Zero Emission Heavy Goods Vehicles

The infrastructure and payload impacts of different options for regulating gross and axle weights

By I Knight & E O'Brien

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Contents

Glossary

Heavy Duty Vehicle (HDV) means a goods vehicle exceeding 3.5 tonnes or a passenger carrying vehicle exceeding 8 passengers in capacity (a bus or coach)

Heavy Goods Vehicle (HGV) means a goods vehicle exceeding 3.5 tonnes

Battery Electric Vehicle (BEV) is a motor vehicle powered by electricity stored solely in batteries.

Fuel Cell Electric Vehicle (FCEV) is a motor vehicle powered by electricity that is generated from Hydrogen by a fuel cell

Zero Emission Vehicle (ZEV) is a motor vehicle that does not emit any harmful pollutants ‘at the tailpipe’, excluding emissions generated during the construction of the vehicle or the generation or transport of the energy used on board.

Gross Vehicle Weight (GVW) is the maximum complete weight of a vehicle and the payload that it is carrying, that is permitted by law. It excludes the weight of any trailers or their load.

Maximum permitted Combination Weight (MCW) is the maximum complete weight of a vehicle including any trailers it is towing and the payload carried, that is permitted by law.

The Weights & Dimensions Directive (or W&D Directive) means Council Directive 96/53/EC, as amended, laying down for certain road vehicles circulating within the Community the maximum authorized dimensions in national and international traffic and the maximum authorized weights in international traffic

Summary

The Challenge

It is Government policy across Europe to encourage wider adoption of vehicles that emit zero CO2 and pollutants ‘at the tailpipe’. Currently, almost all such vehicles are battery electric vehicles (BEVs). However, a BEV drivetrain weighs more and occupies more space than a diesel equivalent. Regulations intended to promote standardization, maintain safety and protect the infrastructure, limit the maximum length and weight of vehicles. If those limits do not change, a heavier drivetrain means that maximum payload weight is reduced. This means that more trucks and more journeys are required to move the same amount of goods. In this situation BEVs, especially for longer journeys where heavier batteries are needed, become commercially less attractive.

To reduce this barrier to adoption, EU regulation has already allowed a two-tonne increase in weight for zero-emission vehicles (ZEVs) in international traffic. However, a new proposal has been submitted by the European Commission to allow an additional two tonnes maximum weight (4 tonnes in total compared with diesel) and also a one tonne increase in the maximum drive axle limit. In practice, this will also apply to national traffic in many Member States, but the situation will vary in those Member States that already permit higher weights for diesel vehicles in their national traffic. The Commission’s Impact Assessment (IA) estimated that in 2040 adopting this proposal would result in 845 million fewer heavy-duty vehicle (HDV) trips and that there would be an increase of 7.3 billion tonne km that are carried by ZEVs. Over the period 2025-2050, it was estimated that this would translate to a cumulative saving to industry of €3.9 billion in transport costs plus being the ‘driving force’ behind the saving from the total package of options of 27.8 million tonnes of CO2, valued at €3.5 billion.

However, allowing more weight on the same number of axles is more damaging to roads and increases the load on bridges. For bridges the total weight of the vehicle combination is generally most important; for wear on the road surface/pavement the axle weights are most important, and the effect of axle weight increases are highly disproportionate. (European Commission, 2023) estimated that the cost of additional road maintenance attributable to its proposal to increase weights for ZEV was a cumulative €4.2 billion. So, the overall benefits of the proposal outweigh the costs, but the costs are significant. Much of the cash benefit of the Commission proposal is attributable to industry, while the costs are attributable to national Government budgets.

This is one important underlying reason for the current political situation with the proposed changes to Directive 96/53/EC (Weights and Dimensions Directive). The weight limit changes were approved by the European Parliament but, as of December 2024, no agreement had been reached by the Council of the EU. It is understood that various reasons have been given but concerns about the road wear impact of the Commission proposal feature prominently.

Seeking a solution

The details published by (European Commission, 2023) were relatively limited, because this was just one policy measure of many involved in the proposal. This study reviewed the evidence that was used to support the Commission proposals as well as technical changes that have taken place even in the short time since the analysis behind the Commission proposal. Independent analyses were undertaken to fill gaps in knowledge, to provide understanding and context and to quantify the effect of options not considered by (European Commission, 2023). The aim of this work was both to improve the understanding of the stakeholders involved in discussions and identify possible options for compromises.

(European Commission, 2023) did not publish the road wear factors underlying its conclusions. The description of the method did not mention the weight condition the road wear factors were calculated in, either in terms of whether the vehicle was fully loaded to mass limits or in terms of how that load was distributed within the vehicle. Infrastructure oriented analyses will often just consider single worst cases based on the maximum permitted load and sometimes these may be impossible or infrequent in service. Real world axle loads are a complex blend of the unladen weight of the vehicle and the trailer, the commodities carried, any unavoidable empty running and in some cases the choices of operators in how it is loaded. For the analysis in this report, a wide range of realistic loading conditions were calculated for different vehicles under baseline and candidate policy measures.

Bridges are expensive and long-lasting assets, so standards require them to be built very conservatively, allowing for potential increases in vehicle mass, increases in traffic, overloading, and deterioration in service. While it is generally considered that bridges built to the most recent design standards (the so-called EuroCodes) will prove more than adequate for the new vehicles proposed by the Commission, there has been concern around some of the older bridge stock in some countries that were designed to much earlier, less demanding, standards and which may have degraded in service.

The analytical methods employed can be considered in the following stages:

1. An axle loading model was developed based on manufacturer specifications for unladen weights and geometries of a range of baseline diesel vehicles and early generation electric vehicles with projections for future gains in energy density. The payload was estimated in relation to empty running and full loads of goods of different densities, from light to heavy. Maximum payloads were based on a central loading position and alternatively when the load was as far forward or as far rearward as possible without overloading any axles.
2. A road wear model was generated based on the AASHTO method (the 4th power law) to generate an average road wear factor per 100 tonnes of goods transported considering a distribution of the different load conditions (empty, full of light, medium or high density goods) that resulted in an average load comparable to that recorded by Eurostat for the sector.
3. A bridge loading analysis was undertaken to compare baseline diesel vehicles, existing BEVs and future BEVs in different regulatory scenarios with the minimum loads required by EuroCode 1.2 and older German bridge design standards (DIN 1072)
4. A cost model was developed to estimate the financial cost of the road wear implied by the load factors per 100 tonnes. This was based on T&E's EU Transport Roadmap Model combined with Infrastructure maintenance costs from the OECD and German road tolling reports.

The Findings

Increasing weight due to zero–emission (ZE) technologies does not have the same effect as increasing the weight available for payload. When payload is added in a semi-trailer, the weight is spread amongst all 5 axles. Only journeys where dense goods that reach the weight limit without filling the volume will be affected by the change. When weight is added due to ZE technology it is spread only amongst the two tractor axles and it is present in every journey the vehicle undertakes, representing a large proportional increase in axle weight when empty or when fully loaded with lightweight goods. When all the different load conditions are considered, the road wear implications of the proposed ZEV allowances are more severe than those for an equivalent increase in payload for an existing diesel vehicle.

Some operations are clearly viable with a BEV range of 300km, or there would be zero uptake of the first generation of vehicles. A large proportion will be possible with 500km, around two-thirds if fast charging is available during driver rest breaks. However, for 90+% of operations to be viable with BEV, a range of around 700km may be needed.

With the generations of BEV technology that are already on the market or arriving in the next year, the availability of space for batteries on a standard 4x2 tractor unit continues to limit the range of vehicles such that 700km on a single charge does not appear feasible without major design changes. Even ranges of around 300km can potentially compromise payload when based on today's vehicle designs.

It is not just the Maximum authorised Combination Weight (MCW) that limits the payload, axle weights can too. When a truck is carrying a commodity that comes close to filling the load space (volume) and reaching maximum weight, then it is not possible to adjust load positions. Due to the extra unladen mass of the tractor, a payload that appears legal based on the MCW minus the unladen weight can result in an overloaded drive axle.

The Commission's proposal to increase MCW to 44 tonnes with a drive axle of 12.5 tonnes is very effective from the vehicle and operator point of view. It enables maximum range to be achieved without compromising maximum payload, while retaining some flexibility in load positioning, helping to avoid unintended axle overloads.

New vehicle designs with improved energy densities and energy efficiencies are expected to enter the market before 2030 which will allow ranges of around 700km and more to be completed, which, in turn, will allow well over 90% of freight vehicles to be replaced with BEVs and close to 100% if a comprehensive fast charging network is in place.

Once large range vehicles are available, 'right sizing' battery capacity on vehicles will be important for payload. Most operations can be undertaken with less than 700km range. With smaller range, lower battery capacity and, in future, improved energy density, the weight penalty is much less. Under the Commission's proposal, these vehicles would retain the same 44 tonne MCW and would benefit from substantial additional payload compared with diesel. However, in some cases the ability to fully exploit this would be limited by the trailer axle weight limits. The better spread of load among the axles, and the fewer required movements in these cases, both contribute to a lower implication for road wear. Availability of fast charging during driver rest breaks is an enabler of smaller batteries on a wider range of vehicles. As such, if an authority wants to protect their physical infrastructure, providing an effective fast charging network for heavy-goods vehicles (HGVs) is important.

Four additional policy options have been identified, of which three have been quantified and compared to the baseline scenario of no change to the current Weights and Dimensions Directive:

- **Baseline scenario:** Five & six axle ZEV combinations can have an MCW of (up to) 42 tonnes and a maximum drive axle weight of 11.5 tonnes.
- **Commission proposal:** Five & six axle ZEVs can have an MCW of 44 tonnes and a maximum drive axle weight of 12.5 tonnes. Payload barriers to the adoption of BEVs would be eliminated and some operational flexibility restored. Vehicles with lower range needs would benefit from substantial payload increases. However, road maintenance costs would be expected to increase by 1.1% to 2.3% depending on the vehicle mix, road construction and maintenance practices and ZEV adoption rate. For example, In Germany an increase of around €1.1billion would be expected over the period 2025-2040 compared to the baseline. The absolute costs would be much smaller in other countries, where slower ZEV adoption rates, lesser HGV activity and reduced maintenance spend, all play a part.
- **Alternative proposal 1:** Five & six axle ZEVs can have a MCW of 43 tonnes and the maximum drive axle load is 11.75 tonnes. Vehicles with a range approaching 700km on a single charge would continue to suffer reduced payload for the very short term. Design flexibility would be limited, for example, the use of very efficient e-axles may be more difficult and the use of more sustainable lower cost lithium iron phosphate (LFP) batteries may be more limited. Load positioning would also be more restricted than the Commission proposal. However, with technology expected to be available before 2030, 700km range vehicles should be possible with payload equal to diesel and lower range versions would have improved payload (compared with diesel). The increase in road maintenance costs would be much lower at between around 0.7% to 1.4%,
- **Alternative proposal 2:** Five axle vehicles benefit from the same change as in alternative 1 (43/11.75 tonnes). In addition to this, six axle vehicle combinations based on 3 axle tractors would retain the 44 tonnes MCW from the Commission proposal. This would mean that a 3 + 3 axle BEV combination would have the same payload capacity as a 2 + 3 axle BEV combination. In diesel form, a 3+3 combination would have a lower payload than a 2+3 combination. Reduced space for batteries, due to the space taken up by the additional axle, means long range vehicles would need

to rely on new vehicle designs that include the elongated cab concept and the next generation of powertrain technologies. Even with these advantages, the longest range options may need to stack some batteries behind the cab. This presents significant design and manufacturing challenges to the vehicle industry and could raise centre of gravity heights, increase rollover risks slightly, and could also erode some of the expected driver comfort benefit of elongated cabs. Such vehicles would be slightly more expensive to buy and run. However, the 3rd axle substantially reduces road wear. Two sub-options of this scenario exist:

- **Alternative proposal 2a:** The use of lift axles is prevented and equal load distribution on the 19-tonne drive axle bogie is required. This is the most limiting option for industry but offers the biggest benefit for infrastructure. If adoption could be incentivized such that by 2031, around 50% of activity was undertaken with 3 axle tractors rather than 5% today, then road maintenance costs could be reduced compared to baseline by between 2.7% and 5.6% depending on vehicle mix and adoption rate of BEV. The economics and feasibility of stimulating demand for 3-axle tractors to 50% of activity have not been investigated.
- **Alternative proposal 2b:** A drive axle limit of 10.5 tonnes for six axle vehicles is imposed and lift axles are allowed. This will mitigate some of the industry issues with running costs but is less effective for infrastructure. With the same assumptions of adoption, then over the period 2025-2040, road maintenance costs in the EU would be reduced by around 0.1% to 0.3% compared with the baseline.

Table 1: Effect of policy options on cumulative road maintenance costs (2025-2040) of 5 and 6 axle articulated vehicles

Policy scenario	Absolute value (€billion)			Relative to baseline (€billion)			Relative to baseline (%)
	DE	PL	RO	DE	PL	RO	
Baseline – Do nothing	47.35	5.58	5.49	-	-	-	-
Commission – 44/12.5 for 5 & 6 axles	48.43	5.64	5.55	+1.07	+0.06	+0.06	+1.1% to +2.3%
Alternative 1 – 43/11.75 for 5 & 6 axles	48.02	5.62	5.53	+0.67	+0.04	+0.04	+0.7% to +1.4%
Alternative 2a – 43/11.75 for 5 axles, 44/9.5 No lift for 6 axles	44.68	5.43	5.33	-2.67	-0.15	-0.15	-5.6% to -2.7%
Alternative 2b – 43/11.75 for 5 axles, 44/10.5 for 6 axles	47.22	5.58	5.48	-0.13	-0.01	-0.01	-0.3% to -0.1%

The effect of the proposed ZE weight increases on bridges is a modest increase in bridge loading on short and medium span bridges that in most cases is less than 5%. In a few cases, the Commission proposal imposes a load increase of a little more than 10%. The alternative proposal for a maximum 43 tonnes reduces this to around 8%. In these cases, an old bridge standard (DIN 1072) requires the bridge to have capacity for around 85% more load, strongly suggesting there are significant reserves of capacity, unless the bridge has substantially degraded in service. In all cases tested, the capacity reserve of DIN

1072 substantially exceeded the increase in loading of the actual vehicle. Newer bridges built in accordance with the Eurocodes would have substantially larger reserves of capacity.

It is considered that if a bridge has lost sufficient capacity that an increase in vehicle induced load of 8% reduces the factor of safety to a level that is deemed unacceptable, then the bridge should be closed to traffic of that weight. However, unless the assessment of available capacity would need to be very accurate if it could confidently conclude that it was safe for loading only a few percent lower. It seems likely that such a bridge should also be closed to the heaviest type of diesel and BEV traffic already permitted by the current version of Directive 96/53/EC. Although this is not an exhaustive analysis, it strongly suggests that the proposed policy options would not have substantial implications for bridge structures, unless they were substantially degraded in service such that it was marginal as to whether they were safe for existing vehicles.

It is also worth noting that bridge calculations contain an allowance for overloading. Many current BEVs are voluntarily installing axle weight monitoring. These are typically not calibrated for sufficient accuracy for enforcement purposes but will help avoid accidental overloads. They could be made mandatory for vehicles taking advantage of the additional weight allowances, such that the allowance for overloading on top of the permitted increase in load was less needed.

1 Introduction

There has been huge progress in vehicle design and battery technology over the last decade, which has enabled the concept of long-haul BEVs to become realistic. It is also the case that a vehicle with sufficient range to enable the daily duty cycles of a large proportion of truck operations will still weigh significantly more than a diesel equivalent. Although hydrogen has a high energy density relative to its weight, it is very poor relative to its volume (the space it takes up). To fit enough hydrogen on board a vehicle to provide a comparable duty cycle means it must be heavily compressed, in some case liquefied at very low temperatures. The nature of hydrogen is that it can also be leaky and difficult to store. While not the case for hydrogen-powered internal combustion engine vehicles (H2-ICE), in a fuel cell electric vehicle (FCEV), there is also a need for a battery (much smaller than for battery powered vehicles) and the fuel cell itself. So, even though hydrogen as a fuel is relatively light, the additional equipment needed to compress, cool, and store the hydrogen as well as converting it to electricity and then motion can still mean the vehicles are heavier than diesel.

Road freight transport is a highly regulated world, with limits on the maximum weight of the vehicle, a vehicle combination and each axle within the vehicle or vehicle combination. So, increased unladen weight means decreased payload, increased cost and more HGVs are required to transport the same volume of goods. This is seen within industry as a substantial barrier to the commercial take up of ZEVs, at least where dense commodities are carried.

The European Commission has proposed a substantial revision to Directive 96/53/EC controlling the weights and dimensions of HDVs. One element is a proposal to increase the maximum weight of a 5 or 6 axle articulated zero-emission truck from the current 42 tonnes to 44 tonnes, and the maximum weight on a single driven axle from 11.5 tonnes to 12.5 tonnes. If implemented, this would allow a new ZEV to weigh four tonnes more than a diesel equivalent but to (at least) retain the same payload capacity, thus removing the commercial barrier. Current allowances of up to 2 tonnes maximum combination weight are limited to the actual additional weight of the technology compared to a diesel equivalent. The Commission has proposed that this will no longer be the case, the additional weight allowance is available irrespective of that marginal difference to a diesel vehicle. This has a number of advantages:

- It grants the additional weight, in a clear and simple way, to new market entrants that do not sell an equivalent diesel vehicle so cannot prove the marginal increase data required for the current regulation.
- It provides a strong commercial incentive to manufacturers to reduce the weight of zero-emission technologies, which would not exist with the marginal increase approach adopted currently.
- It may incentivise operators to accept vehicles with smaller battery capacities, where they can have confidence that they will not need the range, because it will gain them payload.

However, additional vehicle mass can have adverse impacts on the infrastructure that carries the larger loads. In particular, increased axle weights can have disproportionate effects on structural wear of road surfaces and increased total weights can affect the loads imposed on bridge structures.

The Commission proposal has passed its first reading at the European Parliament but, to-date, no agreement has been possible at the Council of the EU, where a number of objections have been made, including but not limited to, on the grounds of the cost of increased road maintenance or bridge improvement.

As such Transport & Environment (T&E) commissioned Apollo Vehicle Safety & Research Driven Solutions to undertake analyses aimed at helping to produce a compromise proposal. This report describes the results of this work and aims to:

- Demonstrate clearly why the Commission considered that increases are necessary.
- Clearly explain the impact of the changes on road wear and bridge loading.

- Consider alternative solutions to the problems and quantify the mitigating effects for infrastructure and any other advantages or disadvantages.

2 Research Methods

2.1 Estimating vehicle & axle weights

Baseline diesel vehicles were derived from published vehicle specifications for a new generation DAF XF[1] and a Volvo FH[2]. The longest wheelbase offered in either version (3.8m) was used in order to be most comparable to BEVs. A single standard semi-trailer model was based on published specifications for a Krone Profiliner[3]. A spreadsheet model was developed based on simple mathematical analyses of loadings, their positions and the equilibrium of moments around a given reference point. This model was used to calculate the:

- Unladen axle weights of the vehicle combination
- Total laden weight and axle weight when:
    - Fully loaded with different commodities of goods from very low density to high density (at increments of 1 kg/m^3)
    - Fully loaded to maximum combination weight
        - With the centre of the gravity of the load positioned at the geometric centre of the semi-trailer
        - With the centre of gravity of the load positioned as far forward as possible without overloading the drive axle(s)
        - With the centre of gravity of the load positioned as far rearward as possible without overloading the semi-trailer axle(s)

A model was then developed to estimate the same parameters for new BEVs. To generate the model, information was collected on the mass of the diesel powertrain components and estimates of their centre of gravity position, plus key parameters for BEVs:

- Battery masses of current generation BEVs 3000 – 5440kg, average 4,093 Source: (Burgdorf, 2024)
- Mass of electric driveline added (motor, invertor and gearbox) 450kg (Mareev, et al., 2018)
- Mass of ICE driveline (diesel engine, fuel tank, transmission and drivetrain) replaced in a long-haul truck 1,700kg (Mareev, et al., 2018). This has been broken down here using the following estimates
    - Capacity of diesel tanks replaced 150 – 900 average 570 litres (mass 479 kg)
    - Mass of diesel tank (empty) 150 kg to 350 kg, average 250 kg
    - Mass of engine 750kg
    - Mass of gearbox 220kg

This allowed the axle weights of a tractor unit with no fuel or powertrain to be estimated. Assuming the engine centre of mass is 20cm in front of the front axle, the gearbox is 75cm behind the front axle and the fuel tanks around 3.5m from the front of the vehicle, suggested a tractor unit weight (minus powertrain) of nearly 5.7 tonnes, with 3.9 tonnes on the front axle and 1.8 tonnes on the rear.

Volumes of space were then defined where the electric motor, gearbox and battery packs could potentially be installed. All manufacturers that currently offer series production BEVs place battery packs at the side of the chassis where diesel tanks would be on traditional vehicles. All will use the space under the cab

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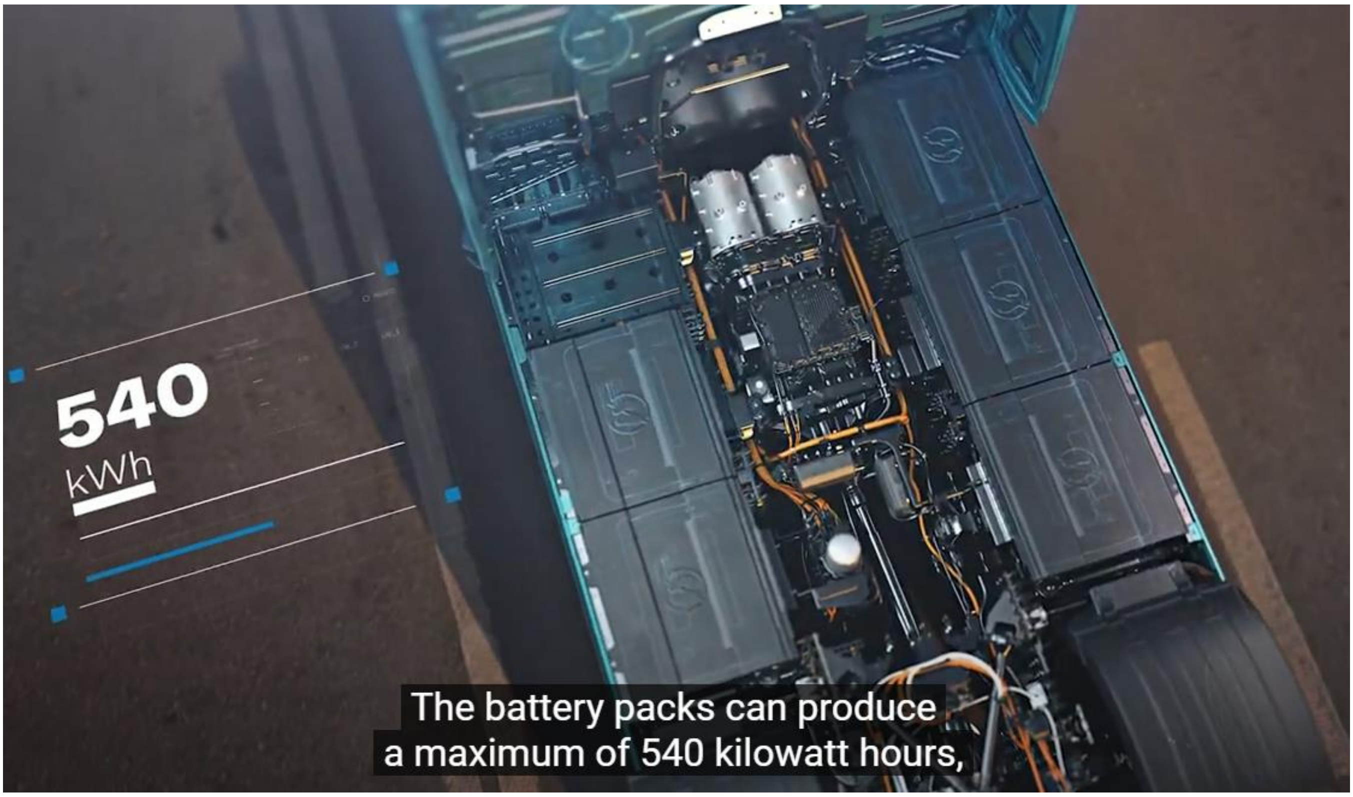
[1] https://www.daf.co.uk/en-gb/trucks/specsheets-search-page
[2] https://www.volvotrucks.co.uk/en-gb/trucks/models/volvo-fh/specifications.html
[3] https://www.krone-trailer.com/en/products/platform-semitrailer/profi-liner

where the engine used to be for more battery packs and/or other componentry such as the invertor. Some place the electric motor and gearbox in a relatively traditional position, albeit further rearward around the back of the cab, and then use a prop shaft and traditional driven axle. Others use an 'e-axle' that integrates the motor and gearbox directly within the axle itself, which frees up space further forward on the chassis for more batteries. Some examples are shown below.



The battery packs can produce
a maximum of 540 kilowatt hours,

Figure 1: Layout of electric motors, gearbox and battery packs in Volvo's first FH Electric units. Source: Volvo YouTube video[4]

In Figure 1, the electric motors are just behind the rear wall of the cab (silver cylinders,centre of the chassis), the gearbox is just behind that, and the drive shaft is just visible at the bottom of the image ahead of the rear axle. An additional battery pack can be added under the cab in the 'engine space'.

Figure 2: Illustration of electric motor and gearbox position (left) and with battery packs and invertor (right).

In Figure 2, the motor appears to be positioned slightly more to the rear, allowing for two additional pack spaces ahead of it, potentially increasing the capacity of batteries that can be installed. Finally, an

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[4] https://youtu.be/JLS9wFr6xaQ?si=5xdBW5ZpQbCrSJ1E

illustration of an integrated e-axle is shown below.

Figure 3: E-axle that integrates electric motor, gearbox and final drive. Source: Volvo[5]

If this component was considered in the installation shown in Figure 3, then it would free up additional space that could also be used for batteries. However, the weight of the motor and gearbox itself would now sit directly on the rear axle and the weight of batteries added in the position vacated would also be more toward the rear of the vehicle. As such, it increases the proportion of the added weight that is carried by the drive axle.

The volume of space available on the chassis for batteries was then converted to the kWh installed capacity of batteries by information on the volumetric energy density (Wh/L or Wh/m^3) of batteries at the pack level. This is converted to the mass of the batteries by the gravimetric energy density (kWh/kg) at the pack level.

Considerable evidence exists of the gravimetric energy density of battery packs. This varies by the battery chemistry used. For example, information provided by T&E suggests that Daimler currently uses LFP battery packs with an energy density of around 140 Wh/kg, while TRATON Group brands Scania and MAN use Lithium Nickel Manganese Cobalt Oxide (NMC) battery packs with a reported energy density of around 175-180 Wh/kg. What gets used in future for which market segments and use cases will depend in part on the outcome of the Weights and Dimensions Directive. If weight becomes less important, then lower density LFP batteries will likely become more popular because of other advantages, such as a reduced requirement for raw materials, lower cost, higher durability and improved thermal stability (lower fire risk).

BloombergNEF (BNEF) publishes data and forecasts on battery energy density[6]. This forecasts significant improvements in energy density but tends to estimate figures for current performance that somewhat exceed what is implied by the current specifications from truck manufacturers. This may be

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[5] https://assets.volvo.com/is/image/VolvoInformationTechnologyAB/Volvo%20Trucks%20e-axle?wid=1400&fit=constrain

[6] https://about.bnef.com/

related to considering battery packs as a component in isolation instead of 'as installed' on a real vehicle where crash protection etc. are all important but may add weight.

So, T&E has undertaken analysis to estimate battery energy densities in future. It involves assuming the BNEF development figures are offset back in time such that a 2025 estimate is based on BNEF data for 2020. The truck market is assumed to be split 64% by NMC batteries and 36% LFP in 2025, evolving to 70% NMC and 30% LFP by 2030. These assumptions are also benchmarked against the current HGV market share of battery chemistries by manufacturers and their corresponding market share. This produces the following estimate of a single typical figure to represent the whole truck industry.

Table 2: Forecast Battery pack Energy Density. Source: T&E estimate

	2025	2026	2027	2028	2029	2030
Forecast typical truck energy density (installed) at the pack level	174	182	191	200	208	217

BNEF do not publish equivalent data for the volumetric energy density of batteries. The following information was used as a guide to relevant figures:

- (US Energy, 2022) found that volumetric energy density had increased from 55 Wh/L in 2008 to 450 in 2020.
- Based on figures from benchmarking passenger cars (Konig, et al., 2021) also found a trend of increasing volumetric energy density at a similar or in some cases greater rate than for gravimetric density. In 2020, they identified state of the art vehicles that were producing around 350 Wh/L.

The evolution of vehicle layouts and battery energy density led to the definition of three generations of heavy-duty BEVs as described below:

- **Gen-0**: These are the first heavy duty trucks that came onto the market in the last couple of years and would have been the basis of first considerations of the needs for the proposed changes to the E&D Directive. Here, the layout is assumed to be with an electric motor and gearbox just behind the cab, most volume for battery packs alongside the chassis (replacing diesel tanks, max 1.57m^3) plus a small volume (up to 0.64m^3) in the diesel engine space at the front for batteries. Gravimetric energy density was assumed to be 164 Wh/kg, lower than the BNEF/T&E suggestion for 2025, but broadly consistent with the first real series production vehicles. An iterative analysis was undertaken with respect to volumetric density, adjusting the figure until the kWh installed capacity, total weight of tractor unit and axle weights of tractor unit all fell within the range of actual figures for first release vehicles configured in this way. This was achieved with a figure of 315 Wh/L, slightly lower than may have been expected based on passenger car figures but well within the published range of estimates.
- **Gen-1**: These represent the most recent vehicle releases on the market or imminent releases where information has been published, recognising that despite only being available for one or two years, the designs are already evolving. It includes an assumption that the motor is moved rearward to enable additional space for batteries, or an integrated e-axle is installed. It assumes that gravimetric energy density improves to 174 Wh/kg and volumetric density improves by the same ratio to give a figure of 334 Wh/L.
- **Gen-2**: represents vehicles that will reach the market before 2030. Besides fundamental vehicle and cab design changes, the base architecture and layout is assumed to be the same as Gen 1 with options for e-axles or rear based motors and drive shafts. It is assumed that energy densities will improve further to 217 Wh/kg and 416 Wh/L.

2.2 Calculating the impacts on structural road wear

Road wear impact is typically assessed by the calculation of ‘standard axles’ to produce a load equivalency factor (Atkinson, et al., 2006). This is a count of how many ‘standard’ axles would produce an equivalent amount of road wear to each actual axle you want to consider. To calculate it the actual axle weight (in Newtons) is divided by the standard 80kN and the result is raised to the power of an exponent. As a rule of thumb, the exponent is typically taken to be a value of 4 and is often referred to as the fourth power law. Applying the fourth power law predicts that if the axle weight doubles, then the associated road wear will increase by a factor of 16.

In reality, the appropriate exponent is different for different types of road construction and different pavement distress mechanisms. (Cost 334, 2001) showed that despite variation in the actual coefficients in different circumstances, the different traffic frequencies of heavier and lighter axles balanced this to mean that it remained a good representation of traffic as a whole.

The spacing between axles and the nature of the tyre contact patch can also affect the road wear of a group of axles, or the whole vehicle (Cost 334, 2001). This is because some road structures will partly transmit the load under one axle to areas of the structure around that axle. If other axles are close, they can add to the load that the pavement directly under the first axle experiences. Other structures may take a finite time to ‘relax’ after an axle passes and if another axle passes before that happens the forces in the structure can be higher. This is why the weight limits in the Directive are related to axle spacing, for example, a single axle can be 10 tonnes but a tandem axle with less than 1.8m space between each axle can only be 19 tonnes, not the sum of two 10 tonne axles.

Road construction engineers will design roads to last for a defined number of passages of standard axles, which accounts for the ‘hostility’ of each vehicle to the road surface and the number of each vehicle type that will pass over it in its life. So, it can be very important to them that the exponent used in their design is the most appropriate for the road type they are building, the type of traffic it is carrying and the real-world loading of those vehicles, including overloading. Even so, different countries take different approaches. In the UK, the method remains based on the standard fourth power law. In Portugal, the preference is to use modifiers for tandem and tridem axles and an exponent of 4 for flexible pavement (e.g. modern asphalt), 6 for semi-rigid pavement, and 12 for rigid pavement (e.g. concrete).

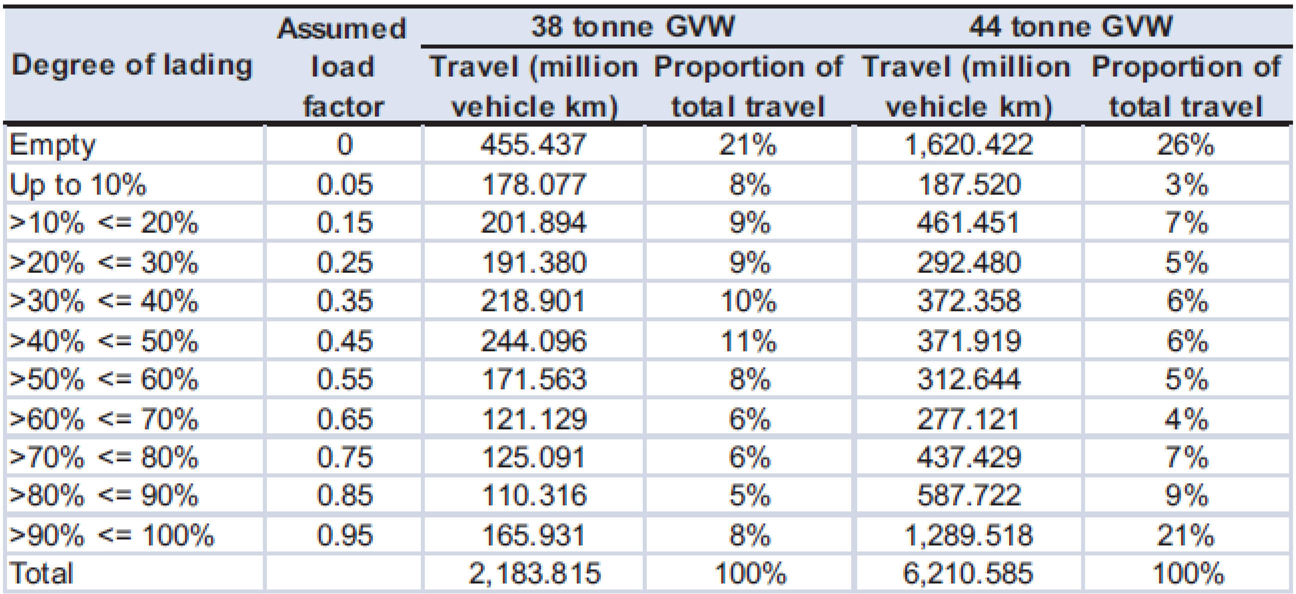
If considering a simple comparison of how hostile one vehicle configuration is compared with another, this is much less needed and could actually complicate the message. The relative change in the number of standard axles with a single exponent of 4 is sufficient to clearly show the effect per vehicle. Dividing the number of standard axles by the payload carried in that condition gives a clear indication of the scale of the national effect by showing the change in road wear per tonne of freight transported. This accounts for the fact that in many changes, the additional axles or increased axle weight will be due to carrying more freight on a single vehicle and hence reducing the number of freight movements.

The Commission Impact Assessment (IA) (European Commission, 2023) shows that the study was done using the more complex method with different factors for groups of axles and different exponents for different types of road surface. In theory this has the benefit of being more accurate, particularly for countries that may have an unusually large length of legacy concrete roads. However, the IA also acknowledges that the information on the proportion of roads in each category, for each country, is not often publicly available and therefore for a substantial number of countries an average was used based on countries that did have information. It is also worth noting that the ‘standard axle’ considered in the Commission study was one of 10 tonnes rather than 80 kN. This means that the number of standard axles for a given vehicle is expressed as being lower. It should not affect the relative comparison here.

The Commission’s IA does not state the vehicle loading assumptions used in the road wear calculation. No single assumption on the state of load is sufficient for an accurate assessment. For example, take the average load. In a mathematical average a trip where the vehicle carried a full load of dense goods (e.g. steel bars) at GVW, counts equally with a trip where a full load of light goods is carried (e.g. boxes of cereal). Thanks to the fourth power law, the road wear of these trips should not be counted equally; increasing the load of steel bars by 2 tonnes will cause much more road wear than adding 2 tonnes to the load of cereals.

The most accurate way to calculate the value is using data on the vehicle kms that a vehicle travels in different states of load (e.g. empty, 10% load, 20% load etc). Such data is not available on an EU wide basis and is relatively scarce on a national basis. In the past it was available from national freight surveys in the UK.

Table 3: Vehicle km at different states of load for vehicles in the UK in 2005. Source: (Knight, et al., 2011) based on data from the Continuing Survey of Road Goods Transported



Degree of lading	Assumed load factor	38 tonne GVW		44 tonne GVW	
		Travel (million vehicle km)	Proportion of total travel	Travel (million vehicle km)	Proportion of total travel
Empty	0	455.437	21%	1,620.422	26%
Up to 10%	0.05	178.077	8%	187.520	3%
>10% <= 20%	0.15	201.894	9%	461.451	7%
>20% <= 30%	0.25	191.380	9%	292.480	5%
>30% <= 40%	0.35	218.901	10%	372.358	6%
>40% <= 50%	0.45	244.096	11%	371.919	6%
>50% <= 60%	0.55	171.563	8%	312.644	5%
>60% <= 70%	0.65	121.129	6%	277.121	4%
>70% <= 80%	0.75	125.091	6%	437.429	7%
>80% <= 90%	0.85	110.316	5%	587.722	9%
>90% <= 100%	0.95	165.931	8%	1,289.518	21%
Total		2,183.815	100%	6,210.585	100%

It can be seen that 21% of all vehicle km (28% of laden vehicle km, excluding empty running) in 44 tonne vehicles are undertaken at >90% of maximum weight capacity, but only around 10% of those laden km in 38 tonne vehicles[7].

Statistics like those above can sometimes be misinterpreted to mean that vehicles are fully loaded for ~20% of the distance travelled, empty for ~25% and part loaded for ~55% of the distance travelled. Although that 55% will inevitably include some journeys where vehicles are not full, it will be far more common that they are simply full in terms of volume, such that no more goods can be carried, but the goods are lower density such that they do not approach the mass limit.

The density of goods shipped by vehicle km will vary in different Member States, depending on the type of economy in that country. A consumer economy with lots of finished products will generally ship a larger proportion of lower density goods than one where heavy industries, mining and manufacturing are more common. The distribution of weights in states of load between empty and full by mass can have a significant impact on the aggregate total road wear.

For this analysis, the approach based on the load factors and vehicle kms at different stages of loading has been used. However, this has been expressed relative to commodity densities to more accurately convey the message that most of those movements are full. Shipment of lower density commodities are full by volume, higher density ones full by mass. The UK distribution data has informed the analysis, but

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[7] This is because, in the UK the lighter vehicles are generally only used for low density freight that is much more likely to reach the volume capacity of the vehicle before it reaches the weight capacity. For dense goods and 'general purpose' haulage the heavier vehicle is always used

it has been adjusted to better reflect EU levels of empty running and average loads[8]. This showed that in the EU-27 in 2021, there was 132.8 billion vehicle kms loaded, of a total of 166.3 billion vehicle kms, such that 33.5 billion vehicle kms, or 20% was unladen. The average load (including empty running within the average) for vehicles with a MCW between 30 and 40 tonnes, was 17.15 tonnes, which represents approximately 66%, which is substantially higher than in the UK, likely representing economic differences.

As such, the pavement wear analysis was undertaken for empty runs and for 10 different full loads representing the range from very lightweight goods to those that would result in being full by mass for all of the assessed vehicle combinations. The resulting load distribution was as shown in Table 4, below.

Table 4: Load conditions upon which road wear calculations were assessed

Commodity examples	Commodity density (kg/m^3)	Proportion of vehicle km represented by that load condition	Average load weighted by vehicle km, including empty running
Empty running	NA	20%	17.06 tonnes
Crisps	<58	2%	
Tobacco, flaked	58-87	3%	
	87-116	3%	
Breakfast Cereal	116-145	4%	
Dry Malt	145-174	4%	
Tea Leaves	174-203	4%	
	203-232	5%	
Tissue Paper	232-261	7%	
	262-310	8%	
Ground coffee	>310	40%	

Any commodities with a density more than that approximated by ground coffee (e.g. wood, metals, aggregates, petrol etc), will reach the weight limit on standard EU goods vehicles without filling the maximum available volume. The distribution of vehicle km by commodity and the resulting mass at full loads produces an estimate of average load that closely represents the EU average load figure.

2.3 Assessment of infrastructure costs

(European Commission, 2023) derived information on infrastructure maintenance costs from OECD data[9]. That source contains just two categories of road infrastructure costs, investment and maintenance. Not all countries had information available for maintenance, more were available for investment. The

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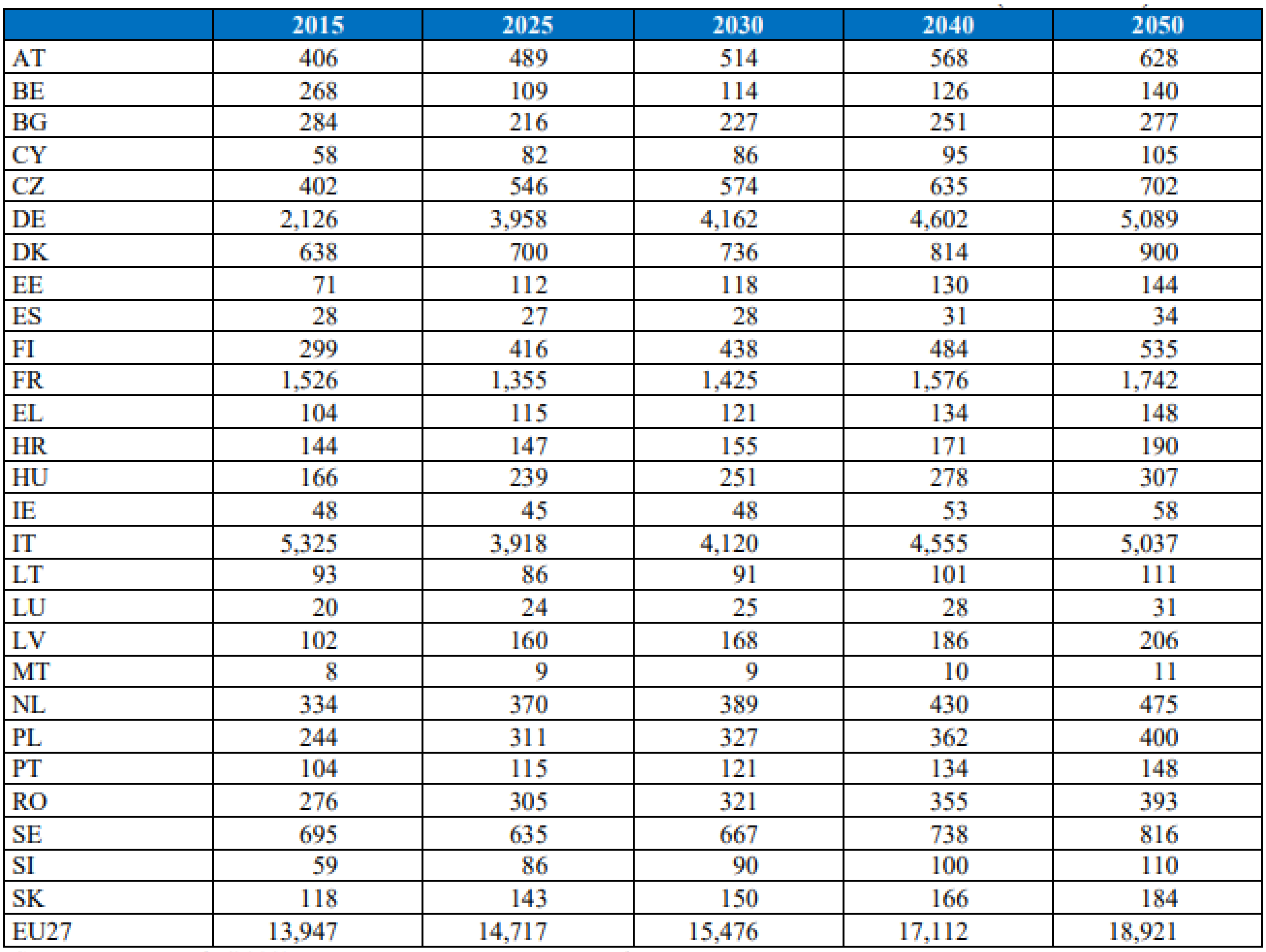
[8] Based on data extracted from Eurostat in 2022 https://ec.europa.eu/eurostat/databrowser/product/page/ROAD_GO_TA_TOTT__custom_3501248.

[9] https://data-explorer.oecd.org/

gaps were estimated based on the data that was available and scaling to other countries. In total it was estimated that in the EU in 2025 around €15 billion would be spent on road maintenance, and around 27% of that would be in Germany.

Table 5: Maintenance costs for road infrastructure attributed to HGVs above 32 tonnes (Eur Million). Source: (European Commission, 2023)



	2015	2025	2030	2040	2050
AT	406	489	514	568	628
BE	268	109	114	126	140
BG	284	216	227	251	277
CY	58	82	86	95	105
CZ	402	546	574	635	702
DE	2,126	3,958	4,162	4,602	5,089
DK	638	700	736	814	900
EE	71	112	118	130	144
ES	28	27	28	31	34
FI	299	416	438	484	535
FR	1,526	1,355	1,425	1,576	1,742
EL	104	115	121	134	148
HR	144	147	155	171	190
HU	166	239	251	278	307
IE	48	45	48	53	58
IT	5,325	3,918	4,120	4,555	5,037
LT	93	86	91	101	111
LU	20	24	25	28	31
LV	102	160	168	186	206
MT	8	9	9	10	11
NL	334	370	389	430	475
PL	244	311	327	362	400
PT	104	115	121	134	148
RO	276	305	321	355	393
SE	695	635	667	738	816
SI	59	86	90	100	110
SK	118	143	150	166	184
EU27	13,947	14,717	15,476	17,112	18,921

For this report, it was decided to look in more detail at three specific countries; Germany, Poland and Romania.

The estimate of the cost effect of increasing axle weights is a function of the total amount of spending on infrastructure maintenance, and the proportion of that which is directly attributable to the weight of 5 or 6 axle HGVs and the number of those that circulate in the country. Multiplying the standard axles per tonne transported, by the tonne km of activity of that type of vehicle in that country, produces a measure of standard axle kms produced by that vehicle type. Dividing the total maintenance cost attributable to that vehicle type by the standard axle kms for the same vehicle type estimates a cost per standard axle km. This cost per standard axle km can then be applied to different vehicles (e.g. BEVs under different policy options) based on the number of standard-axle kms they undertake in the country.

T&E provided data extracted from their European Union Transport Roadmap Model (EUTRM)[10] which models Europe's HDV fleet to assess the impact of the EU's CO2 emission standards on the fleet composition and ZEV uptake. Historical data on activity and growth projections are extracted from the EU

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[10] https://www.transportenvironment.org/articles/why-all-new-freight-trucks-and-buses-need-to-be-zero-emission-by-2035

Reference Scenario which means that the model can project future growth in vehicle activity. The EUTRM provided the projected vehicle activity (in vehicle km) by different HGV categories and axle combinations and the proportion of those that were expected to be undertaken each year by BEVs and by diesel vehicles. The projected ZEV uptake considers regional differences by assuming a faster growth of battery electric activity for Germany as compared to Poland and Romania. The BEV activity was divided to reflect different BEV technology classes and range classes for different length journeys. Calculated standard axle kms for each of those classes was combined to produce the cost estimates. The results can be seen in section 5.

The source of maintenance cost data varied. For Germany, (Korn, et al., 2021) provided a detailed report assessing road infrastructure costs in accordance with Directive 1999/62/EC (Eurovignette Directive) to calculate external costs to feed into road user charging schemes. This showed that Germany was expected to spend an average €14.7 billion euro on roads per year between 2023 and 2027. This is considerably more than was implied by the OECD data. The report laid out detailed tables of how much of this was attributable to weight and other usage and some of these headings strongly implied it included elements of road investment, which would explain the difference. The report also laid out how much was attributable to vehicles of 5 or more axles and a GVW of more than 18 tonnes, slightly different to the approach in the OECD data informing the Commission estimate (European Commission, 2023). Selecting items attributable to those vehicles and to weight related causes, identified a cost attributable to that vehicle activity of around 2.5 billion euro per year, which was more consistent with the implication from the OECD data and assumptions about the proportions caused by different vehicle types, though only around two-thirds of the value estimated in (European Commission, 2023).

For Poland and Romania, the only source identified was the OECD data extrapolated in the European Commission IA and reproduced in Table 5, above.

2.4 Assessing the impact on bridge structures

For bridge structures the general concepts of bridge design and assessment have been very briefly reviewed. The stresses that two baseline vehicles (a 40-tonne diesel vehicle combination and a 42-tonne combination steered by a BEV compliant with current regulations) would generate in a range of different bridge types and spans has been calculated. This allows the increase in stress for different regulatory options to be quantified. The stress that would be generated in those same bridges if the notional minimum loads that design standards require bridges to be capable of carrying has also been calculated, both for the latest Eurocode standard and a much older German standard (DIN 1072) used previously in some countries. The difference between the stress imposed by the design loads and that by the vehicles can be considered the factor of safety inherent in the bridge design, considering suspension dynamics, overloading and allowance for future traffic or vehicle load increases. It also represents an estimate of the amount of carrying capacity that the bridge needs to lose in service before it becomes likely that the real vehicle modelled could cause a risk of collapse.

3 What is the rationale for weight increases?

3.1 Maximum authorised Combination Weight (MCW)

Eurostat data[11] shows that in the EU-27, around 57% of all freight tonne-kms is transported less than 500km and 81% is transported less than 1,000km. A long-haul truck travelling on predominantly highway roads usually average around 80 km/h when considering speed limits, traffic congestion and construction sites, covering up to around 720 km in a 9-hour driving shift. So, those freight movements of more than that will require either a two-driver crew or an overnight stop. An overnight stop provides a potential opportunity to charge for a prolonged period, subject to the availability of chargers at rest stops. There are also opportunities to charge during mandatory driver 45-minute rest breaks and stops to unload at destination(s) etc.

This simplistic analysis is strongly supported by evidence from a large fleet of HGVs in the Netherlands. Here a distribution of daily distances driven was calculated from the data, split by whether the vehicle was rigid or articulated and using normal distributions and adjusting for trip length differences between the Netherlands and the EU. This shows that 50% of articulated vehicles in the fleet complete average daily distances of less than 525 km. Very nearly 90% complete less than 700 km per day. Of course, daily distances for a given vehicle vary and the analysis of the data (Tol, et al., 2022) found that 90% journey length was about 30% higher than the average and this might be a reasonable threshold for what range was required. However, that range could also include charging for 45 minutes at an average 500kW.

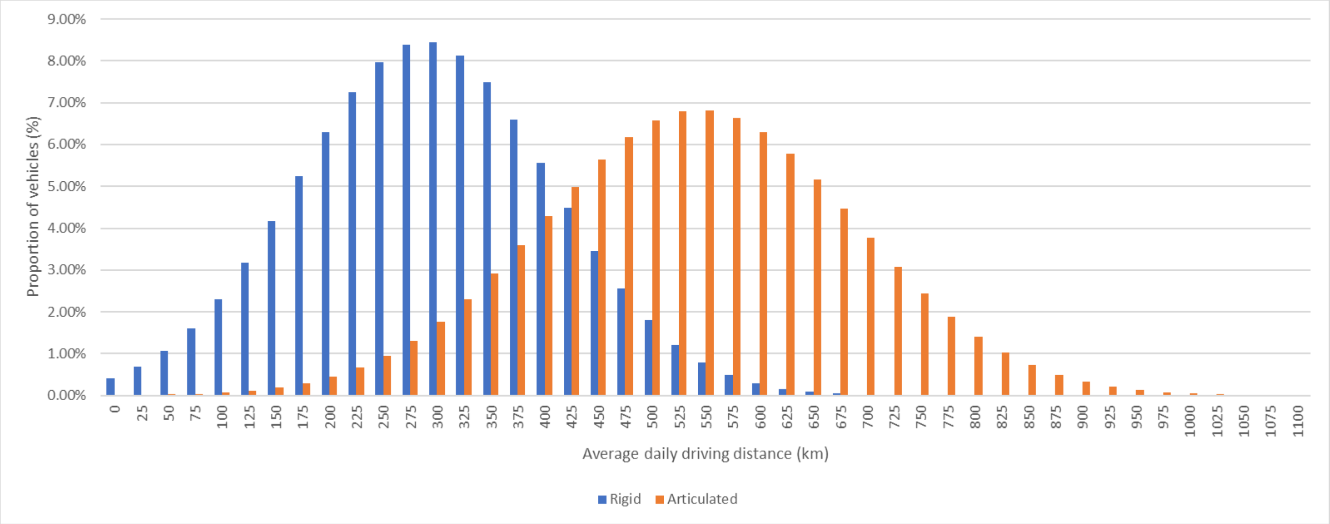

Figure 4: Distribution of the average daily driving distances for vehicles. Source: (Tol, et al., 2022)

Based on these data, three range classes for BEVs were defined based on the distance they could drive without charging; 300km, 500km, and 700km. As such a vehicle with a range class of 700km would be able to complete substantially more than 700km in a day, if fast charging for 45 minutes during the drivers rest break is accounted for (potentially with an average charge rate of 500kW, then 375 kWh could be added) As such, there would be only a small proportion of daily driving distances that could not be completed with a range class of 700 km. For the vast majority of use cases, vehicles with smaller batteries and shorter ranges could be sufficient, reconciling cost considerations and range flexibility.

Few detailed specifications of production BEVs are publicly available but, where they are, comparing like for like diesel and battery electric specifications suggests that the additional 2 tonnes are not enough to equalise payload for the earliest generation of vehicles which came to market over the past few years, even where the range is substantially less than required for a large proportion of the daily driving

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[11] https://ec.europa.eu/eurostat/databrowser/view/road_go_ta_dc__custom_12951728/default/table?lang=en

requirements identified above.

Table 6: Comparison of weights for BEVs and diesel vehicles of the same make, model and specification. Source: Apollo compilation from manufacturer specification sheets.

Make / model	Unladen Mass of tractor unit (kg)[12]			Max BEV Range (km, OEM estimate)	Payload capacity change (kg)
	Diesel Variant	BEV Variant	Change		
Daf XF 4*2[13,14]	7,258	9,995	+2,737	300	-737
Volvo FH 4*2[15,16]	6,855	9,880	+3,025	300	-600
MAN TGX 4*2[17]	7277	10,286	+3,009	450	-1,009
Iveco SWay 4*2[18]	6,981	12,140	+5,159	500	-3,159

It can be seen that for this small selection of vehicles, only range classes of 300 and 500 could be available, not 700, and even the 300 range class adds more than the additional allowed two tonnes. There are already new generation vehicles being promoted (e.g. Volvo are advertising an FH Aero Electric with a range of 600 km for series production in 2026[19]. This is sufficient to meet the daily distance needs of a large proportion of journeys even without charging during a rest break or loading/unloading stop. In fact, it may be significantly more than is needed for a significant proportion of the fleet undertaking duties with much lower daily distances. All of the manufacturers offer a modular approach to battery packs such that the option to 'right size' the battery and number of packs for the operation does exist and mitigates the payload issue identified to some degree. However, long range transport of dense goods would clearly require an increase in the number of vehicles, if the additional unladen weight of the vehicle is not compensated by some means, be that technical improvement or a change to the regulatory limits.

3.2 Drive axle weight

A standard EU articulated vehicle has 5 axles, 2 on the tractor unit and 3 on the semi-trailer. However, the additional weight of the ZE technology will currently all be applied to the 2 axles on the tractor unit. How much gets applied on the front axle and how much gets applied to the rear axle depends on where the ZE technologies, primarily the batteries but also the invertor, motors and gearbox get positioned on

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[12] This is the mass of a tractor unit without a trailer coupled to it or a driver within it, and typically with all required fluids for operation. However, exact definitions, particularly fuel load, can vary between different manufacturers. It is also valid only for the exact specification chosen, a wide selection of possible specification differences will affect the exact unladen weight of any particular vehicle.

[13] https://www.daf.co.uk/api/feature/specsheet/open?container=75cff1d0-28b4-47ad-abe3-391f4f13d71b&filename=TSGBEN016G0209AAAA202501.pdf

[14] https://www.daf.co.uk/api/feature/specsheet/open?container=598908e5-2833-458e-b22c-60789dba35dc&filename=TSGBEN016G0200AAAA202437.pdf – Daf BEV with 325-525 kWh batteries

[15] https://stpi.it.volvo.com/STPIFiles/Volvo/ModelRange/fh42t3a_gbr_eng.pdf

[16] https://stpi.it.volvo.com/STPIFiles/Volvo/ModelRange/fh42te_gbr_eng.pdf. Note that Volvo vehicle specifications were based only on driver weight, no fuel, so adjustments were made to equalize with other vehicles.

[17] Bespoke build specifications provided by MAN UK with only difference powertrain. Batteries 534 kWh.

[18] Specifications provided by Iveco UK. For BEV this relates to the original eSway with 9 batteries and 738kWh, not a second generation expected for imminent release at the time of writing.

[19] https://www.volvotrucks.com/en-en/news-stories/press-releases/2024/sep/breakthrough-volvo-to-launch-electric-truck-with-600-km-range.html

the vehicle.

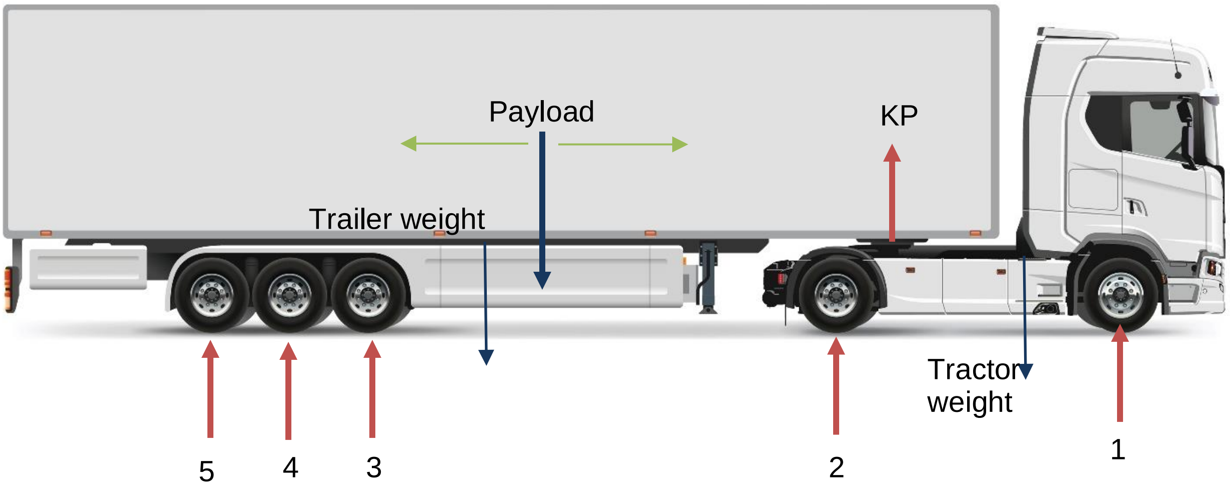

Figure 5: Illustration of load distribution.

The load in the semi-trailer also has a substantial effect on the axle weights of the tractor. The load is applied through the king-pin (KP) which is closest to the rear axle (drive axle, axle 2) of the tractor. So, most of the king-pin load gets added to the rear axle of the tractor (2) but some will add to the front axle (1). The size of the king-pin load depends on the weight of the trailer and its payload and its positioning. A payload of the same goods (uniform density) that fills the available space will have a centre of mass geometrically centred in the semi-trailer. However, very dense loads will not fill the space and may be positioned further forwards or further rearwards than centre. Alternatively, a load of different mixed goods may have higher density goods in one position than another. A centre of gravity forward of the mid-point of the semi-trailer will increase the loads on the king-pin and the tractor unit and decrease the axle loads on the triaxle unit at the rear of the semi-trailer. One rearward of the mid-point will do the opposite.

MCW is limited by law to 40 tonnes for diesel trucks[20], although many EU Member States already make use of allowed derogations to permit 44 tonne diesel trucks within national borders The maximum permitted axle masses for the combination shown in Figure 5 are 10 tonnes for the front, 11.5 tonnes for the drive axle, and 8 tonnes each for the tri-axle semi-trailer bogie. This sums to 45.5 tonnes, 5.5 tonnes more than the MCW. This ‘spare capacity’ or tolerance allows for variation in the loading position without exceeding individual axle masses. The corollary of this is that when loaded to the MCW, at least some of the axles will be loaded to significantly less than their maximum. If additional unladen weight is added to the tractor unit and the MCW stays the same, then the maximum payload reduces. Less payload will reduce the load imposed on both tractor and trailer axles. This means the reduced payload can compensate for the additional unladen weight of the drive axle and front axle potentially keeping their fully laden weight the same. However, the trailer axles would then decrease in their mass when laden. The relationship between regulated loads and the actual axle loads experienced in service for the range of different goods and loading practices is quite complex and variable. Assuming one fixed set of axle loads for use in road wear calculations, particularly if based on the regulated max loads, is a substantial over-simplification of reality.

A model of vehicle axle mass was developed based on current vehicle specifications from vehicle manufacturers for individual tractors and one standard semi-trailer. It mathematically combines the tractor unit, and trailer specifications to produce the following results for the complete articulated combination based on a standard diesel tractor unit. As such, adding axle 1 and axle 2 (the tractor unit axles) for the unladen weight in Table 7 below, will imply a total weight for the tractor that is greater than the diesel weights quoted for the unladen tractor in Table 6. This is because part of the unladen weight of the trailer

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[20] Actually, all vehicles with internal combustion engines are limited to 40 tonnes, diesel is used to represent these for convenience.

has been added to the tractor when the two are considered as a combination.

Table 7: Combination and axle weights used for reference 2+3 tractor semi-trailer diesel baseline

	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Total
Maximum Permitted weight (kg)	10,000	11,500	8,000	8,000	8,000	40,000
Unladen weight (kg)	5,529	3,279	1,513	1,513	1,513	13,349
Available payload (kg)	4,471	8,221	6,487	6,487	6,487	26,651
Fully laden weight (central load 50%)	7,060	10,440	7,500	7,500	7,500	40.000
Fully laden weight (max forward 47%)	7,290	11,500	7,070	7,070	7,070	40.000
Fully laden weight (max rear 53%)	6,799	9,200	8,000	8,000	8,000	40,000

The standard European diesel truck provides significant flexibility. The maximum drive axle load is 11.5 tonnes but with an evenly distributed full load on the trailer, the actual drive axle load when full is less than 10.5 tonnes. There is a positional tolerance on the centre of mass of a full load that is equivalent to plus or minus 3% of the loading length of the semi-trailer, or about 40cm. This allows operators to carry a variety of full loads without any great likelihood of unintentionally overloading a single axle[21].

The model has been used to undertake the same calculation for the baseline Gen-0 BEV currently offered under the legislation allowing GVW to be up to 42 tonnes and the results can be seen in Table 8.

Table 8: Combination and axle weights for baseline Gen-0 BEV, 2+3 tractor semi-trailer combination at 42 tonnes MCW with 468 kWh installed battery capacity, estimated range 330km

	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Total
Maximum Permitted weight (kg)	10,000	11,500	8,000	8,000	8,000	42,000
Unladen weight (kg)	6,240	4,158	1,513	1,513	1,513	14,938
Available payload (kg)	3,760	7,342	6,487	6,487	6,487	27,062
Fully laden weight (central load 50%)	7,807	11,415	7,593	7,593	7,593	42.000
Fully laden (max forward 49.7%)	7,826	11,500	7,558	7,558	7,558	42,000
Fully laden weight (max rear 53.9%)	7,590	10,410	8,000	8,000	8,000	42,000

The increase in the actual unladen combination weight from 13,349 to 14,938 kg is less than the maximum 2 tonnes increase in MCW from 40 to 42 tonnes. This results in a nominal payload increase of

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[21] Overloading can and does still occur if the total load is too large, or where dense goods that do not fill the available space are poorly positioned too far forward or too far back. It can also occur with a full load that is partly unloaded from the rear, because load carried behind the semi-trailer axles actually lifts weight off the king pin and the rear axle of the tractor. So, removing the last few rows of pallets will move the centre of mass forward significantly and increase drive axle loads. However, there is a reasonable degree of “tolerance” in the system.

411kg, compared with the diesel reference. EU Directive 96/53/EC, as amended in 2019 by Regulation (EU) 2019/1242, allows only for the additional weight of the zero emissions equipment to be added to the GVW. So, what should happen in this example is that the MCW should be increased by 14,938-13,349=1,589kg to 41,589kg. Then, the payload will remain the same at 26,651kg.

In practice, it is difficult for manufacturers and type approval authorities to deal with this requirement. For example, for any given diesel tractor unit there will be a wide range of choices of diesel tank capacity, which substantially affects the unladen mass. What specification do you choose as the reference vehicle? Equally, for a BEV in need of maximum range, then the manufacturer will use the longest possible wheelbase to maximise space for the batteries. In diesel form, the same job could be done with a shorter wheelbase. Does the additional mass caused by the longer chassis count as part of the zero emissions equipment qualifying for additional weight? What does a new entrant to the market like Tesla use as the reference weight?

Consultation with an OEM suggests that not all Member States have fully transposed the 2019 amendments to Directive 96/53/EC. Of those that have, a number are thought to have implemented it in a simplified form that simply grants a blanket 2 tonne uplift to BEV. For example, (DfT, 2023) confirmed that in the UK the requirements of the Directive were still implemented even post-Brexit as part of the Trade & Cooperation Agreement with the EU. However, a blanket 2 tonnes was permitted, rather than asking for specific compensation for the existing equipment only. This was because of difficulties identifying all the equipment that should be considered, the context that many vehicles would require more than 2 tonnes to avoid payload loss, and the intention to provide the maximum incentive possible. A similar blanket approach is taken in France[22]. However, in Germany the regulations[23] do still refer to up to 2 tonnes extra on condition the additional weight is due to the ZE technology. It is not known how effectively the requirements are applied in practice and, in fact, it may not yet have been tested in relation to 40/42 tonne vehicles if it is always very easy to show that they are currently at least 2 tonnes heavier.

With the payload centrally (50%) positioned in the semi-trailer, the drive axle weight has increased from 10,440 to 11,415 kg. Although the headline maximum permitted value of 11.5 tonnes has not changed, the reality is that for many full loads, the actual drive axle weight has increased by nearly one tonne. Correspondingly this has reduced the loading flexibility substantially. There is now very little scope for the centre of gravity of the load to be positioned forward of centre. This is less of a problem for very dense loads that don’t fill the space because the load can be moved slightly backwards, but even this makes it more difficult for operators to be confident they will comply with axle weight limits. To mitigate any risks of the reduced operational flexibility in load position, many manufacturers are offering their BEV vehicles with on-board axle weighers (not certified for enforcement) to help operators avoid overloading an axle.

If further increases in weight allowances are considered, it is clear that the drive axle weight will be the limiting factor.

Newer generations of technology with improved battery energy densities and also revised component and tractor layouts will help. The following analysis is based on the improved Gen-1 level technology only very recently available or on vehicles due in 2025. The results are shown below.

Table 9: Combination and axle weights for Gen-1 BEV, 2+3 tractor semi-trailer combination with 800kWh installed battery capacity, estimated range 650 km

	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Total

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[22] https://www.legifrance.gouv.fr/codes/section_lc/LEGITEXT000006074228/LEGISCTA000006129091/

[23] https://www.gesetze-im-internet.de/stvzo_2012/BJNR067910012.html

Maximum Permitted weight (kg)	10,000	11,500	8,000	8,000	8,000	42,000
Unladen weight (kg)	7,247	4,890	1,513	1,513	1,513	16,677
Available payload (kg)	2,753	6,610	6,487	6,487	6,487	25,323
Weight with theoretical Max payload (central load 50%)	8,714	11,680	7,202	7,202	7,202	42,000
Weight with max actual payload (central load 50%)	8,675	11,500	7,051	7,051	7,051	41,327
Fully laden weight (max forward 50.4%)	8,465	11,500	7,344	7,344	7,344	42,000
Fully laden weight (max rear 55%)	8,116	9,881	8,000	8,000	8,000	42,000

At an unladen weight of 16,677 kg, the maximum payload is notionally 25,323 kg, c.1.3 tonnes less than the diesel baseline. However, if this mass is placed centrally in the load space, then the drive axle will still be overloaded (highlighted red in the table). If the payload is centrally positioned, then the maximum that can be carried without overloading the drive axle is 24,650kg, c2 tonnes less than the diesel baseline.

The proposal from the European Commission (European Commission, 2023) is intended to solve this problem by permitting a total of 44 tonnes MCW and an additional 1 tonne on the drive axle, for a total 12.5 tonnes. These limits were applied to the same modelled vehicle with Gen 1 technology, and the results are shown in Table 10, below.

Table 10: Estimated combination & axle weights Gen-1 BEV (e-axle), 2+3 tractor semi-trailer combination (700kWh installed / 650 km range) - Commission proposal of 44 tonne MCW and 12.5 tonne drive axle

	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Total
Maximum Permitted weight (kg)	10,000	12,500	8,000	8,000	8,000	44,000
Unladen weight (kg)	7,247	4,890	1,513	1,513	1,513	16,677
Available payload (kg)	2,753	4,890	6,487	6,487	6,487	27,323
Weight with theoretical Max payload (centrally loaded 50%)	8,830	12,217	7,651	7,651	7,651	44,000
Weight with max actual payload (centrally loaded 50%)	8,830	12,217	7,651	7,651	7,651	44,000
Fully laden weight (max forward 49.3%)	8,893	12,500	7,536	7,536	7,536	44,000
Fully laden weight (max rear 52%)	8,645	11,354	8,000	8,000	8,000	44,000

A payload 672 kg greater than the diesel baseline is now feasible and there is 283 kg ‘spare’ on the drive axle which allows slightly better flexibility in operation, or allows for additional battery mass if needed.

The Commission proposal makes it very feasible to have a 700kWh vehicle with a range more than 500km with Gen-1 technology available today and it can almost achieve the 700km target. From a vehicle and operator perspective, it is a proposal that meets nearly all of the requirements and would be expected to remove significant barriers to the adoption of BEVs for large parts of the road freight industry.

4 Potential alternative policy options

4.1 Technology evolution and ‘right sizing’ of batteries

Data has already been presented showing that developments in battery technology are expected to continue. The next generation of technology, referred to as BEV Gen-2, is expected to become available before 2030. The load distribution calculations were repeated with the Gen-2 assumptions and the results are shown in **Table 11**, below, under the Commission’s proposal for a 4-tonne weight increase with respect to diesel.

Table 11: Estimated combination and axle weights for Gen-2 BEV (e-axle), 2+3 tractor semi-trailer combination (790kWh installed / 710 km range) - Commission proposal of 44 tonne GCW and 12.5 tonne drive axle.

	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Total
Maximum Permitted weight (kg)	10,000	12,500	8,000	8,000	8,000	44,000
Unladen weight (kg)	6,603	4,575	1,513	1,513	1,513	15,718
Available payload (kg)	3,397	7,925	6,487	6,487	6,487	28,282
Weight with theoretical Max payload (centrally loaded 50%)	8,241	12,159	7,867	7,867	7,867	44,000
Weight with max actual payload (centrally loaded 50%)	8,241	12,159	7,867	7,867	7,867	44,000
Fully laden weight (max forward 49.3%)	8,315	12,500	7,728	7,728	7,728	44,000
Fully laden weight (max rear 52%)	8,170	11,830	8,000	8,000	8,000	44,000

Overall, the Gen-2 vehicle is predicted to be 959kg lighter than the Gen-1 vehicle shown in Table 10, while having a higher battery capacity and 60 km greater range, partly due to the battery capacity and partly due to improvements in energy efficiency. When this level of technology is achieved, then under the Commission’s proposal, even this long-range HGV will be able to carry more than 1.6 tonnes extra payload than a standard 40 tonne diesel vehicle.

Recalling the distribution of daily mileage requirements for fleets and assuming charging opportunities are available for rest breaks, then a substantial minority of current articulated vehicles could be replaced by BEVs with a much lower range. Approximately 25% of current articulated vehicles drive a daily distance of 425km or less. Accounting for variation in daily requirements and the possibility of charging during rest breaks, it is estimated that these could be replaced by vehicles in the 300 km range class. If this range was implemented with Gen-2 technology, under the Commission’s proposed revision, then the loads would be as follows.

Table 12: Estimated combination and axle weights for Gen-2 BEV (with e-axle), 2+3 tractor semi-trailer

combination (344kWh / 310 km range) - Commission proposal of 44 tonne GCW and 12.5 tonne drive axle

	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Total
Maximum Permitted weight (kg)	10,000	12,500	8,000	8,000	8,000	44,000
Unladen weight (kg)	5,598	3,533	1,513	1,513	1,513	13,671
Available payload (kg)	4,402	8,967	6,487	6,487	6,487	30,329
Weight with theoretical Max payload (centrally loaded 50%)	7,355	11,666	8,327	8,327	8,327	44,000
Weight with max actual payload (centrally loaded 50%)	7,271	11,276	8,000	8,000	8,000	42,546
Fully laden weight (max forward 48.1%)	7,535	12,500	7,988	7,988	7,988	44,000
Fully laden weight (max rear 48.2%)	7,530	12,470	8,000	8,000	8,000	44,000

With a lower range in the 300 km bracket, the prediction for Gen-2 technology is that the unladen weight would only be around 320kg heavier than a diesel vehicle. As such, nearly all of the 4 tonnes additional MCW will be available as payload. However, the extra payload is positioned on the trailer and the trailer axles will not benefit from any increase in the maximum semi-trailer axle weight limit. If the payload is positioned centrally then it can be seen that the trailer axle weight limits would be exceeded (coloured red). Where dense loads that don't fill the available space, then it is possible to move the load forward in the trailer. However, there is only a very small window of positioning, between 48.1% and 48.2% where the full payload can be carried without exceeding either the drive axle or trailer axle limits. The risk of unintentional overloading may be quite high.

4.2 Alternative option 1: Smaller changes

The analysis so far has shown that the Commission proposal works well for manufacturers and operators, allowing the possibility of replacing even those vehicles travelling relatively high daily mileages with BEVs, using technology levels that are becoming available today. However, when a few years more technical development is considered, and provided sufficient charging infrastructure is available to widely enable rapid charging during driver breaks, then a large proportion of BEVs would be getting quite substantial increases in payload. While this would be a strong commercial incentive to switch to BEVs, the infrastructure maintenance costs associated with the proposal is the crucial element preventing the proposal from being accepted. For a large proportion of the current fleet and daily distance duties, assuming the availability of adequate charging, then particularly when future technology is considered a policy with smaller increases could still ensure at least the same level of payload as a diesel vehicle.

The loadings are shown below for a BEV-2 700 under an alternative policy permitting an MCW of 43 tonnes with a maximum drive axle load of 11,750kg.

Table 13: Estimated combination & axle weights: Gen-2 BEV (e-axle), 2+3 tractor semi-trailer combination (790kWh installed / 710 km range) - Alternative proposal 43 tonne MCW & 11.75 tonne drive axle

	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Total
Maximum Permitted weight (kg)	10,000	11,750	8,000	8,000	8,000	43,000
Unladen weight (kg)	6,603	4,575	1,513	1,513	1,513	15,718
Available payload (kg)	3,397	7,175	6,487	6,487	6,487	27,282
Weight with theoretical Max payload (centrally loaded 50%)	8,183	11,891	7,642	7,642	7,642	43,000
Weight with max actual payload (centrally loaded 50%)	8,152	11,750	7,524	7,524	7,524	42,476
Fully laden weight (max forward 50.4%)	8,152	11,750	7,699	7,699	7,699	43,000
Fully laden weight (max rear 52.2%)	7,995	11,006	8,000	8,000	8,000	43,000

For dense goods that don’t fill the space, it is still possible to achieve the same payload as a diesel vehicle, by moving the load slightly back in the semi-trailer. However, this creates significant risk of accidental overloading of the drive axle with loads of optimum density that fill the volume and the weight limits. The main issue is the drive axle loading and, in this scenario, it is assumed that the vehicle uses ‘e-axle’ technology where the motor and gearbox is integrated in the drive axle. If the vehicle reverts to a design with a motor and gearbox positioned further forward, it creates more challenges in achieving sufficient space for batteries but shifts weight from the drive axle to the front axle. Revised loadings based on this assumption are shown below.

Table 14: Estimated combination & axle weights: Gen-2 BEV (traditional axle), 2+3 tractor semi-trailer combination (790kWh installed / 710 km range) - Alternative proposal 43 tonne MCW & 11.75 tonne drive axle

	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Total
Maximum Permitted weight (kg)	10,000	11,750	8,000	8,000	8,000	43,000
Unladen weight (kg)	7,165	4,578	1,513	1,513	1,513	16,284
Available payload (kg)	2,835	7,172	6,487	6,487	6,487	26,716
Weight with theoretical Max payload (centrally loaded 50%)	8,713	11,742	7,515	7,515	7,515	43,000
Weight with max actual payload (centrally loaded 50%)	8,713	11,742	7,515	7,515	7,515	43,000
Fully laden weight (max forward 49.98%)	8,714	11,750	7,512	7,512	7,512	43,000
Fully laden weight (max rear 52.2%)	8,455	10,545	8,000	8,000	8,000	43,000

It is possible to achieve high range vehicles while having a payload equal to current diesel vehicles but only with technology not expected to be on the market for the next few years. So, some level of disincentive will remain for operators involved in both heavy loads and long distances. The proposal is less flexible for manufacturers and operators than the Commission proposal, limiting the arrangement of componentry on the vehicle and increasing risks of unintentional overloading of the drive axle. However, it would at least equalise payload for a significant proportion of vehicles even in the short term.

4.3 Three axle tractor units

In much of Europe, 3 axle tractor units are mainly used for heavy haulage tasks, such as EMS operations and abnormal indivisible loads (AIL) at weights well in excess of 40 tonnes. In these circumstances, they usually employ two full size rear axles, wheels and tyres and both rear axles are often driven, to ensure a large enough proportion of the total weight is carried on drive axles to ensure good traction.

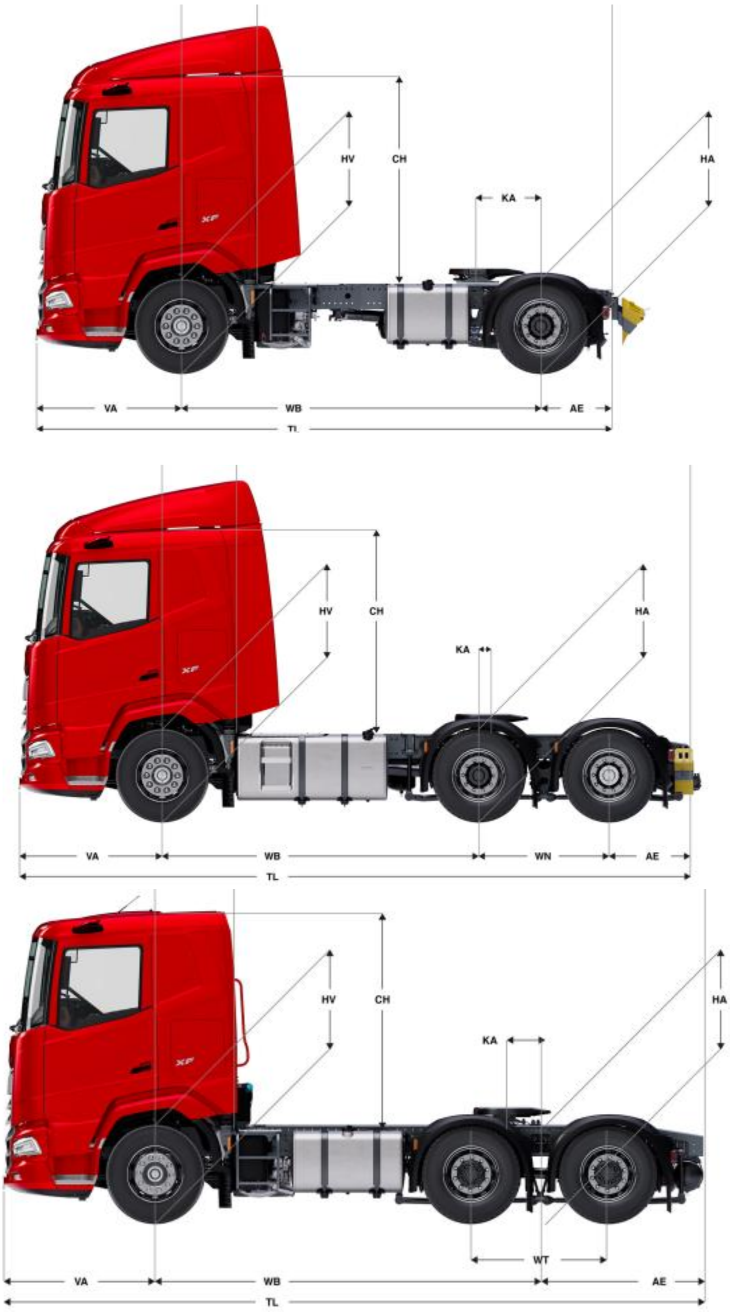

Figure 6: Comparison between Daf XF as 4x2 (top), 6*2 (Middle) and 6x4 (bottom) axle configuration

The 3 axle variants can have a longer chassis behind the 5th wheel and the additional axle reduces the space available between the front axle and the first rear axle. This area at the side of the chassis where diesel tanks are traditionally fitted is the largest volume available in traditional layouts for fitting batteries. So, there is less volume available to install batteries on a 3 axle vehicle compared with a 2 axle vehicle. In addition to this, the extra axle and length also add to the unladen mass.

Currently, Directive 96/53/EC applies the same MCW limit to 6 axle combinations as it does to 5 axle combinations. So, 3 axle tractor units will either be used with two axle trailers, which can suit some operations, or in operations like EMS and AIL that fall outside of those limits. However, some Member States (e.g. Ireland, Czechia, former MS UK) have, in national traffic, allowed 6 axle combinations to have higher mass limits than 5 axle combinations. If the MCW is increased sufficiently to offer more payload than the 5 axle vehicle, then it brings these vehicles into much greater use.

For example, the UK before 1999 permitted a maximum 38 tonnes for vehicles with 5 or more axles but were required by Directive 96/53/EC to increase this to 40 tonnes. This was done in 1999 but at the same time, 6 axle combinations were allowed to have 41 tonnes, creating equal payload for 5 and 6 axle vehicles. In 2001, the value for 6 axle vehicles was increased to 44 tonnes, meaning that they had significantly more payload capacity than a 5 axle combination. The market response is shown in Figure 7, below, where it can be seen that the new 6 axle combinations became the dominant vehicle type within 3 years and within 5 years was used to carry two-thirds of the tonne kms transported by articulated vehicles.

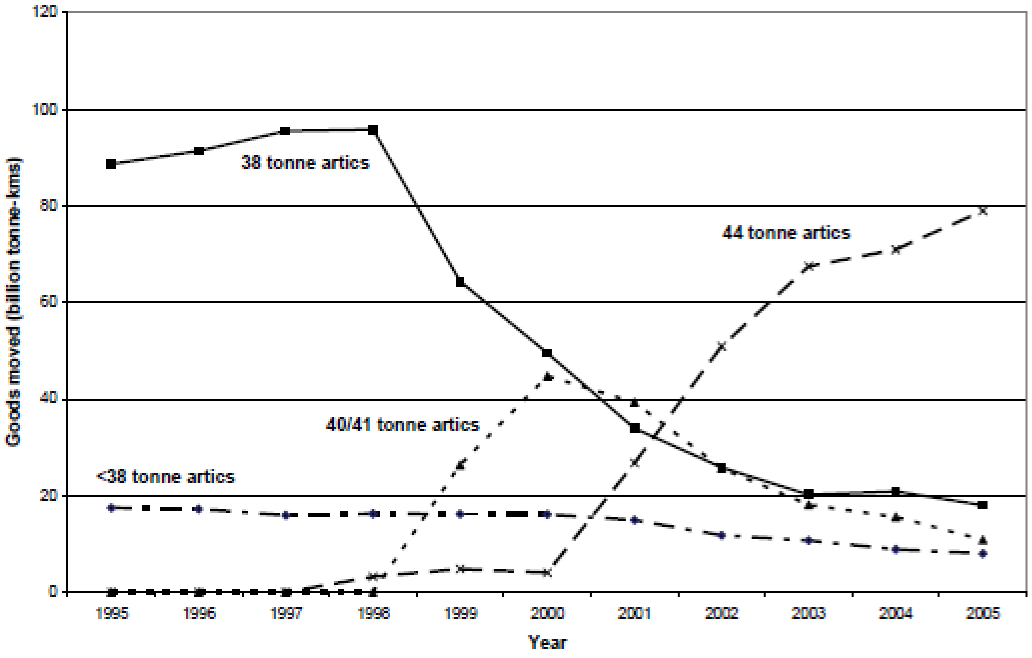

Figure 7: Trends in Goods Moved by Type of articulated vehicle in the UK (1995 – 2005). Source: (Knight, et al., 2008)

This rapid, large-scale adoption was strongly influenced by the extra 3 tonnes of payload available to industry. However, the aim from the Government side was also to reduce road wear. The maximum drive axle load for a 6 axle 44-tonne combination was set at 10.5 tonnes, instead of the 11.5 tonnes allowed for 40 tonne operation. The standard weight for a 2-axle bogie on a tractor unit remained at 19 tonnes.

The disadvantages to this approach were considered to include the extra unladen weight associated with the additional axle, as well as additional tyre and brake wear costs on the extra axle. Within the framework of rules provided, the industry innovated to mitigate these costs. It can be seen from Table 7, presented earlier, that a 10.5 tonne drive axle maximum would actually be just enough to carry the load from a 40 tonne standard diesel combination. The 19 tonne bogie load created the scope for unequal loading between the two rear tractor axles. Axles that automatically lift from the ground when the weight on them are below a certain threshold were developed. As long as the actual total weight of the vehicle was calculated to be less than 40 tonnes, it was legal to have just 5 axles. In addition to this, it was found that at 44 tonnes with a standard 3-axle semi-trailer, the maximum load on the tractor unit bogie was usually substantially less than 19 tonnes. As such, “mid lift” and “tag” axle vehicles became popular, an example of which is shown in Figure 8, below. A mid or pusher axle sits ahead of the drive axle and a tag axle sits behind the drive axle. These are usually axles rated to lower maximum design weights (e.g. 5 tonnes), they will have single tyres not twin tyres and sometimes they will also have small diameter wheels and tyres and they will almost always be ‘lift’ axles.

This has undoubted benefits in reducing the unladen weight of the vehicle and increasing freight efficiency (more payload, fewer journeys when carrying dense goods, less total weight and energy when carrying lightweight goods or empty) and may have reduced costs and environmental impact of tyre and brake wear. However, it will have eroded a substantial proportion of the expected road wear benefits of the change. In effect, all movements at total loads of up to close to 40 tonnes have remained on 5 axles, with the 6th only deploying for the heaviest loads.

A typical characteristic for this arrangement is that the tag or pusher axle will be lifted from the ground until the load on the drive axle exceeds a threshold, around 10 tonnes. At this point the axle is deployed progressively via the air suspension as the load on the bogie increases, such that at a bogie load of 10 tonnes, the lift axle would carry 0 tonnes, but at a bogie load of 19 tonnes it would carry 8.5 tonnes.

Figure 8: Example of a UK spec 6x2 “Mid Lift” tractor unit

The loading for a 6x2 diesel tractor unit that uses full size axles without lift mechanisms (similar to a 6x4 tractor) is shown in Table 15, below. This is considered to be a worst case for unladen weight because the specifications are for a UK DAF XF capable of 44 tonne operation under EU rules for 40 tonnes. The unladen weight of this tractor is 9 tonnes, more than 1.5 tonnes more than a similar 4x2 vehicle. It has been chosen because of the elongated cab concept which means that the combination length is not restricted provided it meets turning circles. This has been designed with a longer wheelbase to accommodate the XG cab, which has 30cm extra from front wheel to back of cab, used to provide more comfort for the driver. It also adds 16cm in front of the front axle to enhance aerodynamics, visibility and safety. The extra wheelbase allows additional space in the ‘fuel tank’ area to accommodate batteries. The lightest 6x2 XF from DAF is just 7.85 tonnes, around 0.5 tonnes heavier than the 4x2 equivalent. However, this has around 0.5m less length available at the side of the chassis for batteries than the heavier variant.

Table 15: Estimated combination and axle weights for a diesel, 3+3 tractor semi-trailer combination at EU standard 40 tonnes

	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Total
Maximum Combination Weight (kg)	10,000	11,500	10,000	8,000	8,000	8,000	40,000
		19,000					
Unladen weight (kg)	5,094	2,701	2,701	1,513	1,513	1,513	15,036
Available payload (kg)	4,906	8,799	4,799	6,487	6,487	6,487	24,964
Fully laden (central load 50%)	5,165	6,738	6,738	7,120	7,120	7,120	40,000
Fully laden (max forward 37.5%)	5,215	9,499	9,499	5,263	5,263	5,263	40,000
Fully laden (max rear 56%)	5,142	5,428	5,428	8,000	8,000	8,000	40,000

This vehicle has nearly 1.7 tonnes less payload at a 40 tonne limit than a 4x2 diesel, which explains why in areas where that same limit applies, the usage of these vehicles is limited.

The same analysis of volumes of space available for batteries, energy densities and efficiencies has been undertaken to assess the feasibility of creating a 6x2 BEV meeting the range and payload needs. The dependence on elongated cabs to provide additional space and likely difficulties in moving the European freight market to 3 axle tractor units in significant numbers has meant that only the near future BEV2 level of technology has been considered in the analysis.

Even with the higher predicted energy densities expected before 2030, then using only the space available under the cab and at the sides in the areas the fuel tanks would be on a diesel, suggests the maximum installed battery capacity that could be achieved would be around 730 kWh. The analysis suggests that even with a battery-to-wheel energy efficiency of 1 kWh per km and a usable fraction of battery capacity at 90 % the maximum range would be around 660 km, a little short of the 700 km target.

The elongated cab concept, as implemented by DAF, allows for an extension of 16 cm at the front of the cab, ahead of the front axle and of 20cm in the wheelbase. This allows for an increase in the volume of battery packs available at the side of the vehicle, already accounted for in the above analysis. However, it also enables a 30cm extension at the rear of the cab, which can be used for additional space (e.g. a wider bed for the driver). The DAF XF includes the frontal extension and the DAF XG has both the frontal and rear extension. So, if a vehicle was created with the same chassis arrangement as for the DAF XG, but with the cab of the XF, up to 30cm length could be available at the back of the cab, in which batteries (or H2 equipment) could potentially be installed. The cab is 2.5m wide and the height is variable but 2.2m would be a reasonable example. If the full 30cm length could be used for batteries, that gives an available volume of 1.65m3 of battery, which at 416 kWh/m3 theoretically allows for up to an additional 686 kWh of battery, far more than the additional 50-60 kWh needed to achieve the target range.

In practice, full exploitation of this space would not be possible. The pack would need to remain stable under braking and frontal collision forces but very heavy batteries in a stack that is 2.2m tall but only 0.3m at the base would be very unstable, requiring a large amount of mechanical reinforcement, further adding weight and reducing volume available. Such a pack would increase the centre of gravity height of the vehicle substantially, increasing the chances of rollover collision. The cab is suspended and can move around, the battery pack would need to be rigidly attached to the chassis. Proper integration of pack and cab may be challenging.

However, a small battery pack of 55 kWh could potentially fit in a volume of 0.13m^3. If it were assumed only 20cm of length were used to allow for mechanical reinforcement of mounting, and only 2m of width to allow better integration with the cab, then the height would only need to be around 33 cm from top of chassis, which may be feasible. This could still be a significant challenge, particularly if integration with the existing cab design was not possible without significant tooling changes at production facilities. The amortization of very large cab design and tooling costs in the HGV industry is typically undertaken over around 20 years and elongated cabs are a recent development. Substantial design changes a short time into their expected lifecycle could be very expensive.

It is notable that at least two prominent new entrants to the HGV market have chosen to offer 6*4 variants: Tesla and Windrose. Both have targeted global markets and 6*4 is a popular configuration in some large markets like North America.

Figure 9: Tesla Semi (left) and Windrose (right)

Tesla showed their vehicle at the IAA in Hannover in 2024[24] and it was claimed there that the intention was to bring it to Europe, no earlier than 2026. It was claimed that it would be compliant with EU regulations. The vehicle visually looks longer than EU trucks but its profiled front would meet elongated cab criteria, so the only constraint would be the ability to meet turning circle requirements with a standard 13.6m semi-trailer. Although Windrose started with the 6*4 configuration, they have now announced plans to manufacture in Europe and a new 4x2 variant for the European market[25].

Further detail emerging from the IAA suggests[26] that the Tesla Semi 6*4 will weigh <9072kg with a 480 km range and 10,433kg at 800km range and an efficiency of 1.05 kwh/km is claimed. This makes the 480 km range variant around the same weight as a standard diesel equivalent (a DAF XF 6*4 diesel[27] with a sleeper cab has a kerbweight of approximately 9.2 tonnes with 510l of diesel on board). This implies zero weight penalty with a 500 km range and around 1.2 tonnes with an 800 km range, well within the existing 2 tonne allowance in the current version of Directive 96/53/EC. Tesla has stated that this is only possible by designing the truck to be an electric vehicle from the start in an integrated design. This is much harder for an existing HGV maker to do while also continuing to sell diesel vehicles and carrying existing tooling amortization costs for current designs. The difference in configuration is illustrated by the unofficial imagery claimed to indicate the battery pack locations.

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[24] https://www.electrive.com/2024/09/19/tesla-wants-to-bring-the-semi-to-europe-but-not-before-2026/

[25] https://windrose.tech/blog/windrose-technology-takes-first-steps-toward-producing-and-delivering-next-generation-long-range-heavy-duty-electric-trucks-in-europe/

[26] https://www.freightcarbonzero.com/zero-carbon-vehicles/tesla-semi-unladen-weights-revealed/18819.article#:~:text=In%20a%20presentation%20of%20around,at%2023%2C000lbs%20(10433kg).

[27] https://www.daf.co.uk/api/feature/specsheet/open?container=598908e5-2833-458e-b22c-60789dba35dc&filename=TSGBEN016G0249AAAA202437.pdf

Figure 10: Illustration of the location of the Tesla semi-battery packs. Source: Unverified internet

4.4 Alternative Option 2: Different limit values for 5 axle and 6 axle combinations

Currently the MCW applied to 5 and 6 axle combinations is the same, except, in intermodal transport where a 2 axle tractor unit with a 3 axle trailer is limited to 42 tonnes but a 5 or 6 axle combination with a 3 axle tractor can carry 44 tonnes. The Commission proposal also applies the same 44 tonne MCW and 12.5 tonne maximum drive axle equally to both 5 and 6 axle combinations.

The analysis suggests that 6 axle combinations have been used with standard diesel vehicles as a way of reducing road wear but that they do lose payload compared with a 5 axle vehicle at the same GVW. While it is theoretically possible to limit the increased weight for BEV only to 3 axle vehicles, there are genuine and significant engineering and logistical challenges to such a shift and aiming to shift all of the market in this way to 3 axle vehicles is considered likely to meet substantial resistance.

What has, therefore, been considered is a proposal that the weight for 5 axle combinations is increased to 43 tonnes GCW with an 11.75 tonne drive axle, as per the option described in section 4.2. However, 6 axle combinations would be permitted to have a 44 tonne MCW. Two sub-options could be considered:

a) A restriction of a drive axle to 9.5 tonnes maximum and/or a requirement for the bogie to share load equally at all stages of load, or a prohibition of lift axles, would offer lower axle weights in a wider range of conditions, further reducing road wear implications. This would tend to encourage 6x4 configurations, because otherwise the total load carried by the single driven axle could be a relatively low proportion of total weight, risking traction issues.

b) A maximum drive axle load of 10.5 tonnes without further restrictions would likely see an approach similar to the UK taken, with a lift axle and unequal load sharing between the two rear axles, which minimises unladen mass and tyre/brake wear.

There are significant uncertainties in the effects on battery volume and resulting traction and road wear performance of the two different approaches. So, the loading model for each was based on the same 6x2 tractor with a full size trailing/lift axle. This baseline vehicle weighs a very similar amount to a 6x4 model, but substantially more than the lightest mid lift solutions. The results are shown below.

Table 16: Estimated combination and axle weights for a BEV 2 700km, 3+3 tractor semi-trailer combination at a proposed 44 tonnes MCW without lift axles and with equal load sharing bogie (sub-option a).

	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Total
Maximum Combination Weight (kg)	10,000	9,500	9,500	8,000	8,000	8,000	44,000
		19,000					
Unladen weight (kg)	7,100	2,901	2,901	1,513	1,513	1,513	17,441
Available payload (kg)	2,900	6,599	6,599	6,487	6,487	6,487	26,559
Weight with Max payload (centrally loaded 50%)	7,175	7,195	7,195	7,479	7,479	7,479	44,000
Fully laden weight (max forward 40.2%)	7,217	9,500	9,500	5,929	5,929	5,929	44,000
Fully laden weight (max rear 53%)	7,163	6,418	6,418	8,000	8,000	8,000	44,000

The payload for this combination is approximately equal to a standard 4x2 diesel at 40 tonnes under current rules and very similar to the payload achieved by a BEV2 700 vehicle in 4x2 configuration under the proposal to allow 43 tonnes MCW and an 11.75 tonne drive axle (see Table 14, presented earlier). In a regulatory scenario where this option was implemented, it would be up to the market to decide which vehicles were more popular. With approximately equal payload, the cost of the 6 axle vehicle would be likely to be very slightly higher, but it would have greater operational flexibility in terms of how the semi-trailer could be loaded while still avoiding overloading individual axle groups.

The analysis below shows how things would be expected to change if axle 3 became a typical lift axle.

Table 17: Estimated combination and axle weights for a BEV 2 700, 3+3 tractor semi-trailer combination at a proposed 44 tonnes MCW with a lift axle (sub-option b).

	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Total
Maximum Combination Weight (kg)	10,000	10,500	8,500	8,000	8,000	8,000	44,000
		19,000					

Unladen weight (kg)	7,100	5,801	0	1,513	1,513	1,513	17,441
Available payload (kg)	2,900	4,699	8,500	6,487	6,487	6,487	26,559
Fully laden (central load 50%)	7,175	10,244	4,146	7,479	7,479	7,479	44,000
Fully laden (max forward 40.2%)	7,217	10,500	8,500	5,929	5,929	5,929	44,000
Fully laden (max rear 53%)	7,163	10,157	2,677	8,000	8,000	8,000	44,000

It can be seen that for exactly the same total weights when fully laden, the drive axle (axle 2) weight is typically significantly higher, which is good for traction but bad for road wear. In addition to this, the drive axle weight is double what it was when unladen (and remains heavier at intermediate stages of load) which is also bad for road wear.

4.5 Alternative option 3: operate a performance based permit system

Directive 96/53/EC has a number of objectives driving it. One economic objective is to achieve standardization and interoperability throughout the EU, with the aim of achieving a competitive efficient industry both nationally within Member States and internationally between them. It also has the objective of protecting the infrastructure used and maintaining safety. Weights and dimensions are used to influence these things. However, weights and dimensions are really just proxies for these measures and how effective they are is open to question. What the regulation is really trying to influence are key performance indicators such as the accessibility of vehicles to all member states, manoeuvrability, dynamic stability, the relative road wear factors, bridge loading etc.

For decades it has been known that the way to mitigate infrastructure loading concerns associated with heavier weights is to spread the load out amongst more axles and more length of road or bridge structure. This is a major part of the rationale behind the European Modular System. The concept of actually regulating performance measures directly representing these risks, rather than indirectly via length or weight, has become known as Performance Based Standards. The use of performance based standards as an alternative to prescriptive weight and dimension limits is a concept first employed in Canada and Australia to more flexibly allow higher productivity vehicles with more payload weight and/or volume provided certain safety, operational and infrastructural performance characteristics were achieved. This system can be applied in many different ways but the ultimate expression of the concept currently in use is in Australia. A set of standard ‘workhorse’ vehicles are permitted uniformly within traditional prescriptive regulations. Where vehicles exceed these standard regulated weights, they are allowed under a permit scheme for individual vehicle combinations.

The vehicles are not subject to any total mass or dimensions limits but must be subjected to performance rating which classifies safety and infrastructure performance into 4 bands. Access to the road network is granted such that the highest performing vehicles can access many more roads than vehicles with lesser performance can. One of the key aims of the system is to manage the type of trade-offs that have been discussed in this report. A vehicle with lower environmental impact can be used but if it increases the hostility to the road surface then it may be restricted only to roads with a high quality road surface, constructed robustly to take heavy loads. It can be excluded from more minor roads built to lower standards that might be significantly damaged by it.

In the context of ZEVs, it could be used to set a regulated method for calculating the hostility of a vehicle combination to the road surface. For example, simply increasing axle weight in order to accommodate ZEVs at equal payload with diesel vehicles would fail the standard relating to vertical loads on the infrastructure. However, this doesn’t matter because there is no prescriptive gross weight limit so the manufacturer can add an axle to reduce axle weight and increase the GVW slightly to compensate that loss. This may still be an issue for the bridge loading standard, but that is ok because there is no prescriptive length limit, so the length and/or wheelbase can be increased slightly to better spread the load on the bridge. If this creates a problem with the manoeuvrability criteria, steered axles can be used and, again, the GVW increased a little to compensate for the increase in unladen weight. This type of approach is very difficult to engineer in prescriptive limits applied to broad categories of vehicles. It would be a ‘top down’ approach and difficult for those setting the regulation to know all the details of specific operations to get the choices right. Even if they could, the regulation would become incredibly complex with a huge range of ‘if statements’ and conditions. The aim of performance based standards is that each industry sector can innovate to produce the most productive vehicle configuration they can while still providing a safe vehicle that protects the infrastructure.

Although the system was designed in Canada and Australia to permit higher capacity vehicles, it is considered that it could also be used to encapsulate the problems caused by zero emission technologies and potentially also the movement of abnormal loads within a single system. For example, it could be written that the standard (Annex 1 of the W&D Directive) weights and dimensions could be exceeded without limit providing that the vehicle was certified according to standards within the following criteria:

- Energy efficiency and tailpipe emissions
- Nature of the load (divisible or indivisible)
- Overall height
- Acceleration and traction performance
- Low speed manoeuvrability and directional stability
- High speed stability
- Infrastructure loading

For each of these performance categories a score could be assigned where 1 demonstrated the best class of performance, equivalent with the ‘standard’ vehicle in most cases (but for example, the opposite for energy efficiency and emissions), and a larger number, 5 for example, could represent substantially degraded performance. The performance standards could be harmonised across the EU and vehicle certification could be an added duty of existing type approval authorities. The Directive could then place an obligation on Member States to categorise their road network according to the same performance levels. Those that did not wish to permit EMS for example, could achieve this very easily by simply stating that all their roads were only accessible to the highest performance categories, equivalent to current vehicles. Even then, innovative and safe solutions might emerge in the market that were able to match the performance of current vehicles in all respects while still providing higher capacity and/or better efficiency or emissions. The network of roads to which vehicles were accessible would not need to change in one quick step but could evolve with growing experience within individual Member States and in line with operational need. If Member States retained route by route control, it may even be possible to constrain use where alternative modes could compete, or to permit increased road access if the vehicle is used for intermodal.

This approach would clearly be a very large departure from the current legislation and would be expected to take significant time to develop on a pan-EU basis. As such, when the recent proposed changes to Directive 96/53/EC were being considered, this would not have seemed attractive in terms of the expected time frame to deliver simpler changes. However, if infrastructure concerns cause that delay anyway, it may become a viable option again, or perhaps in more limited circumstances for countries that already permit 44 tonnes (or more) for diesel.

5 Assessing the Impacts

5.1 Review of the Commission assessment

(European Commission, 2023) undertook economic modelling assessing the effect that reduced payload of BEVs would have on the cost per tonne of those vehicles to predict a reduced uptake of BEVs in the baseline scenario where no changes occurred. This was then repeated for the policy measure to estimate the economic and environmental effects of increasing the uptake. This analysis included effects on battery-electric and fuel-cell electric trucks, buses and coaches but it was numerically dominated by the effect of battery-electric trucks.

The finding was that the measure proposed would, in 2040, result in a decrease in overall vehicle trips of 845 million and a decrease in vehicle km of 172 billion. This translated to cost savings for operators with a net present value (2025 to 2050) of EUR 3.9 billion. The net present value of costs was estimated at an increase of EUR 4.2 billion over the baseline. This cost to national governments represents one major obstacle to implementation of the proposal.

(European Commission, 2023) also highlighted concerns around increased weights on bridge loading. However, several proposed policy measures affected bridge loading; the increased weights for ZEVs, a proposal to allow 12m long rigid vehicles with 5 axles to carry the same MCW (40 tonnes) as a 16.5m articulated vehicle, and a proposal to permit European Modular Systems to cross borders between Member States that permit them nationally. It was noted that if bridges were not adequate to carry the additional loads, they would either be closed to certain types of traffic or upgraded. However, if the choice was to upgrade, then the aim would be to do this work only once. As such, the bridge would be upgraded to a standard sufficient to meet the worst case requirements of the proposal. The ZEV element was not considered the worst-case proposal, so the bridge costs were effectively considered zero for that measure.

5.2 Approach and inputs to the calculation of effects on road maintenance costs

This report has identified three technology levels (Gen-0, -1 and -2) that may be relevant for new vehicles introduced within the 2020s. It has also identified 3 ‘range classes’ of 300, 500 and 700 km. As such, unladen mass, axle weights, payloads, road wear factors per vehicle and per tonne have been calculated, for the permutations highlighted below.

Table 18: Technology level and range classes modelled

Number of axles (tractor + trailer)	Powertrain technology	Range class		
		300	500	700
2+3	Diesel	No	No	Yes
	BEV0	Yes	Yes	No
	BEV1	Yes	Yes	Partial
	BEV2	Yes	Yes	Yes
3+3	Diesel	No	No	Yes
	BEV2	Yes	Yes	Yes

In reality, diesel vehicles could be capable of a range of up to 1500 km and so can be considered as

700+. The vehicles have been modelled with 570 litre diesel capacities for the purposes of mass and payload. With the volumes of space available and the energy densities of batteries at BEV-0, then it was not technically feasible to create a 700km variant. As Gen-0 are expected to be phased out by 2025, they were not further considered. With improvements at BEV-1 a vehicle with 653 km estimated range was created, which was close (shown in the table above as partial and shaded amber). However, for the sake of consistency, it was decided not to model that vehicle through the infrastructure cost process as there are no indications that manufacturers aim for such high ranges for their Gen-1 vehicles.

So, for each scenario, the following vehicles were modelled:

- Diesel
- BEV-1 300
- BEV-1 500
- BEV-2 300
- BEV-2 500
- BEV-2 700

The baseline scenario is one where Directive 96/53/EC is not amended so the rules remain as they are now, permitting 42 tonnes MCW with a drive axle maximum of 11.5 tonnes. However, one important distinction is that the baseline scenario was modelled as if the additional two tonnes was implemented as a blanket increase, rather than compensating only for the actual weight increase associated with the ZE technology. This is because there is evidence that at least some Member States are implementing the policy in this manner and because of the practical difficulty in enforcing the more restrictive policy.

The “Do something” options are:

- Implementing the Commission’s proposal for 5 and 6 axle combinations to be permitted 44 tonnes MCW and 12.5 tonnes drive axle.
- Implementing alternative option 1, to allow 5 and 6 axle combinations to have 43 tonnes MCW and an 11.75 tonne drive axle.
- Implementing alternative option 2, for 5 axle combinations to have 43 tonnes MCW and an 11.75 tonne drive axle and 6 axle combinations to have an MCW of 44 tonnes (with load shared equally between the two axles on the 19 tonne drive bogie, at all stages of loading).

T&E’s EUTRM model estimates the projected market penetration of BEVs in the EU based on the EU’s HDV CO2 emission standards. The modelling was undertaken on 3 Member States as case studies: Germany, Poland and Romania. The base model predicts a certain adoption rate for ZEVs and it has been assumed that the rate in Germany will be slightly quicker than in Poland and Romania. The evaluation period considered was 2025-2040. Although the fleet is not expected to be fully electrified at this time (which means that the full effect on road maintenance costs would not yet be measured), the progress of new technology has also not been assessed with no new developments after 2030. This is because they become progressively more uncertain the further away in time the forecast goes. Projecting to 2050 without also projecting the highly uncertain technology developments would likely significantly overestimate the effect on road wear. Calculations have been undertaken every year, but every other year is shown here for concise presentation.

The proportion of tonne kms estimated to be undertaken by BEVs, is shown in Table 19, below.

Table 19: Proportion of activity (tonne kms) undertaken by BEVs by year and Member State. Source: T&E EUTRM

Axles	Country	2025	2027	2029	2031	2033	2035	2037	2039
2	DE	2%	4%	10%	22%	32%	43%	52%	61%
	PL	1%	2%	5%	9%	13%	18%	24%	31%
	RO	1%	2%	5%	10%	14%	20%	25%	32%
3	DE	1%	3%	9%	21%	31%	42%	51%	59%
	PL	1%	2%	4%	8%	11%	17%	22%	29%
	RO	1%	2%	4%	9%	12%	18%	23%	30%

The predicted proportion of BEVs that fall in each technology and range class is shown in Table 20,20 below.

Table 20: Predicted proportion of BEVs that fall in each defined technology and range class. Source: T&E estimate.

Axles	Tech / range class	2025	2027	2029	2031	2033	2035	2037	2039
2	300 Gen-1	25%	15%	0%	0%	0%	0%	0%	0%
	300 Gen-2	0%	5%	25%	25%	25%	25%	25%	25%
	500 Gen-1	75%	60%	0%	0%	0%	0%	0%	0%
	500 Gen-2	0%	15%	65%	60%	65%	65%	65%	65%
	700 Gen-2	0%	5%	10%	15%	10%	10%	10%	10%
3	300 Gen-1	0%	0%	0%	0%	0%	0%	0%	0%
	300 Gen-2	100%	35%	25%	25%	25%	25%	25%	25%
	500 Gen-1	0%	0%	0%	0%	0%	0%	0%	0%
	500 Gen-2	0%	65%	65%	65%	65%	65%	65%	65%
	700 Gen-2	0%	0%	10%	10%	10%	10%	10%	10%

These proportions have been combined with the data from the EUTRM on the tonne kms in each of the three example countries to produce an estimate of tonne kms by each type of vehicle. An example of results for Germany is shown in Table 21, below, assuming a distribution of vehicle types appropriate for the baseline scenario and each policy option where there is no difference in the weight limit for 5 and 6 axle combinations.

Table 21: Estimated tonne kms (Billion) by different classes of articulated vehicles in Germany under baseline scenario and all options with no change to distribution of 5 and 6 axle combinations. Source: Apollo calculation based on data from T&E EU TRM as modified

Axles	Tech / range class	2025	2027	2029	2031	2033	2035	2037	2039
2	Diesel	342.7	347.6	336.7	297.6	265.1	227.1	192.6	161.7
	300 Gen-1	1.3	2.0	0.0	0.0	0.0	0.0	0.0	0.0
	300 Gen-2	0.0	0.7	9.2	21.5	31.4	42.7	53.2	62.8
	500 Gen-1	4.0	7.9	0.0	0.0	0.0	0.0	0.0	0.0
	500 Gen-2	0.0	2.0	24.0	51.6	81.6	111.0	138.2	163.2
	700 Gen-2	0.0	0.7	3.7	12.9	12.6	17.1	21.3	25.1
3	Diesel	18.0	18.3	17.9	15.9	14.2	12.2	10.4	8.8
	300 Gen-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	300 Gen-2	0.3	0.2	0.4	1.1	1.6	2.2	2.7	3.2
	500 Gen-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	500 Gen-2	0.0	0.4	1.1	2.5	4.1	5.6	7.1	8.4
	700 Gen-2	0.0	0.0	0.2	0.6	0.6	0.9	1.1	1.3

The data in T&E’s EUTRM suggests that 3 axle tractor units perform only around 5% of tonne kms. The second alternative policy option, to give a higher MCW allowance to 6 axle ZE combinations than 5 axle ZE combinations, removes the payload penalty for using 3 axle vehicles that currently exists. That is, a 3 axle diesel tractor towing a 3 axle trailer has between around 0.5 tonne and 1.5 tonne less payload capacity than a 2 axle diesel towing the same 3 axle trailer. Under this alternative option, the payload of a 3+3 BEV combination would have around the same payload as a 2+3 BEV combination and a 2+3 diesel combination. This alone may encourage some increase in the current 5% level. However, it is unlikely to be transformational. To get a large scale shift in usage such as that seen in the UK in the early 2000’s is likely to need substantially more incentive, perhaps reduced vehicle excise duty (road tax) or reduced road tolls for 3 axle tractors (or increases for 2 axle vehicles). An evaluation of likely uptake would require a full economic model and knowledge of all the potential incentives, which was beyond the scope of this study. As such, the road maintenance cost impact of this option has been modelled based on the assumption that the share of 6 axle combinations increases from the current 5 % of tonne kms to 50% between 2026 and 2031 before remaining at that level (a similar timeframe as the shift observed in the UK after changes to regulation in 2001). If this option were to be permitted, it would be up to either the EU or more likely national Governments to introduce incentives to try to achieve these higher levels of usage, if they were concerned with the road wear implications of 2+3 BEVs. If this level of usage were to be achieved, then the vehicle kms in Germany would change to the pattern shown in Table 22.

Table 22: Estimated vehicle kms by different classes of articulated vehicles in Germany, if 50% of BEV activity were shifted to 3 axle BEVs under a policy where 5 axle combinations are 43 tonnes and 6 axles 44 tonnes. Source: Apollo calculation based on data from T&E EUTRM as modified

Axles	Tech / range class	2025	2027	2029	2031	2033	2035	2037	2039
2	Diesel	342.7	347.6	336.7	297.6	265.1	227.1	192.6	161.7
	300 Gen-1	1.2	1.7	0.0	0.0	0.0	0.0	0.0	0.0
	300 Gen-2	0.2	0.8	6.6	11.3	16.5	22.4	27.9	33.0
	500 Gen-1	3.7	6.8	0.0	0.0	0.0	0.0	0.0	0.0
	500 Gen-2	0.0	2.0	17.0	27.1	42.9	58.3	72.6	85.8
	700 Gen-2	0.0	0.6	2.6	6.8	6.6	9.0	11.2	13.2
3	Diesel	18.0	18.3	17.9	15.9	14.2	12.2	10.4	8.8
	300 Gen-1	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0
	300 Gen-2	0.0	0.1	3.1	11.3	16.5	22.4	27.9	33.0
	500 Gen-1	0.2	1.1	0.0	0.0	0.0	0.0	0.0	0.0
	500 Gen-2	0.0	0.3	8.1	27.1	42.9	58.3	72.6	85.8
	700 Gen-2	0.0	0.1	1.2	6.8	6.6	9.0	11.2	13.2

5.3 Summary of Results

The results of the analysis are summarised in terms of payload and road wear factors. Payloads in bold black are the reference value for a 5 axle diesel combination at 40 tonnes. Those policy / combinations that exceed this level are highlighted in green, those that are lower than this level in red. It is worth noting that only options already identified as getting feasibly close to the necessary max range and equal payload have been fully modelled, so more negative options do not appear in this table.

Table 23: Summary of payload and road wear factors by policy option and vehicle category

Policy	Vehicle	Max Payload (kg;	Road wear factor	Road wear factor

Option		centrally loaded)	per vehicle	per 100 tonnes
Do Nothing – 42/11.5 for 5 & 6 axle combinations	2-axle Diesel	**26,651**	3.0	17.8
	2-axle 300 gen1	27,802	4.0	22.9
	2 axle 300 gen2	28,329	3.6	20.4
	2-axle 500 gen1	25,960	4.1	24.4
	2-axle 500 gen2	27,344	3.8	22.1
	2-axle 700 gen2	25,825	4.1	24.6
Commission – 44/12.5	2-axle Diesel	**26,651**	3.0	17.8
	2-axle 300 gen1	28.875	4.1	23.0
	2 axle 300 gen2	28,875	3.8	20.9
	2-axle 500 gen1	28,368	4.8	26.9
	2-axle 500 gen2	28,875	4.2	22.6
	2-axle 700 gen2	28,282	4.8	27.1
Alternative proposals 1 & 2 – 43/11.75	2-axle Diesel	**26,651**	3.0	17.8
	2-axle 300 gen1	28,802	4.1	22.9
	2 axle 300 gen2	28.875	3.8	20.9
	2-axle 500 gen1	26,895	4.3	25.3
	2-axle 500 gen2	28,344	4.1	23.0
	2-axle 700 gen2	26,758	4.4	25.5
Alternative proposal 2a – 5 axles at 43/11.75, 6 axles at 44/9.5 no lift	3-axle Diesel	24,964	1.9	11.8
	3-axle 300 gen 2	28,661	2.2	12.5
	3-axle 500 gen 2	27,458	2.3	13.2
	3-axle 700 gen 2	26,559	2.4	14.1
Alternative proposal 2b – 5 axles at 43/11.75, 6 axles at 44/10.5 lift	3-axle Diesel[28]	24,946	3.4	20.6
	3-axle 300 gen 2	28,661	3.4	18.9
	3-axle 500 gen 2	27,458	3.5	20.0
	3-axle 700 gen 2	26,559	3.6	21.1

These individual vehicle results have been applied to the activity figures shown in Table 21 and Table 22 in the preceding section by multiplying tonne kms by road wear factor per tonne to get road wear km or standard axle kms. The maintenance cost attributable to 5 or 6 axle articulated vehicles (which was derived based on experience with current diesel vehicles) has been divided by the standard axle kms for current diesel vehicles to get a cost per standard axle km:

- Germany €3.86 per billion standard axle kms
- Poland €1.53 per billion standard axle kms

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[28] Note that under rules for 3-axle diesel tractors at 40 tonnes, then the drive axle could be up to 11.5 tonnes, rather than the 10.5 tonnes proposed for BEV in this scenario, meaning that, if a lift axle strategy maximises drive axle load, then it will tend to produce a higher road wear factor

- Romania €12.10 per billion standard axle kms

These differences may reflect the differences in source data estimates but may also reflect genuine differences in the costs of labour and materials and/or construction and maintenance techniques in different countries. Considering the large difference between Romania and Poland specifically, according to the European Commission IA, Romania spends a very similar amount of money on road maintenance to Poland, for example in 2025 €305 million compared with €311million. However, according to T&Es EUTRM model, then in 2025 Romania saw only 12% of the tonne kms by 5 or 6 axle articulated vehicles that Poland did. This is what leads to the much higher estimate of cost per standard axle km.

The cost per standard axle km has then been multiplied by the standard axle kms for all the vehicles in the policy options, diesel and BEV to produce a revised total maintenance cost for each policy option. The cumulative cost for the period 2025 to 2040 has been calculated. This is not a full economic model and so discounted cash flows have not been applied. The cost of each 'do something' option is then compared with the baseline option. The results are shown in Table 24, below.

Table 24: Effect of policy options on cumulative road maintenance costs (2025-2040) of 5 and 6 axle articulated vehicles

Policy scenario	Absolute value (€billion)			Relative to baseline (€billion)			Relative to baseline (%)
	DE	PL	RO	DE	PL	RO	
Baseline – Do nothing	47.35	5.58	5.49	-	-	-	-
Commission – 44/12.5 for 5 & 6 axles	48.43	5.64	5.55	+1.07	+0.06	+0.06	+1.1% to +2.3%
Alternative 1 – 43/11.75 for 5 & 6 axles	48.02	5.62	5.53	+0.67	+0.04	+0.04	+0.7% to +1.4%
Alternative 2a – 43/11.75 for 5 axles, 44/9.5 No lift for 6 axles	44.68	5.43	5.33	-2.67	-0.15	-0.15	-5.6% to -2.7%
Alternative 2b – 43/11.75 for 5 axles, 44/10.5 for 6 axles	47.22	5.58	5.48	-0.13	-0.01	-0.01	-0.3% to -0.1%

It should be noted that the smaller costs in Poland and Romania are not just smaller in absolute values because of the lower maintenance costs and the lower total vehicle traffic. The effect is also a smaller percentage of the total because of the assumed slower rate of adoption of BEVs in those countries.

It should be re-emphasized at this point that the reductions seen in the policy options 2a and 2b depend on whether the market responds to adopt these vehicles, both with manufacturers deciding to build appropriate vehicles and operators buying and using them. With diesel vehicles currently, 3 axle tractors have a significant payload disadvantage (c.0.5 – 1.5 tonnes) compared with 2 axle tractors. This proposal means that for BEVs that payload penalty would disappear but they would not have a positive payload advantage. The extent to which this may be sufficient to promote a shift of the order modelled has not been investigated. However, if Parliament and Council were inclined to accept the alternative option 1, the only potential adverse effects of implementing option 2a or 2b are related to cost in terms of development and purchase price of vehicles, as well as efficiency (more tare weight for the same cargo weight). It includes the action taken in alternative 1 and the worst case is that there is no market uptake of the 3 axle options, which means the result is the same as for alternative 1. Any shift in the market from 5 axle BEV combinations to 6 axle BEV combinations would begin to mitigate the additional infrastructure costs but incur the operational costs, representing a shift in cost from Government to industry. The magnitude of the operational cost has not been investigated in detail in this study, but is considered likely to be smaller than the infrastructure cost saving on the basis of the widespread adoption in the UK. Member States particularly concerned about the infrastructure implications could take national action (e.g. tax or tolling incentives) to encourage such a shift.

5.4 Bridge loading

It is not yet known if the other options that affect bridge loading (EMS internationally, and 40 tonne rigids on 5 axles, already reduced to 36 tonnes) will be retained in their current form in any final agreement between Parliament and Council. If they were removed, then the added weight for zero emissions would be the only option with the potential to affect bridges. As such, an analysis has been undertaken to assess the impact on a more quantitative basis than was reported by (European Commission, 2023). The analysis has considered both the current requirements for new bridges (Eurocode 1.2) and one example of an older standard (DIN 1072) where there will still be a lot of existing bridges in a country designed to that older standard, or a similar national one.

5.4.1 The General Approach to Bridge Design and Assessment

Bridges are designed for a notional load model specified in standards such as Eurocode 1.2[29]. The load model is typically made up of some point forces and some uniformly distributed loading (general pressure) on the road surface. The bridge is designed to resist the stresses generated by the notional load model. In modern standards, the notional model represents an extreme case of traffic on the bridge, i.e., some very heavy passing trucks, typically illegally overloaded. Using data on truck weights and frequencies, a statistical calculation is carried out to determine the worst possible case that might possibly occur on the bridge. For example, the Eurocode 1.2 load model represents the 1 in 1000 year case, the worst case that would be expected in 1000 years of today's traffic. Other safety factors are applied to the collapse case and the final probability of a bridge collapsing has been estimated at about 1 in 1 million.

Bridge condition tends to deteriorate over time and the stock of bridges in many countries is no longer in perfect condition. European bridge owners are obliged to monitor their bridge stock by inspecting their condition and assessing their capacity to carry load. When a new bridge is being designed, it is sensible to be conservative as the cost of providing additional load carrying capacity during the original build is relatively modest. As a result, the notional load models in bridge design standards may be conservative, exaggerating the true traffic loading on the bridge. Some countries also have bridge assessment standards whose load models are less conservative and closer to the true extreme of loading that would be expected once in 1000 years.

Some of the sources of conservatism in the notional load models (see (O'Brien, et al., 2021) for further details) used for the design of new bridges include:

i. Vehicle loading in primary (slow) lane – in the Eurocode, this corresponds to 104 tonne on 15.5 m; in the old German standard, DIN 1072, it corresponds to 90 tonnes on 12 m. Both are far beyond what is allowed without a permit.

ii. Vehicle loading in the adjacent, secondary lane. For 2-lane roads with opposing-direction traffic, the probability of two very heavy trucks meeting at the critical location is remote. For highways, with multiple lanes and same-direction traffic, adjacent side-by-side vehicle loading events will occur. However, the statistics show that the overtaking truck is generally unloaded. Eurocode 1.2

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[29] EN 1991-2:2003 (2003), Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges, European Committee for Standardization.

specifies 53 tonnes on 15.5 m; the old German standard, DIN 1072, specifies 14 tonnes on 15.5 m. The Eurocode is conservative for this but the old German standard is fairly realistic.

iii. For considerations of stress that could lead to failure of the bridge (collapse), the loadings are further increased by 35% and capacity is provided to carry this additional load.

iv. The notional loading is deemed to include an allowance for dynamic amplification – when bridges vibrate, stresses tend to be amplified. However, research studies suggest that the effect of dynamics in typical bridges subject to extreme loads, is not more than about 5% (O'Brien, et al., 2010).

v. While traffic lanes are about 3.65 m wide, the notional load model in both Eurocode 1.2 and the old German standard assumes a lane just 3.0 m wide. This is to allow for possible road works scenarios where lanes may be narrowed. However, such road works scenarios only happen for a small percentage of the bridge's working life, which greatly reduces the probability of an extreme heavy truck(s) happening in combination with road works.

A source of non-conservatism includes:

i. Older bridges were designed using the standards available at the time of their design. Some of these older standards specified notional load models significantly lighter than those specified in today's Eurocode 1.2. This includes, for example, the old German standard, DIN 1072.

Further, it should be reiterated that bridges tend to deteriorate over time and, if not well maintained, they may no longer have the load carrying capacity for which they were designed.

5.4.2 Traffic growth

The tonnage of freight in tonne-km carried on European roads has increased consistently over many years. Its growth tends to roughly track economic growth measured in Gross Domestic Product. The statistical calculations used to determine the notional load models used in standards such as Eurocode 1.2, assume no growth in traffic. In the absence of an increase in allowable maximum gross weight, growth in freight volume implies an increase in the frequency of heavy vehicles. This increases the probability of there being a heavy vehicle in the 'secondary lane', i.e., the lane adjacent to the most heavily loaded slow lane. As a result, growth does increase the traffic loading in bridges, but the effect is modest. In simulations, (O'Brien, et al., 2014) found that 4.1% annual growth in traffic volume increased the stresses on a 15 m span bridge by between 3.5% and 7.4% over a 75-year period.

5.4.3 Fatigue damage (wear and tear)

Steel and composite bridges with orthotropic steel decks are sometimes prone to fatigue damage over time. This can happen when the national standard at the time of design allowed excessively thin steel plating and/or fatigue-sensitive details which can allow stress concentrations. Fatigue damage is essentially a 'wear-and-tear' issue, with damage in the form of fatigue cracking progressing over time. Unlike most other bridge types, the key issue is no longer that of a probability of one dangerous combination of extremely heavy trucks, but rather an accumulation of damage over time due to many moderately heavy trucks.

For bridges prone to fatigue damage, an increase in gross weight of the most common types of truck would result in an increase in the rate of deterioration, reducing the expected remaining life and/or increasing the maintenance actions required.

5.4.4 Calculated increase in stresses due to changes in tractor weights and dimensions

A calculation has been carried out on the implications of changes in tractor weights and dimensions for bridge stresses (bending moments and shear forces) for a range of bridge forms (e.g., single span, 2-span), locations on the bridge (at centre or at the supports) and lengths. As an example, a bridge 9.3 m wide is considered carrying two lanes of traffic, each 3.65 m, and a 2 m hard shoulder. Two vehicles with the maximum allowable weights (shown in Table 25) are assumed to be travelling side by side. In each case, the maximum stress has been calculated for the 'old' (deemed to be current) situations and compared to the ‘new’ situations. Two old situations are considered, corresponding to (i) baseline diesel tractors and (ii) the currently allowed baseline battery electric tractors. Two new situations are also considered, (I) one corresponding to a possible compromise configuration and (II) one corresponding to a full 2 t increase in allowable gross weight. It should be noted that for the bridge analysis, it is the rare worst case that is most important to consider, not the typical high frequency condition. As such, the load distribution of the vehicles was based on the most forward load position that would maximise the load on the drive axle, to produce the single highest axle load. The weights and configurations are summarized in the table. They were calculated on the same basis as described in earlier sections. However, the bridge and road wear work was undertaken in parallel, so some small differences have emerged as alternative assumptions were evolved during the analysis of road wear. These are not considered likely to have a material effect on the results.

Table 25: Vehicle configurations considered

Short name	Description	Axle weights (t)					Axle spacings (m)			
		Ax1	Ax2	Ax3	Ax4	Ax5	1-2	2-3	3-4	4-5
Old (i)	Baseline diesel vehicle combination, 40t MCW	7285	11500	7064	7064	7064	3.8	5.65	1.31	1.31
Old (ii)	Baseline battery-electric vehicle combination, 42t MCW	8299	11500	7400	7400	7400	3.8	5.65	1.31	1.31
New (I)	Possible compromise battery-electric combination, 43t MCW	8874	11750	7459	7459	7459	3.8	5.65	1.31	1.31
New (II)	Battery-electric combination, 44t MCW	8807	12500	7564	7564	7564	3.8	5.65	1.31	1.31

It is impractical, and beyond the scope of this study, to consider all possible permutations/situations. However, many situations have been considered, with a focus on short-span bridges which are most likely to be adversely affected (long-span bridges are governed by congested traffic with large combinations of mixed vehicles, many of which will be unloaded and/or cars; short spans are more vulnerable as they are generally governed by the weight of a single passing truck). The bridge forms and locations considered are listed in Table 26. These forms and locations are based on experience by the authors on the types of design details that govern in typical bridge configurations. The total bridge lengths considered for these forms/locations are: 5 and 7.5 m for forms/locations 1 to 4 and 10, 15, 20 and 30 m for all forms/locations. These short-medium bridge lengths will be the most critical lengths to be checked, since an increase in vehicle tractor weight will have relatively less influence in longer bridges.

Table 26: Bridge forms, stresses (bending moments or shear forces) and locations

Form/location Number	Description

F1, F2	Maximum bending moment at the centre of a simply supported and fixed-fixed span, respectively.
F3, F4	Shear force at the left & right ends of simply supported bridge (assuming traffic flowing left to right).
F5*	Central support moment in a two-span continuous bridge.

* For lengths of 10 m and over, only.

The results are summarised in Table 27 to Table 30, for the four permutations respectively: New (I) vs Old (i); New (II) vs Old (i); New (I) vs Old (ii) and New (II) vs Old (ii). For each permutation, the maximum stresses for the new configuration are compared to the corresponding maximum stresses for the old configuration and the % difference calculated – 5th column. The results are colour-coded according to this % difference, with values in excess of 10% shaded in red – see Table 28. The stress is also calculated in accordance with the old German standard, DIN 1072: 1985-12 as this standard is generally less onerous than Eurocode 1.2 and gives the load carrying capacity for which bridges in that jurisdiction were designed at that time. The % difference in this case (rightmost column) gives the excess capacity between the stress the bridge was designed to carry and that generated by two trucks of the old configuration. Thus, for example, the first row of Table 27 gives the results for form/location F1 for a bridge of length, 5 m. New configuration (I) can be seen to increase the stress (bending moment) from 349 kNm to 368 kNm, i.e., by 5.6%, when compared with old configuration (i). However, the old DIN standard specifies a stress of 503 kNm, which is 44% greater than the old configuration stress of 349 kNm. This is effectively a margin of safety – a bridge designed in accordance with the standard, would have capacity 44% in excess of what is generated by the crossing of two fully loaded trucks with Configuration (i). This assumes no deterioration in bridge load carrying capacity since it was designed. However, the difference is considerable – a 38.4% (44% - 5.6%) reduction in bridge capacity would be required before the change in configuration has an adverse effect.

Of the four tables, Table 28 gives the greatest increases due to the new configuration in comparison with the old, i.e., when New (II) (electric tractor with 2 t increase in tractor weight) is compared to Old (i) (baseline diesel tractor). Taking the last row of Table 28 as an example, it can be seen that for form/location F5 in a bridge of length 30 m, the new tractor results in a stress 10.4% greater than the baseline diesel tractor. However, for that case, the old DIN standard generates a stress 90% greater than the baseline diesel case which suggests considerable excess capacity.

The case where the excess capacity implicit in the old DIN standard is closest to the increase due to the new tractor is form/location F2 for a bridge of 5 m length – see 2nd row of Table 28. In this case the new configuration increases the stress by 8.7% and the excess capacity implicit in the old DIN standard is 29%. Hence a reduction in capacity of 20.3% would mean that the new configuration would result in a stress greater than the capacity to resist it. It would take a further 8.7% reduction in capacity for there to be a problem with the old diesel tractor.

Table 27: Bridge stresses and % differences: New (I) vs Old (i) [<5% in green, 5% to 7.5% in yellow, 7.5% to 10% in orange, >10% in red]

Bridge length	Bridge form & location	Old configuration (i)	New configuration (I)	% difference	DIN 1072 standard	% difference
5 m	F1	349	368	5.6	503	44
	F2	141	144	2.2	181	29
	F3	296	313	5.6	464	57
	F4	303	320	5.6	464	53
	F5	NA	NA	NA	NA	NA
7.5 m	F1	601	634	5.6	959	60
	F2	239	253	5.6	359	50
	F3	336	355	5.6	560	67
	F4	340	359	5.6	560	65
	F5	NA	NA	NA	NA	NA
10 m	F1	861	909	5.6	1464	70
	F2	364	385	5.6	575	58
	F3	392	413	5.3	603	54
	F4	359	380	5.8	668	86
	F5	237	247	4.4	353	49
15 m	F1	1500	1577	5.1	2811	87
	F2	617	652	5.6	1083	75
	F3	502	531	5.8	716	43
	F4	449	470	4.9	834	86
	F5	451	475	5.4	717	59
20 m	F1	2335	2456	5.2	4476	92
	F2	923	972	5.4	1710	85
	F3	572	609	6.4	870	52
	F4	518	564	8.9	958	85
	F5	682	731	7.2	1052	54
30 m	F1	4296	4565	6.3	8432	96
	F2	1705	1801	5.6	3246	90
	F3	643	687	6.9	1107	72
	F4	607	657	8.3	1166	92
	F5	960	1040	8.3	1829	90

Table 28: Bridge stresses and % differences: New (II) vs Old (i) [<5% in green, 5% to 7.5% in yellow, 7.5%

to 10% in orange, >10% in red]

Bridge length	Bridge form & location	Old configuration (i)	New configuration (II)	% difference	DIN 1072 standard	% difference
5 m	F1	349	373	7.1	503	44
	F2	141	153	8.7	181	29
	F3	296	317	7.1	464	57
	F4	303	324	7.1	464	53
	F5	NA	NA	NA	NA	NA
7.5 m	F1	601	643	7.1	959	60
	F2	239	256	7.1	359	50
	F3	336	360	7.1	560	67
	F4	340	365	7.1	560	65
	F5	NA	NA	NA	NA	NA
10 m	F1	861	922	7.1	1464	70
	F2	364	390	7.1	575	58
	F3	392	420	7.2	603	54
	F4	359	389	8.2	668	86
	F5	237	255	7.7	353	49
15 m	F1	1500	1610	7.3	2811	87
	F2	617	661	7.1	1083	75
	F3	502	543	8.1	716	43
	F4	449	484	7.9	834	86
	F5	451	489	8.5	717	59
20 m	F1	2335	2515	7.7	4476	92
	F2	923	989	7.2	1710	85
	F3	572	623	8.8	870	52
	F4	518	577	11.5	958	85
	F5	682	748	9.7	1052	54
30 m	F1	4296	4673	8.8	8432	96
	F2	1705	1841	8.0	3246	90
	F3	643	703	9.3	1107	72
	F4	607	673	10.9	1166	92
	F5	960	1060	10.4	1829	90

Table 29: Table 3c – Bridge stresses and % differences: New (I) vs Old (ii) [<5% in green, 5% to 7.5% in yellow, 7.5% to 10% in orange, >10% in red]

Bridge length	Bridge form & location	Old configuration (ii)	New configuration (I)	% difference	DIN 1072 standard	% difference
5 m	F1	365	368	0.8	503	38
	F2	141	144	2.2	181	29
	F3	310	313	0.8	464	50
	F4	317	320	0.8	464	46
	F5	NA	NA	NA	NA	NA
7.5 m	F1	629	634	0.8	959	52
	F2	251	253	0.8	359	43
	F3	352	355	0.8	560	59
	F4	357	359	0.8	560	57
	F5	NA	NA	NA	NA	NA
10 m	F1	902	909	0.8	1464	62
	F2	382	385	0.8	575	51
	F3	409	413	0.9	603	48
	F4	376	380	1.0	668	78
	F5	244	247	1.3	353	44
15 m	F1	1562	1577	1.0	2811	80
	F2	647	652	0.8	1083	68
	F3	523	531	1.4	716	37
	F4	459	470	2.4	834	82
	F5	467	475	1.7	717	54
20 m	F1	2427	2456	1.2	4476	84
	F2	964	972	0.9	1710	77
	F3	599	609	1.8	870	45
	F4	547	564	3.1	958	75
	F5	715	731	2.2	1052	47
30 m	F1	4487	4565	1.7	8432	88
	F2	1777	1801	1.3	3246	83
	F3	674	687	2.0	1107	64
	F4	639	657	2.8	1166	82
	F5	1014	1040	2.5	1829	80

Table 30: Bridge stresses and % differences: New (II) vs Old (ii) [<5% in green, 5% to 7.5% in yellow, 7.5% to 10% in orange, >10% in red]

Bridge	Bridge form	Old	New	%	DIN 1072	%

length	& location	configuration (ii)	configuration (II)	difference	standard	difference
5 m	F1	365	373	2.2	503	38
	F2	141	153	8.7	181	29
	F3	310	317	2.2	464	50
	F4	317	324	2.2	464	46
	F5	NA	NA	NA	NA	NA
7.5 m	F1	629	643	2.2	959	52
	F2	251	256	2.2	359	43
	F3	352	360	2.2	560	59
	F4	357	365	2.2	560	57
	F5	NA	NA	NA	NA	NA
10 m	F1	902	922	2.2	1464	62
	F2	382	390	2.2	575	51
	F3	409	420	2.8	603	48
	F4	376	389	3.3	668	78
	F5	244	255	4.5	353	44
15 m	F1	1562	1610	3.1	2811	80
	F2	647	661	2.2	1083	68
	F3	523	543	3.7	716	37
	F4	459	484	5.4	834	82
	F5	467	489	4.7	717	54
20 m	F1	2427	2515	3.6	4476	84
	F2	964	989	2.6	1710	77
	F3	599	623	4.0	870	45
	F4	547	577	5.5	958	75
	F5	715	748	4.7	1052	47
30 m	F1	4487	4673	4.1	8432	88
	F2	1777	1841	3.6	3246	83
	F3	674	703	4.3	1107	64
	F4	639	673	5.2	1166	82
	F5	1014	1060	4.5	1829	80

The implications for bridges of the proposed changes in tractor weights is considered in this section. It is noted that bridges have a number of sources of conservatism in their design, most notably the 35% additional capacity for stress violations that may result in collapse. The issue of traffic growth is discussed and it is concluded that this does tend to increase stress levels but not by a great deal. Fatigue is also discussed for steel and composite bridges – unlike other bridge phenomena, fatigue has a cumulative effect so an increase in the weights of tractors, causing increased stresses, will reduce remaining safe working life and/or will require an increase in maintenance/repair actions. However, the effect is modest and will only occur in a small number of critical locations.

A number of bridge lengths, forms and stress types are considered in detail. Masonry arch bridges are not considered in this – their behaviour is highly non-linear and is unsuited to this type of calculation. Two new tractors are considered and two old tractors. Stresses (bending moments and shear forces) are calculated for the old and new vehicle configurations and the percentage increases (new versus old) calculated. Increases in stress levels in excess of 10% were found for a small number of cases. The excess capacity for these bridge lengths/forms were also calculated, assuming they had been designed in accordance with the old DIN standard, used in some European countries in the past. Even though the load model specified in the old DIN standard is generally less conservative than that in Eurocode 1.2, it implies capacity well in excess of two fully loaded vehicles of the new configuration. For one example considered, two vehicles with the new electric tractor result in an increase in stress (over the baseline diesel tractor) of 11.5%. However, for this particular bridge form and length, the load model of the old DIN standard results in 85% excess capacity. Of all stresses and lengths considered, the closest case was an increase in stress due to the truck with electric tractor of 8.7% and an excess capacity for a bridge designed in accordance with the old DIN standard of 29%.

It is concluded that the proposed increases in vehicle tractor weights will only have a modest effect on bridge stress levels – for most bridge forms and lengths, the stresses are increased by less than 10%. For all cases considered, bridges designed in accordance with the old DIN standard that have not deteriorated, have capacity substantially in excess of the proposed new vehicle configurations and weights. Bridges are designed for extreme levels of load, levels with remote probabilities of occurring in their lifetime. These loading scenarios consist of vehicles with weights far in excess of the legal limits under consideration here. It is therefore not surprising that the old DIN standard, despite being less conservative than Eurocode 1, generates stress levels well in excess of the proposed new BEVs.

6 Conclusions

Increasing weight due to ZE technologies does not have the same effect as increasing the weight available for payload. When payload is added in a semi-trailer the weight is spread amongst all 5 axles. Only journeys where dense goods that reach the weight limit without filling the volume will be affected by the change. When weight is added due to ZE technology it is spread only amongst the 2 tractor axles and it is present in every journey the vehicle undertakes, representing a large proportional increase in axle weight when empty or lightly loaded. The road wear implications are more severe and this needs to be accounted for.

Some operations are clearly viable with a BEV range of 300km, a large proportion will be possible with 500km, around two-thirds if fast charging is available during driver rest breaks. However, for 90+% of operations to be viable with BEV a range of around 700km may be needed.

With the generations of BEV technology that are already on the market or arriving on the market in the next year, the availability of space for batteries on a standard 4x2 tractor unit continues to limit the range of vehicles such that 700km on a single charge does not appear feasible due to the limitations on space for batteries and the volumetric energy density. Even ranges of around 300km can potentially compromise payload.

It is not just the MCW that limits the payload, axle weights can too. When commodities of densities that come close to filling both the trailer volume and the mass capacity simultaneously, then it is not possible to adjust load positions. With a payload that is theoretically possible based on the MCW minus the unladen weight, this can result in an overloaded drive axle.

The Commission’s proposal to increase MCW to 44 tonnes with a drive axle of 12.5 tonnes is very effective from a vehicle and operator point of view. It enables the maximum ranges to be achieved without compromising max payload, while retaining some flexibility in load position without risking axle overload.

ZE Vehicles with improved energy density and efficiency are expected to enter the market before 2030 which allow range of up to around 700km.

‘Right sizing’ battery capacity on vehicles will become important for payload and cost. Most operations can be undertaken with less than the maximum range. Under the Commission’s proposal these vehicles could benefit from substantial additional payload compared with diesel, as well as a reduced implication for road wear. Availability of fast charging during driver rest breaks is an enabler of smaller batteries on a wider range of vehicles. As such, if an authority wants to protect their physical infrastructure, providing an effective fast charging network for HGVs is important.

Four additional policy options have been identified of which three have been quantified and compared to the baseline scenario of no change to the current Weights and Dimensions Directive:

- **Baseline scenario:** Five & six axle ZEV combinations can have an MCW of (up to) 42 tonnes and a maximum drive axle weight of 11.5 tonnes.

- **Commission proposal:** Five & six axle ZEVs can have an MCW of 44 tonnes and a maximum drive axle weight of 12.5 tonnes. Payload barriers to the adoption of BEVs would be eliminated and some operational flexibility restored. Vehicles with lower range needs would benefit from substantial payload increases. However, road maintenance costs would be expected to increase by 1.1% to 2.3% depending on the vehicle mix, road construction and maintenance practices and ZEV adoption rate. For example, In Germany an increase of around €1.1billion would be expected over the period 2025-2040 compared to the baseline. The absolute costs would be much smaller in other countries, where slower ZEV adoption rates, lesser HGV activity and reduced maintenance spend, all play a part.

- **Alternative proposal 1:** Five & six axle ZEVs can have a MCW of 43 tonnes and the maximum drive axle load is 11.75 tonnes. Vehicles with a range approaching 700km on a single charge would continue to have payload implications for the very short term. Design flexibility would be limited, for example, the use of very efficient e-axles may be more difficult, the use of more sustainable lower cost lithium iron phosphate (LFP) batteries may be more limited. Load positioning would also be more restricted than the Commission proposal. However, with technology available within 3 or 4 years, 700km range vehicles should be possible with payload equal to diesel and lower range versions would have improved payload (compared with diesel). The increase in road maintenance costs would be much lower at between around 0.7% to 1.4%,

- **Alternative proposal 2:** Five axle vehicles benefit from the same change as in alternative 1 (43/11.75 tonnes). In addition to this, six axle vehicle combinations based on 3 axle tractors retain the 44 tonnes MCW from the Commission proposal. This would mean that a 3 + 3 axle BEV combination would have the same payload capacity as a 2 + 3 axle BEVl combination. In diesel form, a 3+3 combination would have a lower payload than a 2+3 combination. Reduced space for batteries, due to the space taken up by the additional axle, means long range vehicles would need to rely on the new vehicle design including the elongated cab concept and the next generation of technologies. Even with this, the longest ranges may need to stack some batteries behind the cab. This presents significant design and manufacturing challenges to the vehicle industry and could raise centre of gravity heights with associated increase in rollover risks. Such vehicles would be slightly more expensive to buy and run. However, the 3rd axle substantially reduces road wear. Two sub-options of this scenario exist:

    - **Alternative proposal 2a:** The use of lift axles is prevented and equal load distribution on the 19-tonne drive axle bogie is required. This is most limiting for industry but offers the biggest benefit for infrastructure. If adoption could be incentivized such that by 2031, around 50% of activity was undertaken with 3 axle tractors rather than 5% today, then road maintenance costs could be reduced by between 2.7% and 5.6% depending on vehicle mix and adoption rate of BEV. The economics and feasibility of stimulating demand for 3-axle tractors to 50% of activity have not been investigated.

    - **Alternative proposal 2b:** A drive axle limit of 10.5 tonnes for six axle vehicles is imposed and lift axles are allowed. This will mitigate some of the industry issues with running costs but is less effective for infrastructure. With the same assumptions of adoption, then over the period 2025-2040, road maintenance costs in Germany could be reduced by €0.1 billion compared with the baseline, or €1.2 billion compared with the Commission proposal. Road maintenance costs in the EU would be typically reduced by 0.1% to 0.3% compared with the baseline.

The effect of the proposed ZE weight increases on bridges is a modest increase in bridge loading on short and medium span bridges that in most cases is less than 5%. In a few cases, the Commission proposal imposes a load increase of a little more than 10%. The alternative proposal for a max 43 tonnes reduces this to around 8 %. In these cases, an old bridge standard (DIN 1072) requires the bridge to have capacity for around 85% more load, strongly suggesting there is significant reserves of capacity, unless the bridge has substantially degraded in service. In all cases tested, the capacity reserve of DIN 1072 substantially exceeded the increase in loading of the actual vehicle. Newer bridges built in accordance with the Eurocodes would have substantially larger reserves of capacity.

It is considered that if a bridge has lost sufficient capacity that an increase in vehicle induced load of 8% is a significant risk of collapse then the bridge should be closed to traffic of that weight. However, unless the assessment of available capacity is very accurate it seems likely that such a bridge should also be closed to the heaviest type of Diesel and BEV traffic already permitted by the current version of Directive 96/53/EC.

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