

These lecture notes will provide additional insight into the non-financial factors that are of relevance when considering switching your fleet to electric.

Range and batteries

Range is considered a major obstacle in the adoption of electric vehicles. The range is mainly dependent on the size of the battery pack of the car. When as a fleet owner or automaker you have to decide on the desired range of your vehicle there are many factors to take into consideration. Of course cost play an important role but also the weight of a battery could influence the driveability. Moreover you have to take into account the desires of your costumers, how afraid they are of a limited range. A smaller range means more recharging which could reduce the ease of use of the vehicles.

Looking at the battery pack weight, the major determinant is the energy density of the energy carrier. Gasoline has a relatively high energy density making it a suitable carrier for energy to cover long distances. Comparing it to the lead-acid battery with which it had to compete in the early years it is easy to imagine that gasoline became the more favorable option. Battery energy density however has greatly improved in more recent years with the introduction of the lithium-ion battery and especially the developments in the mobile phone industry. Lithium-ion batteries have a more than 10 times higher energy density than lead-acid batteries. New technologies with other chemicals, such as solid-state batteries, are expected to increase the battery energy density in the coming years. As an alternative to batteries, hydrogen has an energy density that is comparable to gasoline. However



it needs to be transformed to a liquid first to be ready for transport in car. This density however makes it suitable for longer distance trips. The high energy density could make it especially suitable for long distance heavy duty trucks. If you like to know more about batteries please have a look at the Electric Cars: Technology course.

For battery electric vehicle the lower energy density means that the car will be heavier than a gasoline equivalent with a similar range. This additional weight could influence the driveability of the car. Many manufacturers however used this weight to their advantage and placed the battery pack on the floor of the vehicle as can be seen in the picture. This creates additional stability as the center of gravity of the vehicle is low. In other vehicle designs the battery is placed in the trunk creating a different driving experience. For buses this can be problematic, they require a larger battery pack. Due to the design of a bus it is not always possible to fit the battery completely in the floor. The battery pack is therefore placed on the roof of the bus. The rooftop location also easily connects the battery to overhead charging systems commonly used for buses. This can create instability and thus a different driving experience you might have to get used to.

Recharging

Re-charging an electric vehicle is a different experience than refueling a gasoline car. Depending on the battery pack size, the car has to be recharged more often and recharging times can be considerably longer. Many countries do not have a dense charging infrastructure. This could create range anxiety, the fear that you run



out of fuel, especially among first time users and could reduce the ease-of-use.

This range anxiety often disappears as drivers get experience with driving an electric vehicle. This experience shows the drivers that the ranges that are currently available are mostly suited to their daily driving needs. As this graph shows, that majority of the daily driving distances is below 100 miles, the average range of electric vehicles in the market. Recharging your vehicle overnight is therefore more than sufficient to meet more than 95% of the daily needs without recharging somewhere else but home.

This experience can be seen in the number of charging events per day per vehicle that were tracked in field experiments. Most drivers only recharge their vehicles once or twice. These are often the most familiar places, at home and at work. Recharging more than 3 times is a rarity even with current electric vehicles that have a limited range. Although recharging an electric vehicle on the road can be a hassle on the road and it takes longer than refueling your gasoline car, the practice shows that this is a rarity, most recharging can be done overnight which could actually save you time. Plugging in your car after all only takes you seconds, you can leave the car parked overnight and drive it away fully charged the next morning.



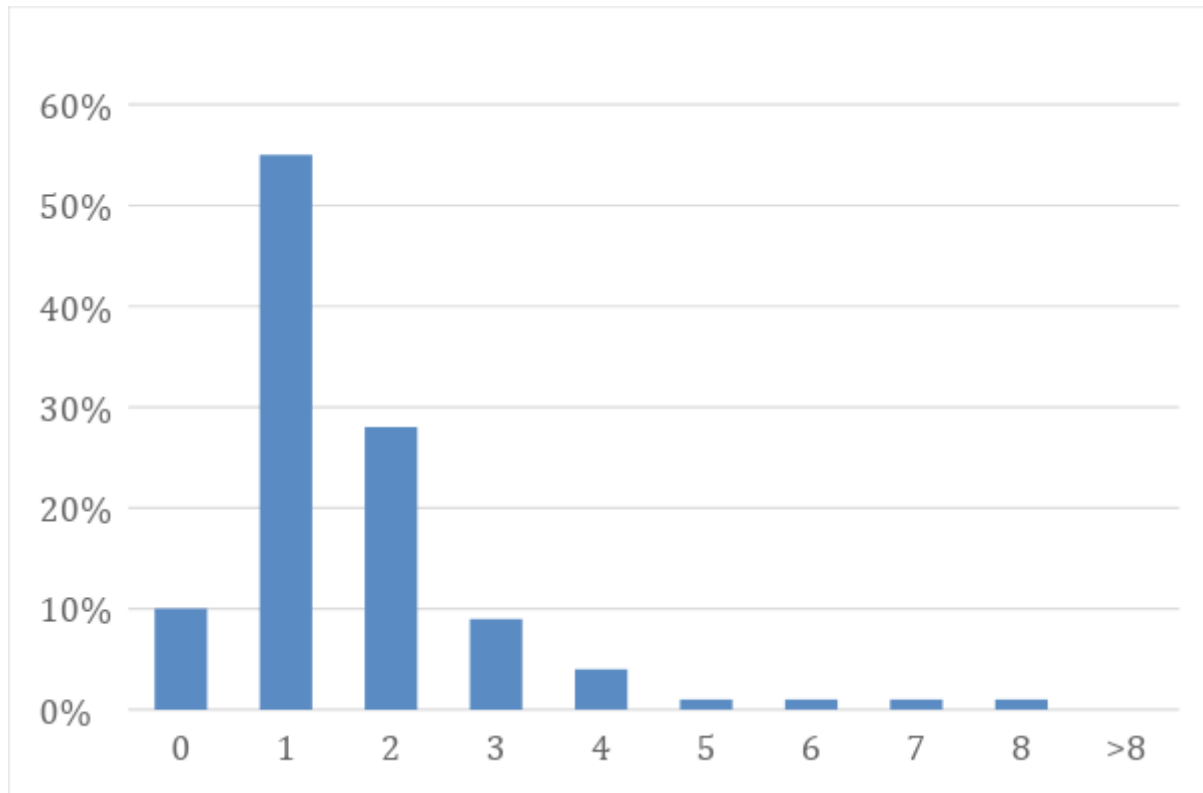


Image source: Smart, Powell & Schey , 2013, Extended Range Electric Vehicle Driving and Charging Behavior Observed Early in the EV Project, SAE World Congress 2013.

Performance

Driving a car should also be fun, performance of a car therefore also matters. So how do electric cars perform? Compared to the gasoline engine, electric vehicles have the benefit that they have instant torque available. This allows the vehicle to quickly accelerate. Electric vehicles are therefore beating records when it comes to 0-100 km/hour times. This performance metric is one of the reasons why electric cars are outselling many of their competitors in the luxury segment. On the longer run, and when it comes top speed, gasoline engines are a better pick. Many electric



vehicle manufacturers have limited the maximum speeds to relatively low levels. These high speeds require a greater amount of energy and thus limiting the range of the vehicle.

Electric vehicles are often praised as zero-emission vehicles. Their environmental impact when driving is minimal, their so-called Tank-to-wheel emissions are non-existent. However, the electricity produced does not always come from clean sources. How does the electric vehicle compare when a coal fired plant produces the energy used? When assessing the environmental footprint of a vehicle it is important to assess the entire life cycle of a vehicle. Such a complete assessment of the emissions over the lifetime of a vehicle is called life cycle assessment. This research technique is commonly used across many fields. Depending on the area of research it is important to set the system boundaries in a correct manner to include all the relevant factors. Life cycle assessment for vehicle emissions include the manufacturing of the vehicle, including the powertrain but also the chassis or glider of the vehicle. In case of battery electric vehicles the battery itself is also an important source of emissions. The production of the fuel itself, so called well-to-tank emissions should also be taken into account.

Tank-to-wheel emissions are the major part of lifetime emissions. The source of electricity is therefore an important factor. As this graph shows there can be large differences in the amount of renewable sources that are used for production. Comparisons are therefore often done at a national level. Life cycle assessments



that include emissions from electricity are often made on the current situation. However with the current shift to more renewable energy sources, the production of electricity is becoming less carbon intensive. This also means that driving an electric vehicle becomes cleaner along its lifetime.

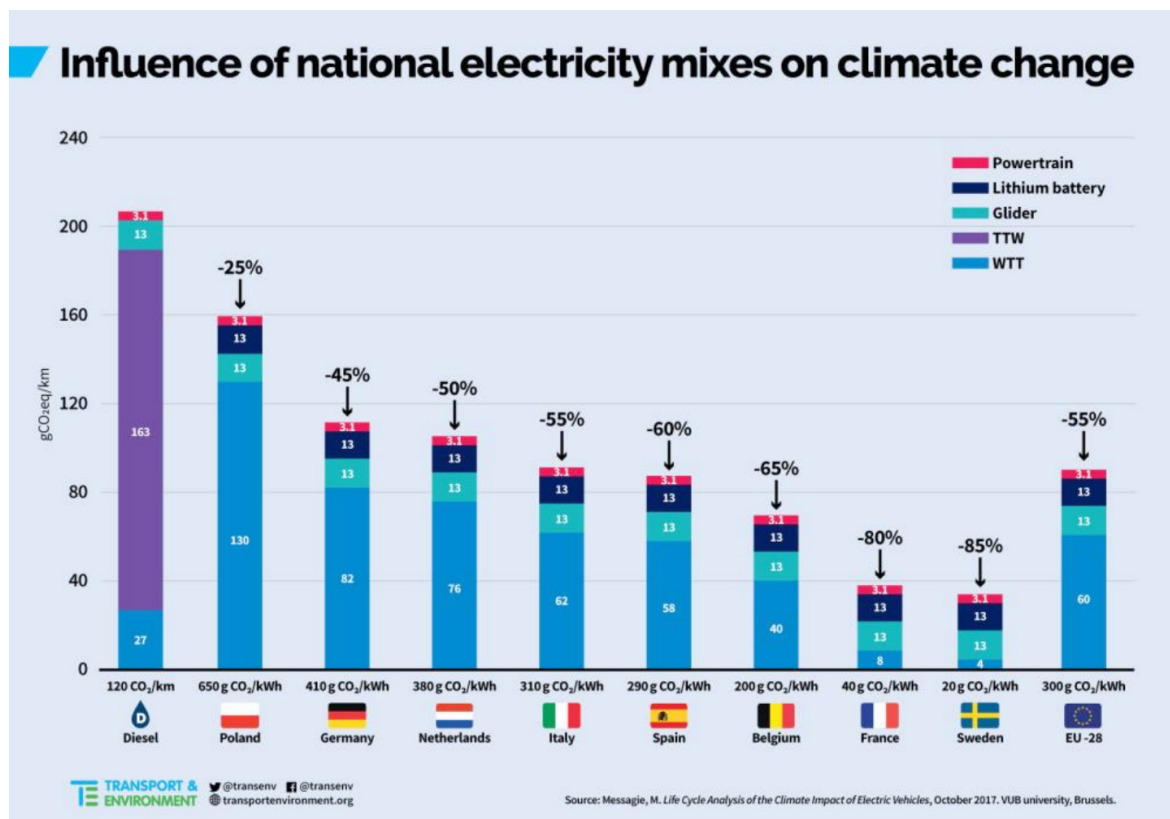


Image source: Messagie, M., Boureima, F. S., Coosemans, T., Macharis, C., & Mierlo, J. V. (2014). A range-based vehicle life cycle assessment incorporating variability in the environmental assessment of different vehicle technologies and fuels. *Energies*, 7(3), 1467-1482.

The production of the battery of an electric vehicle creates additional emissions compared to gasoline cars. One of the major factors is the mining of rare metals that are needed. Especially the metals needed for the production of the cathode



can be problematic. Automakers are therefore making trade-offs in the chemical composition of their batteries. The market prices of these metals react to the demand and other political sensitivities. As an example battery makers are shying away from Cobalt. The mining of Cobalt is concentrated in the Democratic Republic of Congo which currently has an unstable regime. These political sensitivities have driven up prices of Cobalt which led battery makers to look for alternatives with other metals.

When all these factors that produce emissions over the lifetime of a vehicle are calculated a fair comparison is possible. The carbon intensity of the electricity produced can however vary across countries. This comparison shows that for electric vehicles, emissions are relatively high in countries such as Poland and the Netherlands because they have many coal fired plants in operation. In countries that depend more on renewable and nuclear sources for their electricity production, life time emissions are much lower. In general it can be concluded that even for the most carbon intensives countries, CO₂ emissions for electric vehicles are lower than their gasoline or diesel equivalents.

A factor that is not taken into account in the presented life cycle analysis is the disposal of the car. For the recycling of the chassis and powertrain infrastructures are already in place. However the batteries with possible toxic chemicals need to be disposed in a new manner. Automakers are thinking about instead of recycling the battery components, about reusing degraded batteries. These batteries, if no longer fit for use in vehicles, can still be used in storage solutions. The market for storage is growing with more renewable and decentralized electricity production.



Some automakers therefore provide business models in which the car owner does not own the battery but leases it. In this way car manufacturers keep full control over the entire lifetime of the battery and can get the most out of it.

One of the uncertain factors when it comes to purchasing an electric vehicle is the

Battery lifetime

battery life time. As many of the electric vehicles on the road are relatively new much is unknown about the longevity of the battery. Early experiences from drivers indicate that the battery lifetime could actually be longer than the average lifetime of a vehicle if used in a correct manner. One of the determining factors is of course the number of kilometers driven and therefore also the number of recharge cycles. To optimize the life of your battery it is best to slowly charge the vehicle as much as possible. Fast charging can decrease the lifespan significantly. Battery experts advice not to completely drain your battery when driving. It is also not advised to completely fill the battery as the internal resistance of the battery builds up if fully charged.

Experiences on the battery lifetime however differ from driver to driver. Some had to replace their battery after just 1 or 2 years of driving, while others still have more than 95% battery capacity after more than 200.000 kilometers on the road. These differences are mainly due to the different battery composition across automakers and their battery management systems. A good battery management system also helps to control the process of charging and therefore preventing overheating or overcharging using a too high voltage. Such overheating can provoke chemical process within the battery and thus reducing the capacity it can hold.

