Use Change emissions and is not currently under revision.

In the conclusion of [1], in par. 7.1.1, it is reported that: '*Biofuels are projected to have a limited impact. The EU Reference Scenario 2020 projects that biofuels and biomethane would constitute 6.8% of all transport fuels (excluding hydrogen and electricity) in 2030 and in 2050'.*

In [19] 'Truck CO2: Europe's chance to lead', the Transport & Environment (T&E) position paper on the review of the HDV CO2 standards, which openly supports direct electrification, the authors argue that the use of

biofuels will not be possible for the transport sector because of limited supply, and agree that *'the limited quantities available will be needed to decarbonize hard-to-abate sectors where electrification is not an option such as aviation, maritime shipping and parts of industry'.*

Based on these observations, and recalling that 7% of the transport fuels is about the quantity of fuel required to power work/building machines, agricultural machineries and tractors, we have exclude the electrification of these vehicles from this analysis as they are difficult to electrify and will likely be able to use biofuels.

5 Limitations and regulations for HDVs

5.1 Driving time and rest periods

Regulation (EC) No 561/2006 provides a common set of rules for maximum daily and fortnightly driving times, as well as daily and weekly minimum rest periods. These rules apply to all drivers of road haulage and passenger transport vehicles, with some exceptions. The rules establish:

Driving time

- Daily: not exceeding 9 hours and can be extended up to 10 hours max. twice a week;
- Weekly: not exceeding 56 hours; and
- Fortnightly: not exceeding 90 hours.

It is permissible to exceed the daily/weekly driving times up to one hour to let the driver reach their own place of residence or the employer's operational centre at the beginning of a weekly rest period.

Rest periods

- Daily: at least 11 hours and can be reduced to 9 hours max. three times a week. Daily rest period can be split into 3 hours rest followed by 9 hours rest to make a total of 12 hours daily rest;
- Breaks: at least 45 minutes (divisible into 15 minutes followed by 30 minutes) after no more than 4.5 hours consecutive driving; and
- Weekly: 45 continuous hours, which can be reduced every second week to 24 hours. Weekly rest is to be taken after six days of working, except for coach drivers engaged in a single occasional service of international transport of passengers who may postpone their weekly rest period after 12 days to facilitate coach holidays.

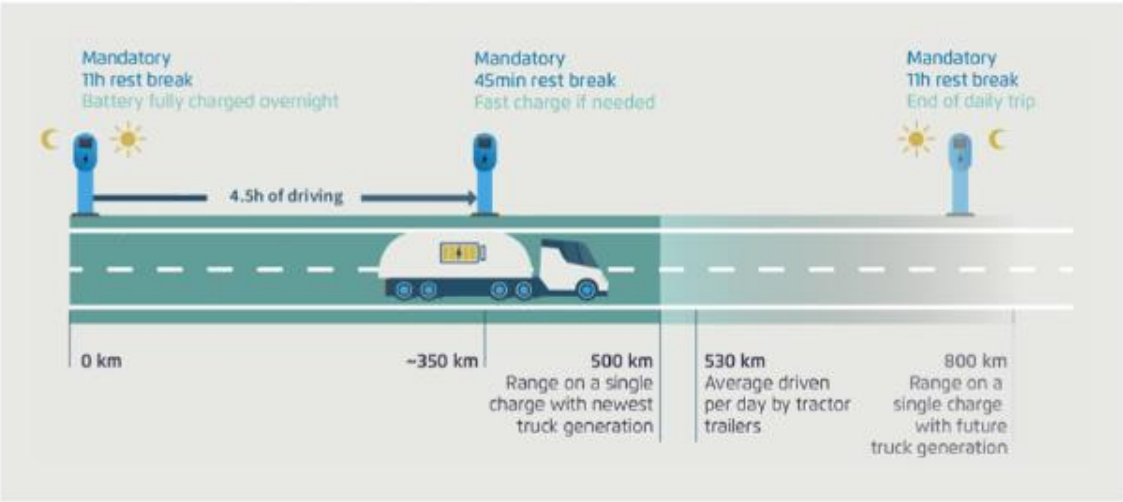

Figure 13. Daily driving patterns of electric long-haul trucks [20].

5.2 Location and duration of truck stops

The identification of the current stop locations of trucks is crucial as these sites could be the optimal locations to begin the installation of charging infrastructure for commercial vehicles.

Based on GPS coordinates of 400,000 trucks in operation trough Europe, Fraunhofer Institute for Systems and Innovation Research ISI, on behalf of ACEA, has conducted an analysis on location and duration of truck stops [21]. The analysis found that 10% of the locations most frequently used by trucks account for some 50% of the total stops made by trucks, both for regional and long-haul trucks.

Location of stops

In general, truck stop locations follow major motorways and the distance to the nearest motorway may be used as a criterion to characterise truck stop locations. The result is as follows:

Distance from motorways	Category	Approximate share
0 m – 200 km	Rest areas (directly located on motorway)	4%
200 m – 1 km	Rest areas (close to motorways)	25%
1 km – 5 km	Rest areas and companies & logistic locations	40%
> 5 km	Companies & Logistic hubs	30%

A further analysis with the aim of identifying the objects in the vicinity (with a radius of 200 m) of the truck stop locations has found the following characteristics:

Category	Approximate share
Rest areas	30 – 50 %
Companies & Logistic hubs	25 – 45 %
Ports	1 – 5 %
Unclear	< 50 %

Duration of stops

The percentages for duration classes of the long-haul and regional stops are shown in the following Figure 14.

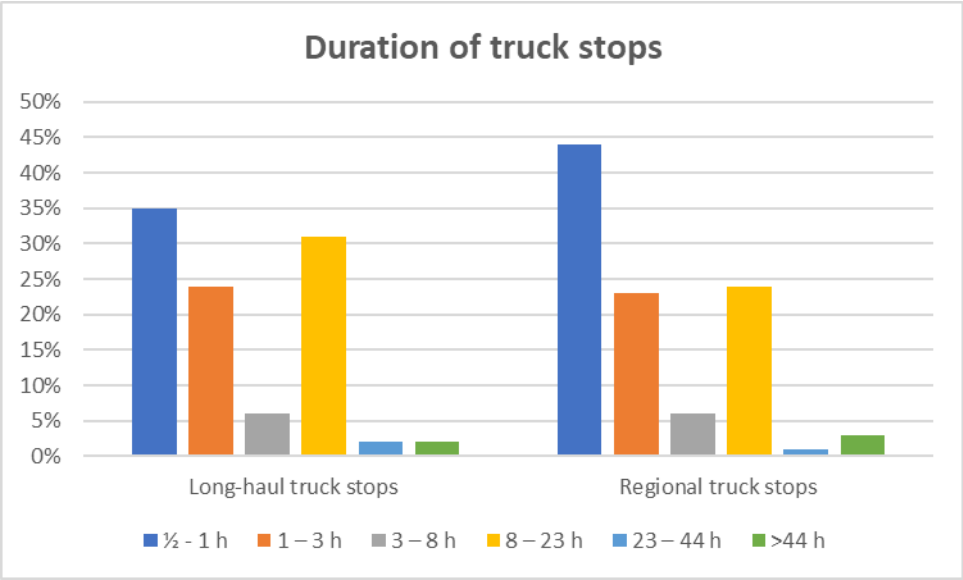

Figure 14. Share of stop durations in long-haul and regional operation by duration [21].

On average, approximately one third of the number of stops in long-haul operations are shorter than one hour and approximately one quarter are between one and three hours. Longer stops are typically 8 – 23 hours long and make up between one quarter and one third. Stops longer than 23 hours are exceptional and are typically less than 5%.
The typical shares of stop durations in regional operation are similar: short stops are most common and very long stops quite exceptional. However, very short stops of below one hour play an even higher role in regional truck operation and are approximately 44% on average.
If durations are further grouped into short stops of up to three hours, intermediate stops of 3 – 8 h and long stops of more than 23 h, then hardly any stops are of intermediate stop duration.

5.3 Weights and dimensions directive

Directive 96/53/EC defines the authorised dimensions and weight for trucks, buses and coaches involved in international traffic. The aim of the directive is to guarantee the free movement of goods in the EU, setting maximum limits for heavy goods vehicles, buses and coaches carrying out international transport within the EU. It also requested the application to national transport companies of the standards set for international transport.

The directive has been firstly amended by Directive (EU) 2015/719, permitting an additional weight of 1 ton for alternative fuelled motor vehicles.

In 2019, the Directive 96/53 was newly amended by Directive (EU) 2019/1242, to also cover zero emission technology.

According to the Directive, for new HDVs the permitted additional weights are:

- 1 ton for alternatively fuelled technology, confirming directive 2015/719; and
- 2 tons for zero emission technology.

According to [20], battery electric trucks for the urban, regional and construction duty cycles have no penalties on the maximum payloads, even in the year 2020. For the long-haul truck, despite the additional weight allowance for zero-emission trucks (EU, 2019), the large batteries required in the early years in

combination with the relatively low energy density of batteries results in a temporary penalty on the maximum for the long-haul BEV. The long-haul BEV with the large battery has a penalty of 3200 kg on the maximum payload in 2020 which reduces to zero by 2030. Similarly, the medium battery version has an initial payload penalty of 670 kg in 2020. Its payload penalty decreases to zero by 2024. The mass of the FCEV drivetrain for the long-haul truck is sufficiently low not to result in any payload penalty, partly due to the increased weight allowance of zero-emission trucks.

6 Annex A: available types of HDVs

Middle truck N2	
Size	7.2–12 tons GVW (Gross Vehicle Weight)
Application	Local traffic, regional delivery
Holder	Mostly private
Annual mileage	Depending on the context of use. According to KBA, an average of 39,000 km per year [22]
Consumption every 100 km	Depending on the context of use, load and driving style, there are big differences, on average 19 l of diesel [22]
Fleet turnover	10 years [22]

Heavy truck N3 / Tractor-trailer	
Size	From 12 tons GVW
Application	Long distance transportation, heavy distribution transportation
Holder	Mostly private
Annual mileage	100,000 km [22]
Consumption every 100 km	30 l [22]
Fleet turnover	6–8 years [22]

Urban bus	
Size	More than 8 seats (11–18 tons)
Application	City and regional traffic, increasingly also in long-distance traffic

Holder	Public/private
Annual mileage	40,000 km [23]
Consumption every 100 km	40 l [23]
Fleet turnover	13 years [7]

Intercity bus	
Size	11–26 tons
Application	Scheduled service – intercity
Holder	Mostly public and private for long-distance transport
Annual mileage	100,000 – 220,000 km [23]
Consumption every 100 km	27 l [23]
Fleet turnover	13 years [7]

Work machine	
Definition	Vehicle for construction, renovation, developing, demolition or public works site
Application	In construction sites and open-cast mines; in the mine, even in closed environments
Holder	Mostly private
Annual work performance	Very heterogeneous from approximately 800 to over 2000 h per year [22]
Consumption per hour	Very heterogeneous from 15–45 l/h [22]
Fleet turnover	5–15 years depending on the device [22]

Collection vehicle	
Definition	Device used for the collection, transportation or delivery of solid waste or recyclable materials

Application	Settlement area and public roads
Holder	Mostly public (municipalities)
Annual mileage	About 16,000 km per year, depending on the area of application [22]
Consumption every 100 km	Varies considerably depending on the collection area, 50–120 l of diesel [22]
Fleet turnover	8 years (payback period) [22]

Cleaning Vehicle	
Definition	Road, sidewalk or sewer cleaning vehicle
Application	Public place
Holder	Mostly public
Annual work performance	1000 – 1500 h per year [22]
Consumption per hour	Depending on the size and performance, on average 4–5 litres of diesel / h [22] [24]
Fleet turnover	10 years [22]

Agricultural machine / tractor	
Definition	Device used in farming or other agriculture
Application	Agricultural land, public / private roads
Holder	Mostly private
Annual work performance	Depending on the application, 700–900 hours per year [22]
Consumption per hour	Depending on the size and power, up to 10 litres of diesel [22]
Fleet turnover	8–12 years [22] [24]

7 Annex B: driving cycles for inland passenger boats and inland ferries

In recent years, new transport segments have been embracing the transition toward electrification. These include ferries and passenger boat for short sea and inland shipping. Indeed, these vessels present predictable operations cadenced by short and fixed routes, which makes them particularly suitable for pure battery-based propulsion.

Critical aspects are related to charging requirements. Indeed, weight and volume constraints limit the size of the onboard battery, which needs to be charged between the transits to complete the daily service. However, the charging time is often limited by strict schedules, and high-power charging is required.

Ferries, used for both passenger and vehicle transport, represent the most promising segments for full electrification as they can be directly converted by retrofitting. On the other hand, passenger boats present more stringent space and weight constraints and require new optimised hulls to host the battery pack.

Table 8 presents some of the electric ferries already in operation in Europe. As shown, ferries present large daily energy consumption (on the MWh scale), and their charging power request can be on the MW scale.

Table 8. Electric Ferries in operation in Europe. References are reported in each row.

Name	Length (m)	Gross tonnage (kg)	Sailing distance (km)	Capacity (passenger-car)	Battery size (MWh)	Opportunity Charging power (MW)
MF Ampere (new build) 2015 [25]	80	1589	5.5	360–120	1	1.2
Ellen (new build) 2019 [26]	60	996	40	196–31	4.3	4
MF Folgefonn (retrofit) (retrofit) 2017 [27]	76	1182	3.5	199–76	1	1
MF Grotte (new build) 2021 [28]	50	925	3.4	396–35	1.1	2.6

Inland ferry	
Application	Passenger and vehicle transport
Holder	Private
Annual work performance	4000 h/years

Consumption per hour	Depending on the size, up to 120 l/h
Fleet turnover	Up to 60 years

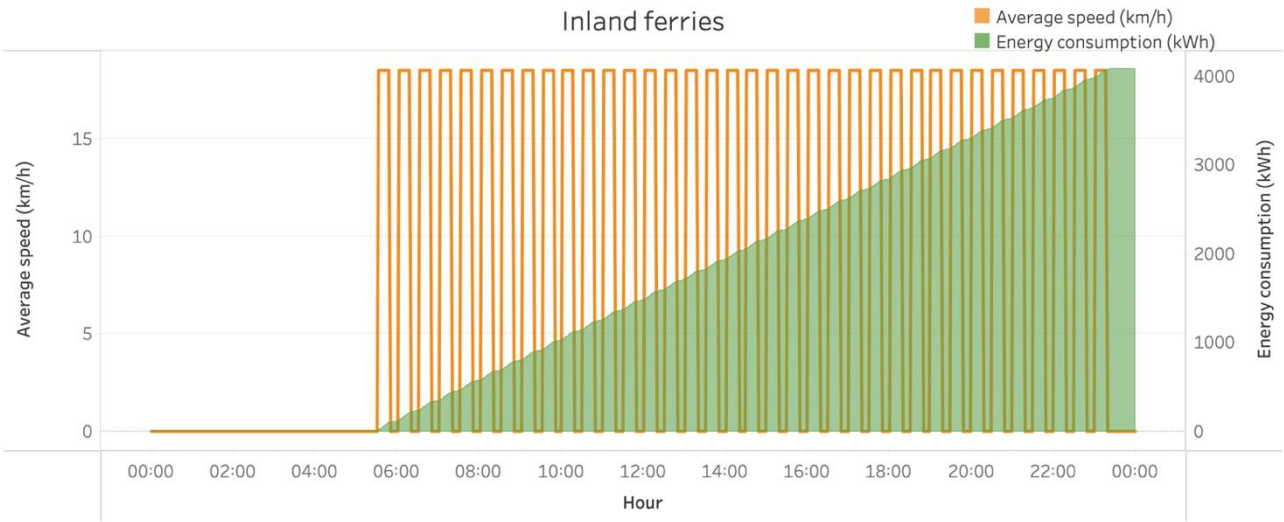

Figure 15. Inland ferries representative driving profile (RSE study based on the operative profile of the ferries in service in Lake Maggiore [29]).

Inland passenger boat	
Application	Passenger transport
Holder	Private
Annual work performance	2500–3000 h/years
Consumption per hour	Depending on the size, up to 100 l/h
Fleet turnover	Up to 60 years

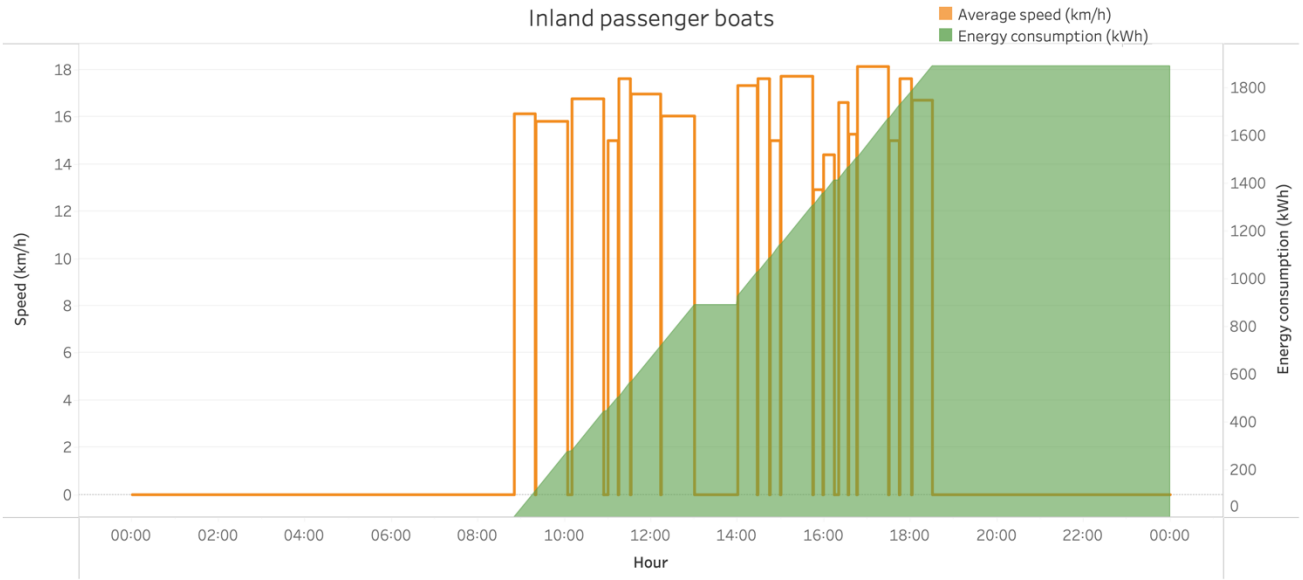

Figure 16. Inland passenger boat representative driving profile (RSE study based on the operative profile of the ferries in service in Garda Lake [29]).

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