NEW CHALLENGES FOR TIRES ON BATTERY ELECTRIC TRUCKS

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Abstract

As Trucks and buses account for a strong proportion of greenhouse gaz transport emissions, there is an increasing pressure to decarbonize this sector. Battery electric trucks is a solution going to be widely adopted in many regions of the world.

Battery electric trucks are heavier than diesel trucks, which has an impact on the payload since gross combination weight (GCW) is limited. To limit the induced impact on fleet profitability, regulations are going to evolve. In Europe for example, the GCW is increased for BEV by 2t today, and 4t in coming years. This bonus can mainly be carried by the steer axle. Then, the tires may have to be redesigned to be as safe as today, but with more load.

Electrified trucks are more powerful than diesel trucks and especially, more torque is available. Drivers usually enjoy this higher acceleration potential. We can expect more tire wear under traction torque.

Beyond the better tank to wheel efficiency, electric trucks open the possibility to recover kinetic or potential energy to recharge the battery. Instead of wasting mechanical energy in the vehicle motion, the battery can recover some of it through the electric engine and drive tires. An electric truck will brake more with its drive tires only, much more than a diesel truck uses its retarder system, which will wear drive tires faster under braking torque. With simulations to estimate the tire forces changes and a tire wear model it is possible to present a first assessment of the impacts.

Finally, the tire rolling resistance, a key factor for diesel truck efficiency, has a new role for BEV: rather than influencing GHG tailpipe emissions, rolling resistance will be influencing the vehicle range.

As a conclusion, tires need significant performance improvements to perform on zero emission trucks as well as they perform on internal combustion engine vehicles. The evolution of vehicle architectures & evolution of usage can have new impact. Services around tires will be needed for tire selection and management, range estimations and freight movement optimizations. Retreading improvements are needed for both performance and process. Considering BEV affordability, one can expect more trucks under "Truck as a service" contracts instead of owned trucks, which could change the game on the way tires are used by end users.

Keywords: electric, battery, truck, tire, heavy vehicles.

1. Battery electric trucks specificities

1.1. Context and scope

Trucks and buses account for 25% of greenhouse gaz transport emissions in Europe and USA. This strong proportion leads to an increasing pressure to decarbonize this sector. OEMs and shippers are pushing to step out of fossil fuels to make their activities more sustainable, and at the same time, governments put in place norms and regulations to accelerate the transition to Zero Emission Vehicles. This leads to the development of battery electric vehicles (BEV), and fuel cell electric (FCEV).
OEMs demonstrate high ambitions in BEV sales, but the ramp up is slower than forecasted: even though some leading fleets are strongly engaged in this transition, vehicle and infrastructure costs remain high, range is still limited, and the public infrastructure ensuring a charging solution on the road is still nascent. Furthermore, fleets are highly impacted by these new powertrains: the transport plan needs to be rethought to take electric charging into account, and routing also needs to be adapted among other things.

The question of the impact of BEV on tires expectations is not well shared and the late awareness on electric urban buses tires makes it worth to debate now.

This paper focuses on tractor semi-trailer configuration in the European zone, since this configuration accounts for nearly 80% of class 8 in Europe.
To decarbonize the road freight transport, several powertrain technologies are on the shelf: BEV (Battery Electric Vehicle), FCEV (Fuel Cell Electric Vehicle), H2 ICE (Internal Combustion Engine H2). The highest sales at short term is forecasted to be BEV, since almost all European manufacturers have planned their commercial launch for battery electric tractor in 1st semester 2025 and the charging network is getting deployed. It is illustrated with the graph on figure 1 from S&P Global , 2023.

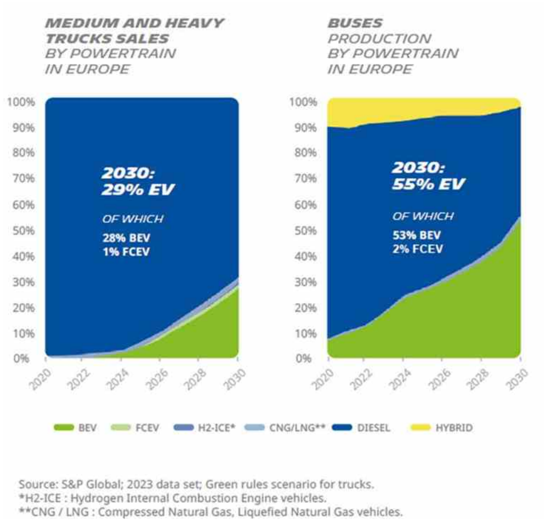


Figure 1 :
Sales forecasts from S&P Global dataset

Currently, there aren't many electric heavy trucks on the road to assess the impact of their specificities with field surveys. Nevertheless, truck manufacturers are already expressing new expectations on tires. The tire manufacturers should work with prognosis of the impact to build the technical proposal. Tires for BEV trucks need to be available for truck SOP without field validations possible before. An accurate risk analysis is also required in advance to correctly design the tires for this new usage. This paper aims at starting discussions around the quantified impacts of electric powertrains on tire performance.

1.2. How a battery electric truck is different from a diesel truck?

When we compare main elements constituting a diesel and a BEV tractor powertrain, we see that one could expect 3t additional tare weight, as decomposed in the figure 2:

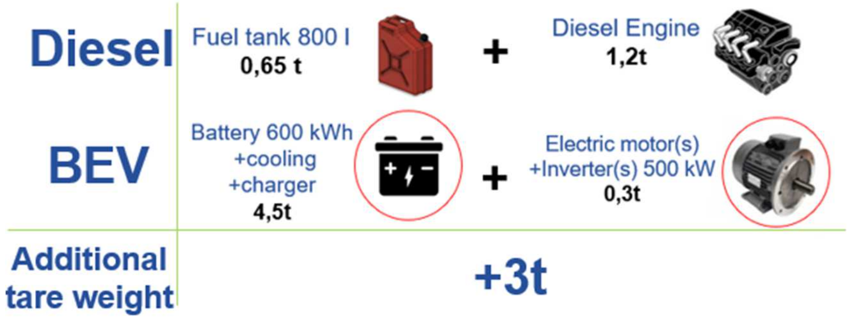


Figure 2 : decomposition of weight differences between diesel and battery electric trucks

This is explained by the energy density of batteries, which is around 0.15 kWh/kg in 2020 with forecast 0.23kWh/kg in 2030 (ref2, Basma & Rodriguez, 2022), while diesel is nearly 11kWh/kg. Then, even if the efficiency ratio is at least twice better for an electric powertrain, we easily understand that keeping the same range will be a big challenge. When diesel trucks propose more than 2500km with 800L diesel, BEV is limited to 500km with 600kWh batteries.

For that reason, the electric truck must recover as much energy as possible in braking phases or in downhill situations, to avoid wasting energy in the disk brakes, as illustrated in Fig.3. This is made possible thanks to reversibility of the electric engine. The consequence is that the electric engine is no not only sized for its traction performance, but for its braking performance, as a retarder system. Thus, electric trucks are more powerful than diesel ones, to enable the highest level of energy recuperation.

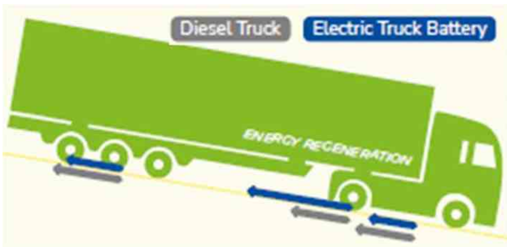


Figure 3 :
Braking forces in downhill diesel VS electric

On the Figure below, we can see that the electric motor delivers more power than the diesel one. This results in more traction force available above 15 kph and below 50kph:

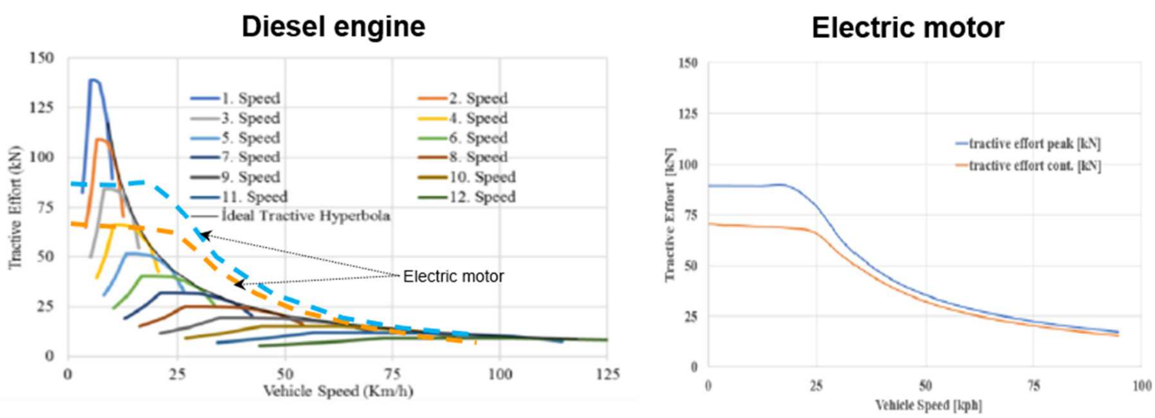


Figure 4 : Traction force diagram diesel 12 speeds VS BEV 1 speed (Kopplow, 2023)

From the few announcements made by OEMs, it appears that chassis architecture, powertrain architecture and set-up will differ from one OEM to the next. For example, the engine power, battery technology and max regenerative braking power could vary a lot between truck models.

Furthermore, the free space where to fit the batteries increases when using an e-axle instead of a conventional drive axle, as you can see on the following drawings:

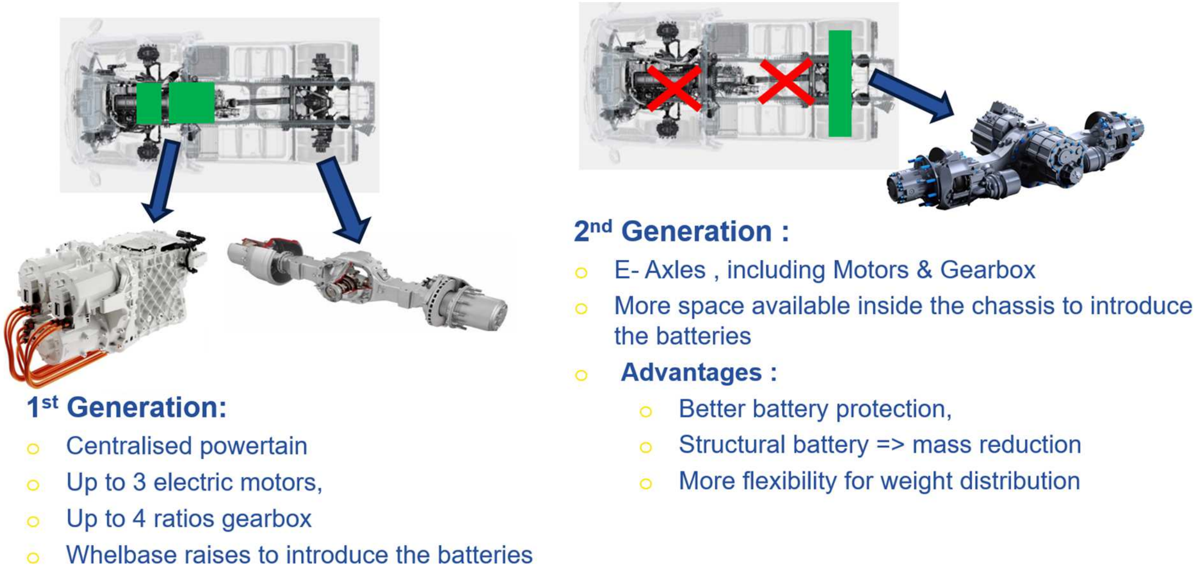
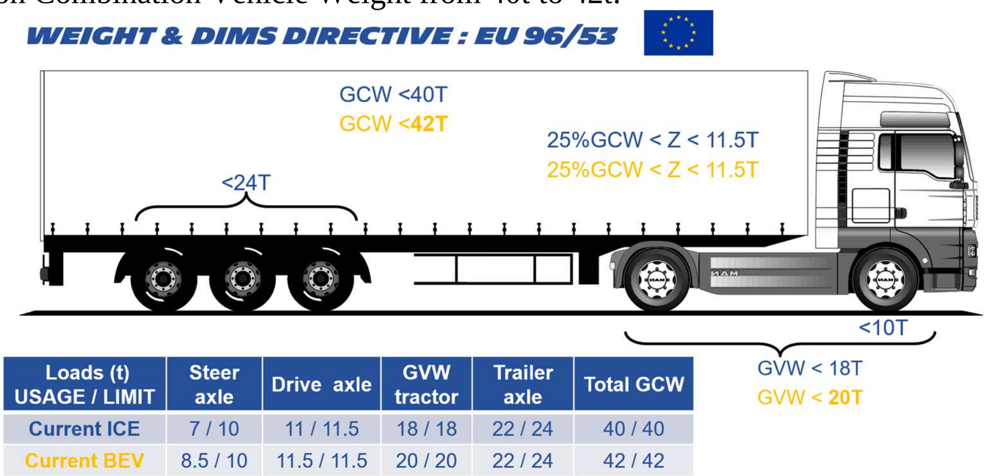


Figure 5: BEV chassis architecture

2. Tire endurance at high load capacity needs to be upgraded

To help the deployment of battery electric trucks on the market, the European regulator enforced a bonus on Combination Vehicle Weight from 40t to 42t:



Loads (t) USAGE / LIMIT	Steer axle	Drive axle	GVW tractor	Trailer axle	Total GCW
Current ICE	7 / 10	11 / 11.5	18 / 18	22 / 24	40 / 40
Current BEV	8.5 / 10	11.5 / 11.5	20 / 20	22 / 24	42 / 42

Figure 6 : Usage weight and legal limit per axle for diesel and BEV trucks in Europe

As the bonus is only on CVW and not on axle loads, the usage load can be mainly increased on the axles not yet at the maximum of legal limit. This is the case of the steer axle, limited to 10t, commonly used at 7t for 40t CVW and going to move to 8.5t in BEV case for 42t CVW.

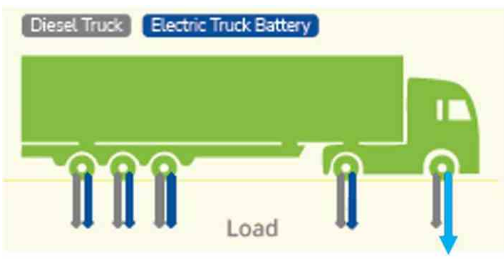


Figure 7:
Load distribution comparison diesel VS BEV

The truck tires sold on the market must comply with standards defining their size, speed index and load index for a given nominal pressure. The list of existing standards in Europe is managed by ETRTO (European Tire and Rim Technical Organization) and new standards can be introduced under request by tire manufacturers and agreements between them. The most common tire size in Europe for heavy trucks is 315/70R22.5, which standard load index is 4 tons @ 9 bars. This is the maximum load the tire can carry, but the performance of this tire size on the market is observed with lower loads.

With Weight In Motion data, it is possible to better know what is today's statistical load on the tires. On the opposite graph Fig.8, the statistics of steer axle load have been studied by IFSTTAR (Institut Français Scientifique de Technique de Transport et d'Aménagement des Réseaux, Schmidt & Domprobst, 2016). This is the statistical distribution on the front axle of 2 million tractor semi-trailers (tire load is obtained by dividing axle load by 2). We observe that the 8t load on the front axle (4t on steer tires) is almost never reached, even if it is the tire load capacity.

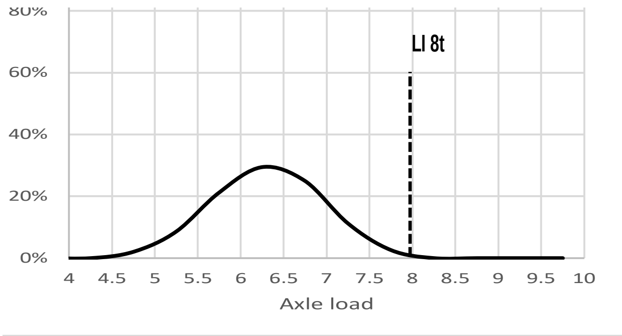


Figure 8 :
Statistical steer axle load of diesel trators semi in France

When we consider that the tire max usage load at max CVW will move from 7t to 8.5t, one should also ask the question of the change in the distribution. We can imagine the 3 following scenarios:

- If only +500kg on steer empty weight
- Steer axle 8t5 when convoy loaded 42t
- Steer axle 8t5 empty, no payload on steer axle

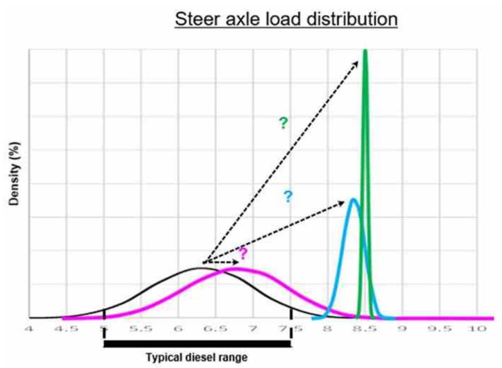


Figure 9:
hypothesis of load distribution change for BEV

All these scenarios would require the same tire Load Index (LI) but would not have the same consequences on the tire endurance and on the tire lifetime.

The actual load distribution shift depends on the position where the OEM fits the batteries, on the battery weight, on the wheelbase and on the fifth wheel position. The first public electric trucks architecture and empty loads gathered shows that tire manufacturers will not have to simply handle a 500kg load shift (pink curve hypothesis in Fig.9). Collaboration between OEM and tire manufacturer is needed to adapt tire design to the actual new tire load distribution.

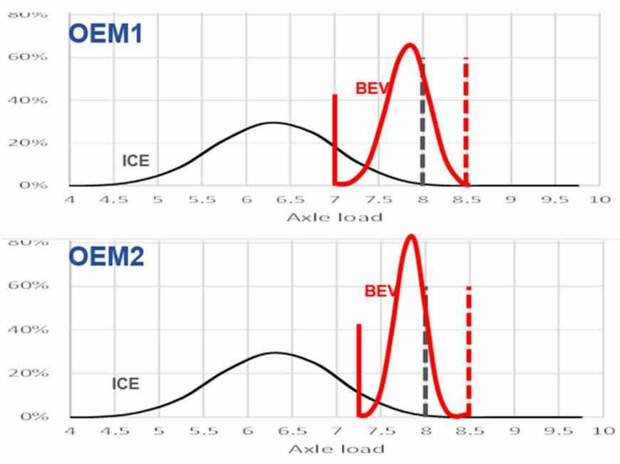


Figure 10:
Actual expected load distribution shift for BEV of 2 OEMs

A truck tire must be removed due to the tread wear and not due to casing endurance. Without tire technologies, the OEM expectations to carry more load can be achieved by a tread mileage reduction, to remove tire earlier on tread wear. This will lead to an increase of Tire Road Wear Particles (TRWP) emissions.
The tread void volume of the front tires needs to be kept at a similar level to the current model to store the water and secure wet grip performance. This considered, the way to limit the casing number of cycles is to downgrade the tread material erosion properties, which would generate the same quantity of Tire Road Wear Particles but on a lower mileage performance.
With a redesign of the tire, and with new technologies in casing structure, improvements are possible to keep the tire mileage and particle emissions at current level and carry the additional load required by electric trucks.

3. Tire wear life will be reduced

3.1. The wear rate is increased

As already introduced in the first paragraph, the braking strategy of battery trucks needs to be adapted to maximize the energy recovery for range: in several situations where the diesel convoy would be slowed down by braking with disks on all the axles, the BEV will brake with its electric engine on drive axle only. The drive tires will be more stressed on BEV than on diesel truck and should deliver a lower mileage.
Furthermore, as a more powerful engine is fitted, the driving style may be more severe in acceleration.

To quantify the impact of the electric powertrain on the tire wear, it is not possible to compare statistics of tire mileage on diesel trucks with statistics on electric trucks since the BEV are not massively in service on the roads.
To estimate the impact without available usage quantitative facts, we have used simulation results from OEM tools. This work has been done in partnership with one OEM because this approach needs to consider the actual powertrain and brakes management depending on the OEM strategy. This simulation considers the powertrain management (incl a driver model) and the vehicle dynamics for both the diesel and the BEV truck. The result is the tires forces on a given usage.

Once knowing the forces applied on the tires for each truck type, we have run a tire wear simulation. It consists in a FEM model with erosion rules to calculate the tire wear speed.
We have selected 2 different usages defined by the speed profile and the slope profile. The regional delivery (RD) usage is more speed dynamic, low speed and quite flat. The long-haul (LH) usage has a higher speed, less acceleration situations and is hillier.

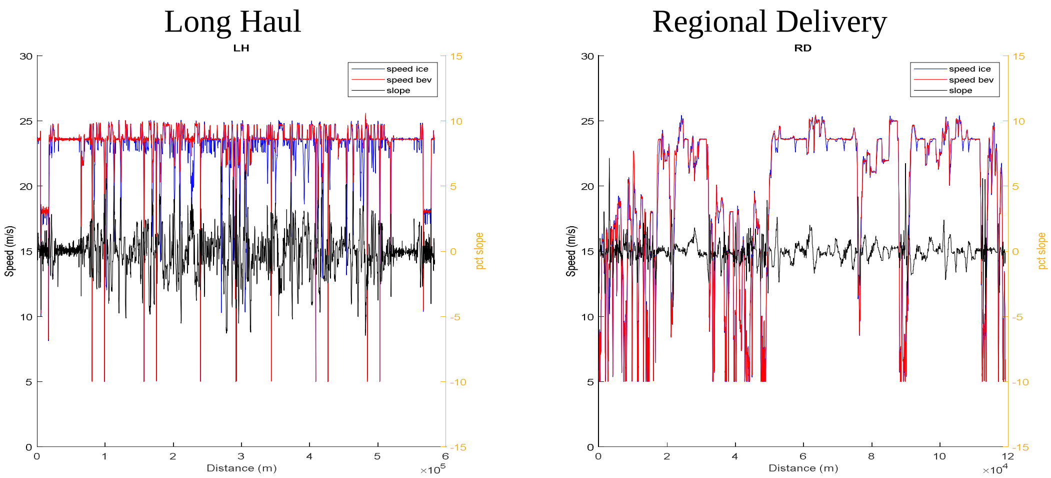


Figure 11: Usage definition

The diesel vehicle is loaded at 40t while the electric vehicle uses the bonus load at 42t. Firstly, we can compare the longitudinal force on drive axle as a function of vehicle speed between both trucks (ICE & BEV):

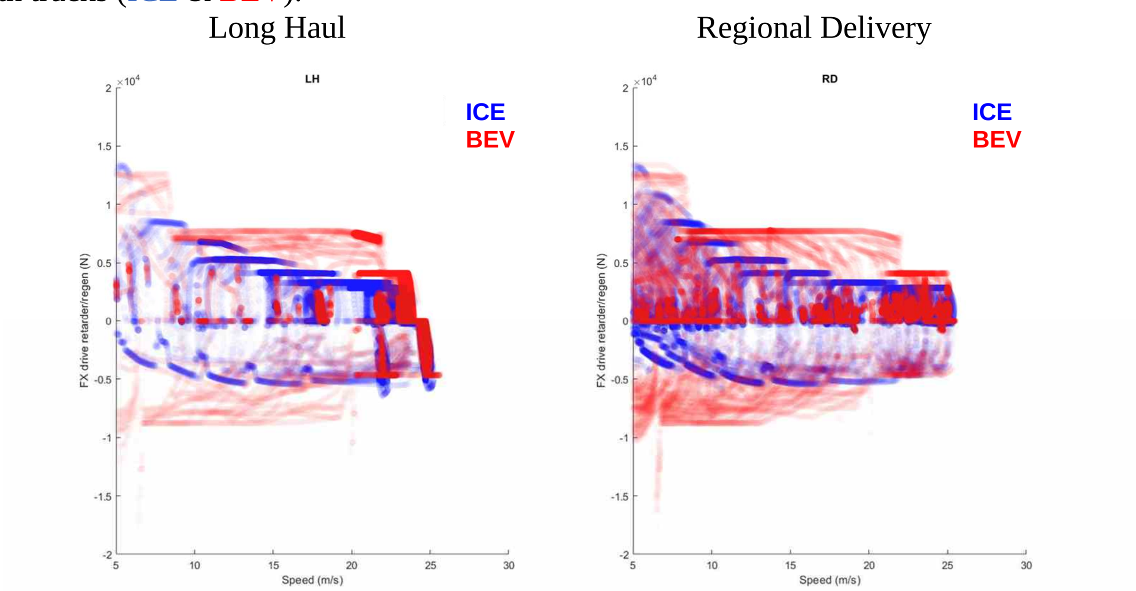


Figure 12: Force speed cartography

We can see that the BEV generates more traction torque than diesel at high speeds and more braking force at low speeds. This is more visible on the regional delivery usage than on the long-haul. We can explain this additional braking forces on the BEV by the change in the brake balance between front and drive axles: The BEV brakes more with drive axle instead of steer axle, as plotted on the following graph, which represents the distribution of the proportion of the total braking force done by the steer axle:

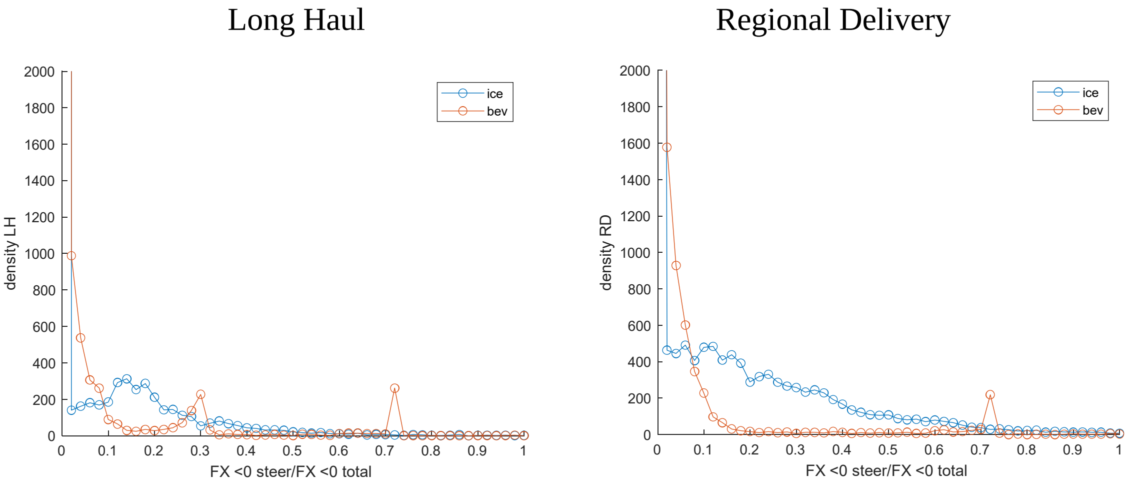


Figure 13: statistical distribution of braking force balance

The tire forces have been postprocessed with a tire wear simulation tool. It is based on the calculation results of Finite Element Method (FEM), as illustrated in Fig.14, at the tire forces functioning points and a rubber erosion law to integrate the lost tread depth per wheel rotation along the considered usage.

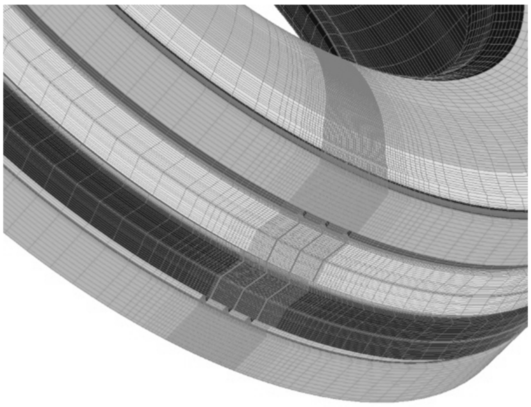


Figure 14: Tire FEM meshing

The calculated wear rate (homogeneous to mm tread/km), shows that the drive tire wear is significantly impacted:

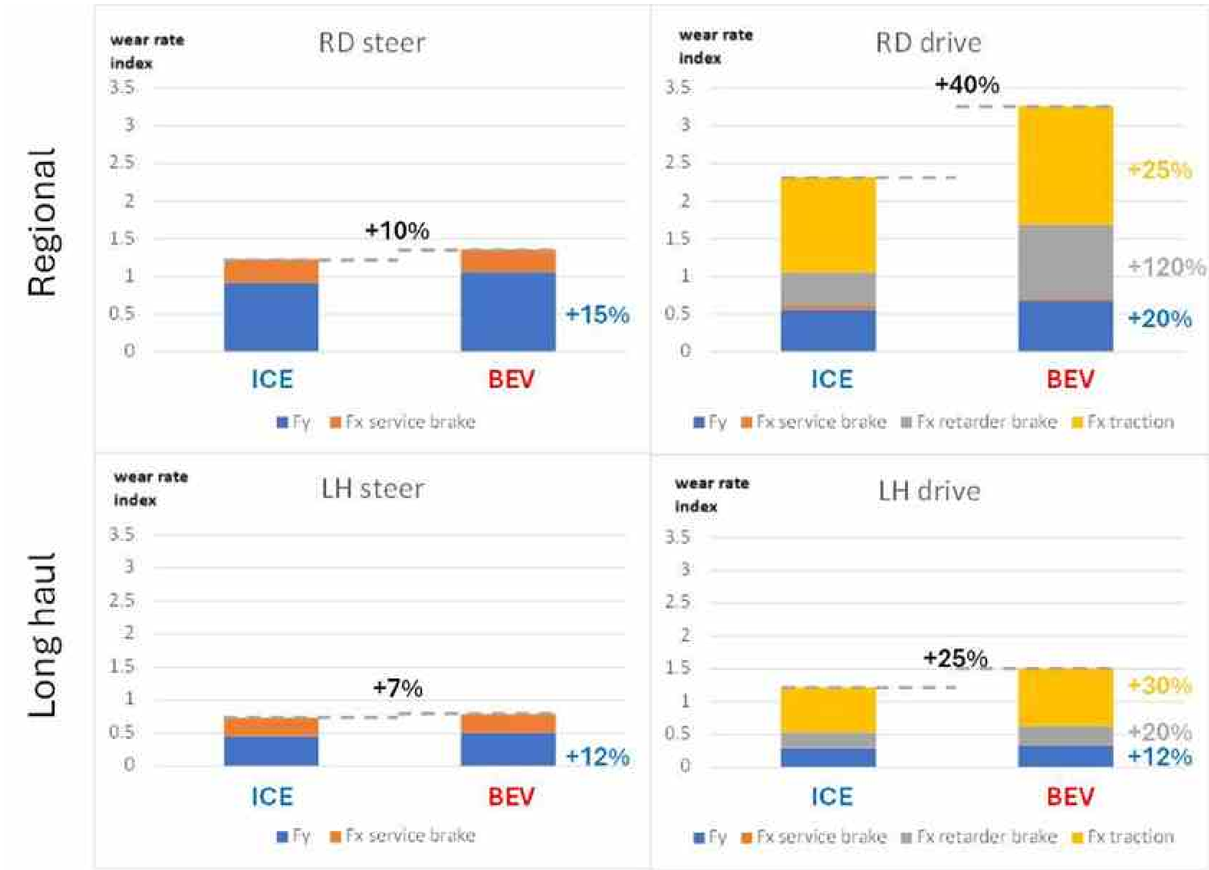


Figure 15: electric powertrain impact on tire wear speed

The total wear rate is decomposed in contributions from the solicitations applied on the tire:

- Negative longitudinal force from service brake (disks)
- Negative longitudinal force from retarder brake (regenerative braking for BEV)
- Positive longitudinal force from traction
- Lateral force in turns

The regional delivery usage is more severe with a higher total wear rate due to more stop and go, and higher lateral accelerations. On drive axle, we don’t see a contribution of service brakes on tire wear rate since the brake of this axle is mainly the retarder.
As a part of the brake forces are transferred from steer axle to drive axle, especially on regional delivery usage with several stop and go, the wear rate on drive axle is increased by 40%. It is mainly due to the regenerative braking contribution, which is more than doubled (+120%). We also see an increase of the contribution of traction force, explained by the increase of CVW (42t instead of 40t) and same speed profile target.

The steer position is not significantly affected by electrification in terms of wear, excepted a small increase due to the additional load on front axle, which increases the lateral force contribution.

3.2. Load transfer effect can worsen the result

When doing such a study we had to consider forces simulations from a very simple vehicle chassis model, to take advantage of powertrain model reliability. But this neglects an important mechanism on tire wear study. Indeed, when the drive axle brakes the whole convoy with regenerative braking, the load on drive axle changes due to load transfers, as explained by the opposite drawing.

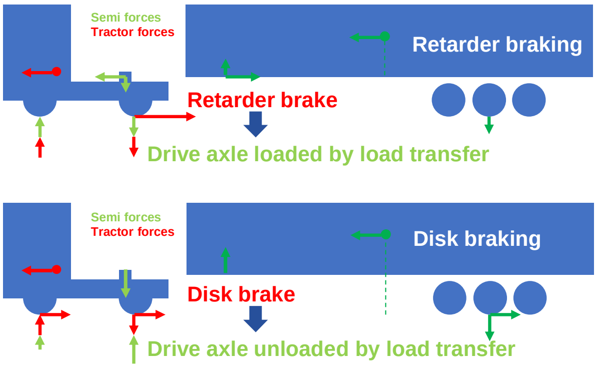


Figure 16:
Load transfers comparison between service brake and regen brake

This leads to a load reduction on the drive axle, when it brakes the convoy by itself, resulting in more slip of the tire, resulting in additional wear. On the opposite graph, we show the load variation on each of the 5 axles (normalized by longitudinal deceleration) for drive brake or all axles brake:

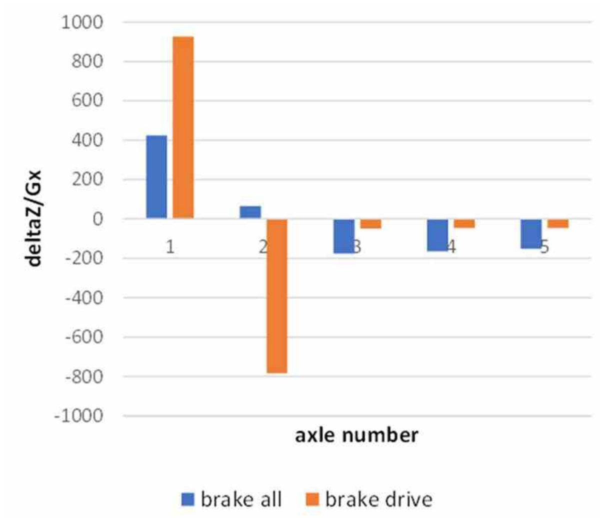


Figure 17: load transfers normalized by deceleration

3.3. We expect a further impact due to irregular wear

A third effect must be considered when speaking of tire wear on electric trucks. The wear profile is expected to be different from diesel trucks, since the braking force is higher. We expect by simulation to increase the tread depth difference between tread center and side by more than 2mm at end of life, thus reducing furthermore the mileage performance.

To conclude with tire wear on battery electric trucks, we can estimate by simulation a higher wear rate vs diesel trucks:

- Long Haul: +7% for Steer and +25% for Drive
- Regional: +10% for Steer and +40% for Drive

These figures are conservative because they don't take the load transfers effect into account, nore the worsened wear profile. Some isolated cases already show -50% mileage on the drive position.

4. Energy efficiency and tire rolling resistance : what is at stake?

The tire rolling resistance coefficient (RRC) is a phenomenon that dissipates energy by heating the tire, due to the viscous properties of rubber materials constituting the tire. The improvement of rolling resistance is well known to reduce the fuel consumption of a diesel truck, but we can wonder if it will be the same for electric energy of a battery truck.

When the tire rolling resistance coefficient is reduced, the tire saves energy spent at the crankshaft to move the truck. This results in fuel consumption reduction because this energy saved at the crankshaft does not have to be pumped in the tank. Between the fuel torque crankshaft reduction and the fuel consumption reduction, there is the diesel engine efficiency ratio. For a given RRC reduction, fuel consumption reductions are even higher when the engine efficiency ratio is lower. This can be understood with a Willans diagram as presented opposite Fig.17. This figure doesn't aims at simulating with precision the tire RRC reduction impact on fuel consumption but it is useful to explain the differences between diesel and BEV.

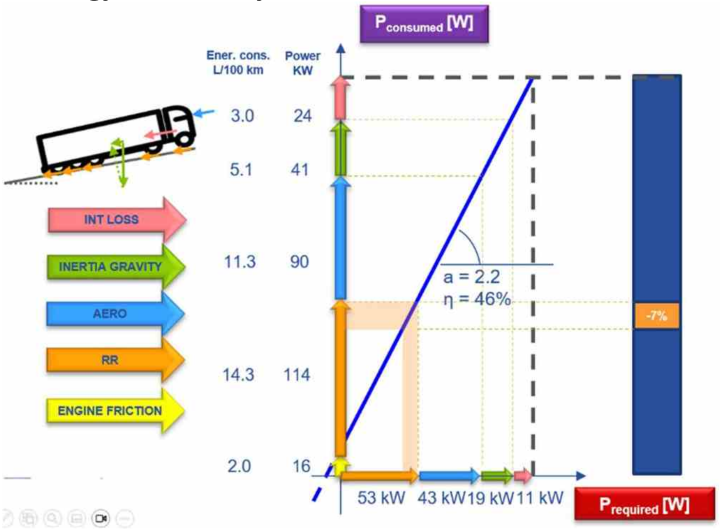


Figure 18: Energy consumption decomposition

For an electric truck, the engine efficiency ratio is better with peak at 95% instead of 45% for diesel, so the absolute energy gains before the engine are expected to be lower. Nevertheless, the whole energy consumption is improved with electric trucks, so a change in RRC results in similar effects in energy consumption in % between diesel trucks and battery electric trucks.

Energy consumption simulations on same usage definition have been done for diesel truck and electric truck, for a reference tire at 5kg/t and a low rolling resistance tire at 4kg/t. The results are presented in kWh/100km for diesel and battery to make the comparison easier:

	tire RRC (kg/t)	Long Haul cycle (kWh/100km)	Regional cycle (kWh/100km)
Diesel truck	5	357	429
	4	332	403
		-7%	**-6%**
Batt. Elec. truck	5	120	111
	4	112	102
		-7%	**-8%**

At the tank, the game doesn't change significantly for eTrucks (same energy relative gains but lower absolute gains).
Under iso usage hypothesis, RRC may pay better (relative gains) in regional applications for eTrucks. This is explained by the fact that a low RRC tire improves efficiency only when the truck spends energy (while traction). As the eTrucks recover energy while braking or downhill phases, it can recover more energy when low RRC tires fitted, which improves the distance over which low RRC is being beneficial.
Low RRC cannot be valorize anymore by CO2 reduction on BEV, but it could be slightly valorized by energy cost because electricity is more affordable with slow charging.
The main low RRC valorization is range, valued by end users needing a bit more range than the standard proposed by the OEM.

5. Conclusion : electric trucks are more challenging for tires

We should not forget that tires on battery electric trucks are also more audible in the global vehicle noise since the engine becomes less noisy. With higher traction and regenerative braking forces, grip performance should be kept at best level. In the end, the tire has more to deliver on a BEV than on diesel truck:

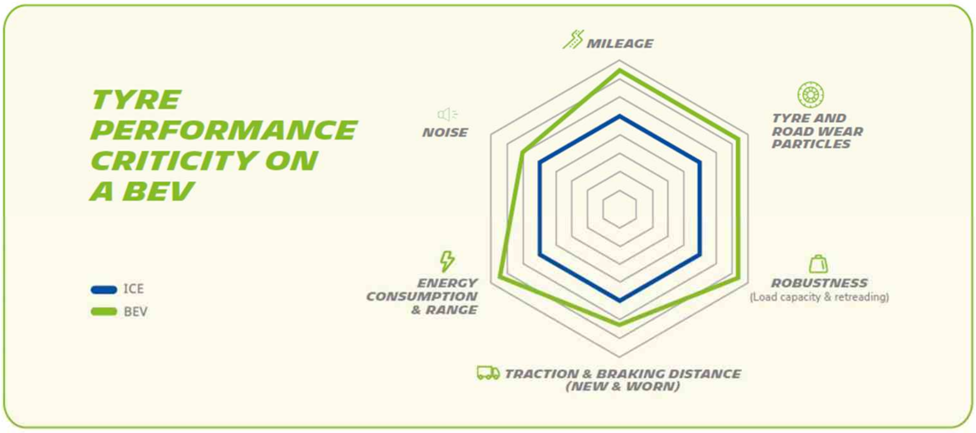
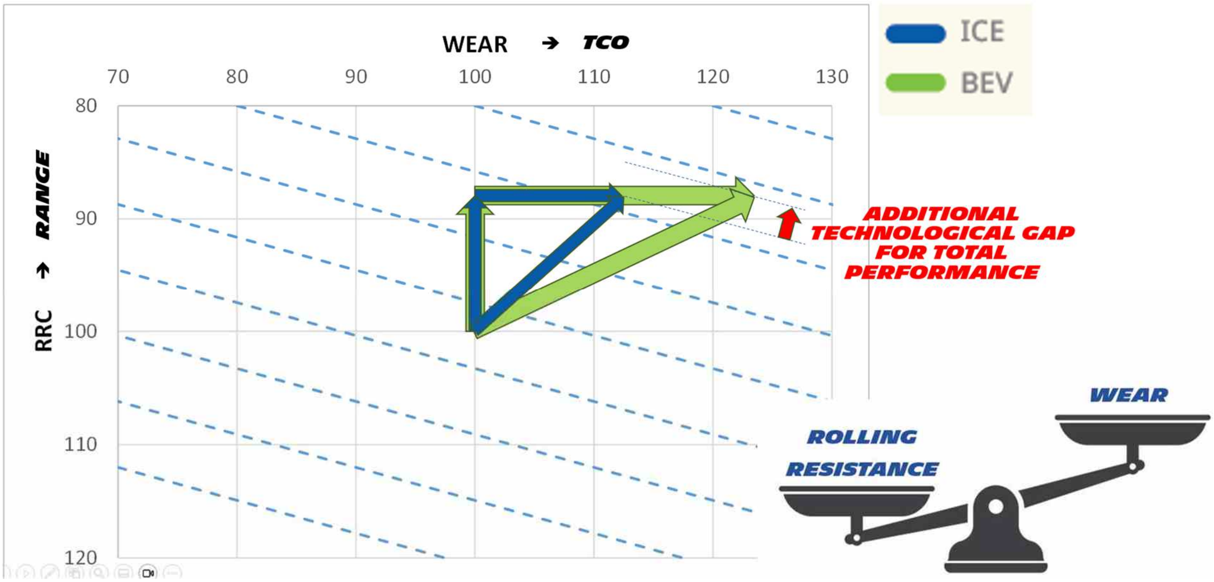


Figure 19: Tire Performance criticity on a BEV (Ref.4, Michelin White paper 2024)

In the previous chapters, we have seen that a battery electric truck highly challenges the tires regarding the wear performance, and that on the energy consumption-RRC side, it is nearly the same dynamic.
As the low rolling resistance tires are often the result of a compromise on wear mileage, it is expected that the needs of the end users will be globally more challenging for tires, especially on the drive axle. On the graph below, we illustrate the need for a technological gap for BEV tires to improve the mileage with the same RRC:



To conclude, eTrucks are requiring more total performance to tires what will prevent to achieve low RRC with tread depth reduction (dotted blue lines). Manufacturers will have to deploy tires technologies to address these new stakes.

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