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CHALLENGES AND OPPORTUNITIES FOR CREATING A SUSTAINABLE GLOBAL MARKET FOR ELECTRIC VEHICLES

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Abstract

The automotive sector is one of the largest contributors to Greenhouse gas (GHG) emissions around the world. In order to combat the issues related to vehicle pollution (climate change, health, and environmental hazards), there has been an increased push towards using Electric Vehicles (EVs), including hybrids and purely electric vehicles (BEVs). This review paper takes an in-depth look at the challenges faced by the global automotive market. A quick review of the vehicle lifecycle is presented, along with all the energy expenditure and emissions at different stages. Studies conducted by various governmental entities, OEMs (Original Equipment Manufacturers), environmental scientists and independent groups in Europe and North America show that there is a substantial difference in the environmental impacts between traditional internal combustion engine vehicles (ICEVs) and EVs. Overall, EVs prove to be less polluting than ICEVs, however, this largely depends on the source of energy used for electricity supply. Results from assessments around the world have been presented, followed by a review of the strategies for introducing EVs to the global automotive market in an environmentally and economically viable manner. It is also important to look at the performance and customer satisfaction surveys in order to improve the public perception of EVs. Lastly, the paper explores the need for global migration toward renewable sources of energy in order to truly combat the aforementioned problems in a systemic manner.

Keywords: Electric cars, Carbon footprint, Vehicle pollution, Greenhouse gases, Climate Change, Battery recycling, Sustainability in automotive Engineering, Systems Engineering

1. Introduction

The automotive market is one of the most rapidly evolving sectors in terms of technology and innovation. However, it is also one of the largest causes of Greenhouse Gas (GHG) emission. In the US, the transportation sector recently became the largest source of GHG pollution [1] [2] and countries in Europe are showing a similar trend. This includes emissions from operating cars, trucks, planes, trains and shipping. Many developed and developing countries around the world are noticing similar alarming trends. This paper looks closely at the ground transport vehicle market, which accounted for approx. 12% of the carbon emissions in the EU and have similar percentages in other developed regions around the world [3]

Despite the push towards vehicle electrification [3], the contribution of the transportation sector to total GHG pollution has been increasing year on year [4]. This has been due to an increase in the number of vehicles manufactured and sold, as well as the concomitant increase in the number of vehicles owned per 1000 people in most markets [5].

The energy consumption and the resulting emissions for the transportation sector can be split into three major categories based on different phases in the vehicle lifecycle, as shown in Fig. 1. The highest contribution to the emissions comes from their operation (use phase) and accounts for up to 90% of the total emissions based on Fig. 2 and Fig. 3 [6] [7].

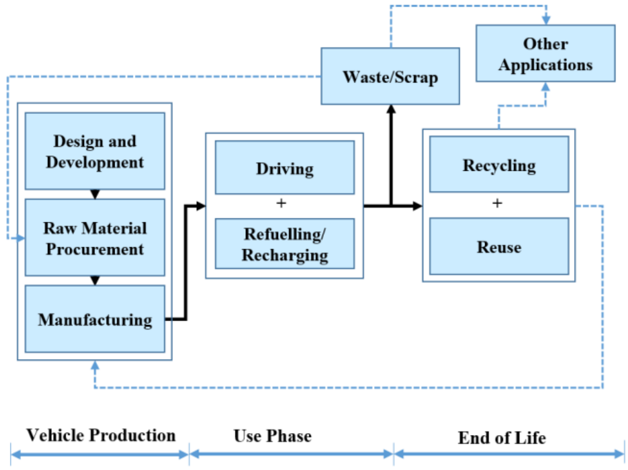

Fig. 1. Vehicle Lifecycle: Cradle to Grave

Due to concerns around climate change and health impacts of vehicle pollution, there has been an increased push for reducing emissions in the short term as well as in the long term. Countries such as Germany and India have set ambitious goals to stop the manufacturing of IC engine vehicles by 2030. However, there are many problems and challenges in terms of making the technological and infrastructural shift towards battery electrification. These have been explored in this paper (Section 3), all of which link back to Fig. 1. In addition, reducing tailpipe emissions from vehicles is an extremely facile solution, and in some cases would not be advantageous in the long run. It is necessary to look at the total emissions that would result from vehicular operations (Section 2) and take into account all the nuances involved (sections 3, 4 and 5). Lastly, it is important for economies around the world to move toward cleaner sources of energy (Section 7) since all other economic and financial sectors work in tandem with the energy sector. A systems thinking approach is needed in order to engineer a sustainable shift toward EVs in the automotive sector.

2. Total Lifecycle Emissions

A study [6] carried out by the Union of Concerned Scientists (UCS) found that based on the EVs sold in the US in 2014 in conjunction with the power plant emission data, driving an EV produced emissions similar to a gasoline vehicle that gets 68 miles per gallon on average (MPG_{ghg}, discussed in Section 6). This number is significantly higher than the average miles that ICEVs are able to travel on a gallon of fuel (approx. 29 mpg). The study also added that the total emissions for the midsize BEV are, on an average 51% lower than its gasoline equivalent. This difference can be as high as 53% for a full-size BEV. The reduction in emissions is directly related to the duration of the use phase and the total length for which the vehicle is driven.

Due to the differences in vehicle design, production, operation, and processing at the end of vehicle life, the GHG emission profile of the two vehicles is substantially different.

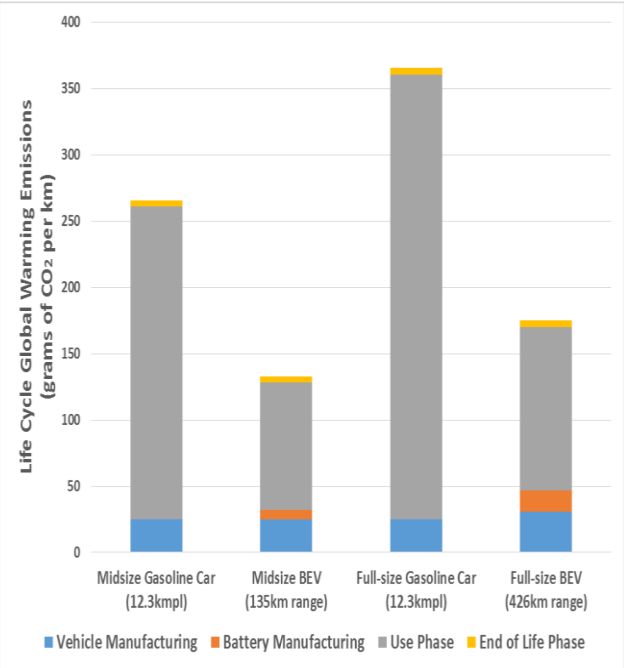

Fig. 2. GHG Emissions for the entire vehicle lifecycle: ICEVs vs BEVs [6]

Another study [7] assessed the total emissions from vehicle lifecycle in terms of equivalent tonnes of CO_2. The assessments were based on a 2015 vehicle in use for 150,000km using 10% ethanol blend (for ICEVs) and 500g/kWh grid electricity. The results corroborate the earlier results from USC, in that the emissions from EVs are lesser than those from ICEVs over the entire lifetime, even if the EVs have a bigger carbon footprint during the production phase. The carbon footprint of EVs and ICEVs during the end of their life recycling/scrapping remain low in comparison with the emissions from their use phase [6].

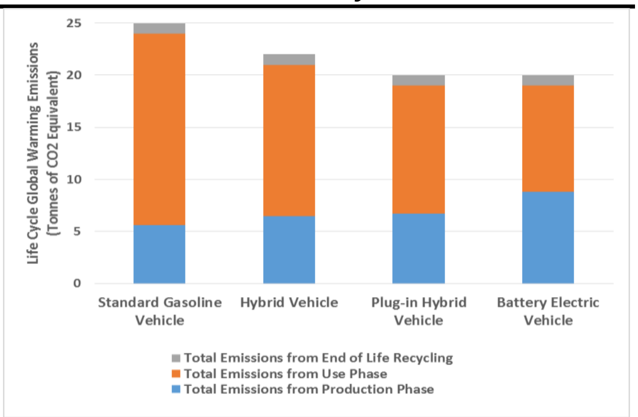

Fig. 3. Total Lifecycle GHG Emissions Gasoline Vehicles, Hybrid Vehicles, Plug-in Hybrid Vehicles and BEVs [6]

The total emissions from a vehicle over its lifetime (GHG_{Total}) can be expressed as:

$$GHG_{Total} = GHG_P + GHG_{WTW} + \frac{GHG_{In}}{n} + GHG_E \quad ..(1)$$

Where,
GHG_P = Emissions from vehicle production
GHG_{WTW} = Well-to-Wheel Emissions from the use phase
GHG_{In} = Emissions from construction and maintenance of new infrastructure
n = Number of vehicles that would make use of the new infrastructure
GHG_E = Emissions from recycling/scrapping at the end of the use phase

3. Vehicle Production

This initial phase of the vehicle lifecycle generally lasts for 30-48 months, depending on the amount of design and engineering required, technological breakthroughs needed and production timelines.

3.1. Vehicle Design and Engineering

A number of external and internal factors affect the design considerations for a vehicle, such as customer expectations, weight and size requirements, performance and safety targets, Government norms and Emission Standards, competitor vehicle specifications, etc. [8]. Studies show that 20-40% of the EV owners in developed countries cite 'the environment' as a reason why they chose EV rather than an ICEV, while even fewer cite their 'interest in newer technology' as the reason behind the adoption (5% in California, 28% in the UK) [9]. These figures are much lower in developing countries, where vehicular pollution and emissions tend to be the highest. EVs need to outperform current ICEVs in terms of performance so as to make it more viable and for them to be adopted globally. Vehicle performance and design is a key miscellaneous consideration for the sustainable growth of the EV market.

BEVs (and even hybrid vehicles) have a heavy Lithium-Ion battery pack that is usually placed below the floor. Thus, the Centre of Gravity (CoG) of a BEV is geometrically lower than that of an equivalent ICEV. Lower centre of gravity implies a greater ride handling and stability. EV trials and feedback from private owners show consistently positive findings with regard to the performance and overall driving experience of EVs. Several kinds of research and EV trials report that customers generally find EVs to be more comfortable and smooth. EVs also provide an instant acceleration upon the driver's manoeuvring. This is overwhelmingly seen as an advantage by its users (70% in Norway, 90% among all Tesla Owners and 66% among Nissan Leaf Owners) [9].

Range (total distance covered in a single charge) is one of the most important factors that customers consider when purchasing a new vehicle. This is still perceived as the greatest downside of BEVs. Trials and research have shown that most customers are able to complete their day-to-day travels quite easily [9]. The vehicle range that the best EVs on the market deliver still fall short of the range that customers are able to get on a full tank with their ICEVs (256 miles on the Tesla Model S vs. 400 miles on a comparable gasoline vehicle) [6]. Another performance concern is due to the reduction in BEV range in cold climate conditions. 60% of the EV users in Norway cite this as a crucial concern [9]. Yuksel and Michalek [10] showed that there tends to be an optimal temperature range for operation of the vehicle (approx. 70ºF), and as the ambient temperature deviates from the optimal conditions, the energy consumption per mile of the vehicle reduces substantially. The study also found that there is likely to be greater fluctuation in vehicle range where temperature varies significantly, thereby adding to the range anxiety among customers. The study carried out by UCS [6] points out that widespread use of BEVs has been recent and it remains to be seen whether they provide a useful life comparable to ICEVs (10-15 years). The same study projected the average useful life of BEVs to be around 150,000km; in contrast to the useful life of midsize ICEVs, which is approx. 179,000km.

Many countries and states where the adoption rates of EVs are high have been actively installing facilities for charging their vehicles for free at public stations. EV owners generally report that they are able to save money that otherwise would be spent on fuel costs, even if the EVs might be higher in cost upfront. Owners also find it easier and more convenient to charge their EVs at home [9]. Some OEMs consider designing electric buses (that would be used for public transport) with easily removable and replicable battery packs, such that the time between trips can be reduced and the total distance that the vehicles can travel on any given day can be maximised.

The crashworthiness of the vehicle tends to reduce due to the lowered CoG [11]. This can readily be counteracted by improvements in design, especially due to the absence of an engine block in the front end of the vehicle. The battery thermal design and cooling is a key focus for OEMs [12]. Car battery packs have been averse to hazards due to excessive thermal condition, where it can continue to spread throughout the battery pack or a portion thereof until overheating cells are sufficiently cooled or the entire battery pack or the portion is consumed. This reaction may take anywhere between a few minutes to several hours, depending on the battery cell arrangement, battery capacity, design, and cooling system parameters. Underfloor protection is also of paramount importance when it comes to BEV design. Impact with the underfloor may damage to the battery pack, especially for the SUVs and off-road capable vehicles. OEMs generally shield the battery pack with aluminium and titanium in order to provide required structural rigidity.

BEVs offer some advantages over traditional ICEVs under miscellaneous conditions. In cold temperature regions, during a blizzard, snow is likely to clog the engine air intake system, leading to engine shut-off [13]. Barring any other failure modes, BEVs are capable of travelling for their full range in such conditions. In BRIC countries and other developing regions, ICEVs sometimes face hydrostatic lock related failure issues due to water ingress in the engine air intake [14]. BEVs are more capable of successfully traversing through high depths of water without any detrimental failures.

There are a number of trade-offs and relative advantages and disadvantages when it comes to vehicle design and engineering between BEVs and ICEVs. Studies also show that early adopters of the EV technology report high rates of satisfaction with their choice (54% extremely satisfied, 38% satisfied in California and 91% extremely satisfied, 9% satisfied In Norway). However, the perception of EVs among the general public still remains mixed due to low rates of adoption and high vehicle costs.

3.2. Raw Material Procurement and Manufacturing of Vehicles

The parts, materials, and processes used for manufacturing electric vehicles differ significantly compared to an equivalent ICEV of the same capacity. BEVs also need different ratios and proportions of the raw materials such as copper, aluminium and steel. Larger battery pack naturally increases the range of the vehicle, which would be desirable. However, that comes with the downside of higher curb weight and an increase in the carbon footprint of the vehicle during manufacture [6]. The study performed by UCS [6] used Nissan LEAF for benchmarking the performance of midsize midrange BEV and used the Tesla Model S for benchmarking the Full-size long-range-SUV. It also assumed average fuel efficiency and performance for the equivalent gasoline vehicles of each category. The study found that manufacturing emissions of a midsize BEV are 15% (equivalent to 1 tonne of CO_2) higher than a comparable gasoline vehicle. Battery manufacturing is the greatest contributor to the increased emissions during manufacturing, however, it accounts for only a small percentage of the car's respective total emissions. In fact, the increase in manufacturing emissions can be offset by a BEV in as fast as a year (approx. 15,000km) or at most three years in the US (approx. 39,000km).

Production of a lithium-ion battery requires lithium, in addition to cobalt, nickel along with other metals. Studies have shown that there are enough lithium reserves to meet the increasing global demand for manufacturing EV batteries. Metals such as Cobalt and Nickel are relatively more expensive, and their reserves are limited. [6]. It is also predicted that by the year 2025, EV batteries will account for 90% of the entire lithium-ion battery market [15]. There have been significant reductions in battery costs over the past 10 years; however, battery costs are predicted to level off between $150-300 per kWh over the next 10 years [16].

Global warming emissions from producing a vehicle can vary by as much as 30 percent, depending on the source of electricity. There is significant scope for saving the manufacturing-related emissions by utilising renewable energy sources. Recently, many OEMs have started switching to greener choices for their manufacturing needs [6].

Hawkins et al. [17] carried out a similar study for the grids with European electricity mix. They posit that during manufacturing, BEVs have the potential for significant increase in human toxicity, freshwater eutrophication, and metal depletion impacts, largely emanating from the vehicle supply chain. They found that EVs offer a 10-24% decrease in Global Warming Potential (GWP) relative to conventional diesel or gasoline vehicles assuming lifecycle of 150,000km. The study also points out that the results are sensitive to assumptions regarding electricity source, use phase energy consumption, vehicle lifetime and battery replacement schedules (if any). For instance, assuming a vehicle lifetime of 200,000km increases the GWP difference to 27-29% in favour of the EVs. Whereas, a lifetime of 100,000km would reduce it down to 9-14% compared to an equivalent gasoline vehicle and the GWP difference would be indistinguishable for a diesel vehicle. The study concluded that improving the environmental profile of EVs necessitate engagement around reducing vehicle production supply chain impacts and promoting clean electricity sources in decision making regarding electricity infrastructure.

4. Use Phase

The use phase of the vehicle lasts for approx. 10-15 years and is the most important phase w.r.t. climate change, GHG emissions, and sustainability engineering concerns.

NASA's Goddard Institute for Space Studies (GISS) assessed the potential of different economic sectors to alter Earth's climate [18]. The same gases and aerosols are emitted by most sectors, however, each sector has a unique portfolio of gases and aerosols that affect the climate in unique ways and on different timescales. An interesting observation made by the study was that the greenhouse gases tend to promote global warming, whereas, sulfates and other aerosols tend to promote cooling. The automotive sector releases maximum portion of GHG while emitting the least sulfates, which in turn makes it the greatest contributor to atmospheric warming. On the other hand, the industrial sector releases a much higher portion of aerosols and actually contributes a significant amount to the cooling system. However, this cannot be misconstrued with reduced atmospheric pollution, and due to health concerns, many developed countries have been reducing aerosol emissions from the industries. This action has had an unwanted negative effect of accelerating climate change. Generally, aerosols can make clouds brighter and cause them to last longer, thereby reflecting more sunlight and producing a cooling effect. But aerosols like black carbon or soot actually absorb incoming radiation, heats the atmosphere, thus leading to greater warming. GHG emissions have a more long term impact since they accumulate in the atmosphere and intensify over time. On the other hand, aerosols can rain out after a few days and tend to have a more short-term effect.

The study also gave projections for relative emissions and contributions in the future- for 2050 and 2100. By 2050, it was estimated that electric power generation will overtake road transportation as the biggest promoter of warming. By the year 2100, the industrial sector will most likely become the largest contributor.

4.1 Well-to-Wheel Emissions

Tailpipe emissions do not provide a complete picture of vehicular emissions during the use phase. Tailpipe emissions incorrectly show zero emissions from BEVs during the use phase. Well-to-Wheel emissions are a much better indicator and track the energy expenditure and GHG emissions from the source of energy to the vehicle wheels [19] [20].

As seen in Fig. 4, the fuel (petrol/diesel) has a path to cover from its reserve to the station (called as Well-to-Tank) and also from the station to the wheels (Tank-to-Wheels). It is important to note that the WTT emissions and energy consumption are significantly lesser than those for TTW. Secondly, the TTW energy conversion efficiency depends on the vehicle's engine and transmission, and its emissions are inevitably closer to the consumers.

As seen in Fig. 5, the energy from the reserve (fossil fuels or renewables) has a path to cover from its reserve to the station (Well-to-Tank) and also from the station to the wheels (Tank-to-Wheels) [20]. However, the WTT emissions and energy consumption are significantly greater than those for TTW. In fact, the TTW emissions are closer to zero. Secondly, the TTW energy conversion efficiency depends on the vehicle's motors and transmission and is much higher than that for ICEVs. The WTW emissions from BEV operation are relatively isolated from the vehicle and the consumers. The emissions and energy expenditure for hybrid vehicles would be a mix of BEV and ICEV WTW paths [19].

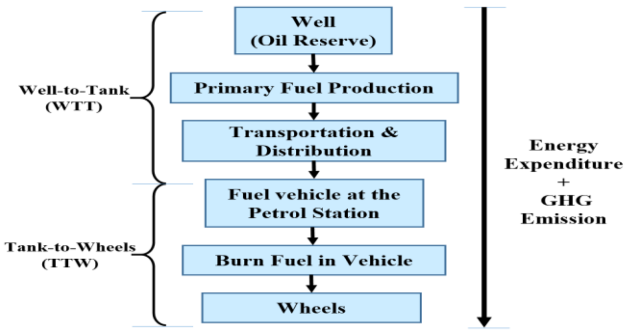

Fig. 4. Well-to-Wheel emissions for ICEVs during the use phase

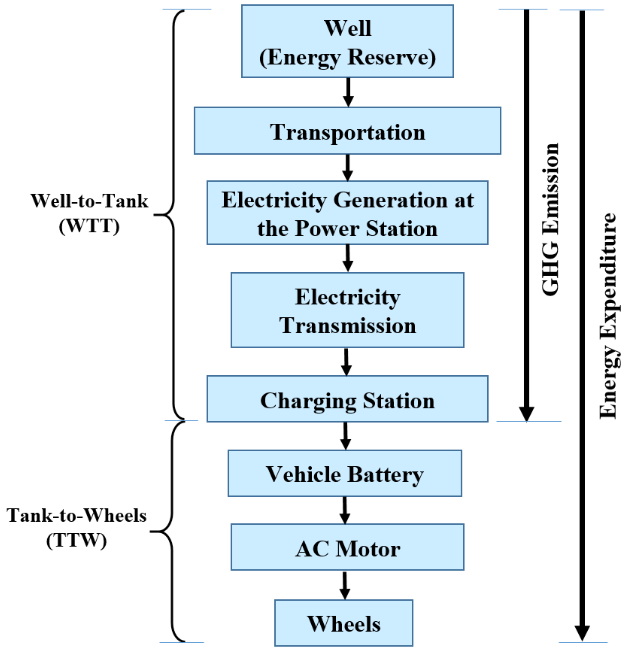

Fig. 5. Well-to-Wheel emissions for BEVs during the use phase

Battery-electric cars still produce less CO_2 during their lifetime than petrol and diesel cars, based on 500g/kWh of CO_2 emitted during electricity generation. In fact, the UK National Grid is much cleaner today (similar to other European grids) at around 300g/kWh, making battery EVs even cleaner. In general, it is clear that the emissions from EVs in this phase are very sensitive to the source of energy used for electricity generation [7].

4.2. Infrastructure Development

The WTW emission and energy consumption estimates assume that the infrastructure required for ICEVs and BEVs are readily available for use and don't need any maintenance and repair work. In order to promote the use of BEV

Infrastructure development is one of the biggest challenges when it comes to popularising the use of BEVs. Substantial investments and Government push would be needed in order to increase the number of charging stations in public car parks, universities, workplaces, etc. [21]. Numerous studies are being conducted in this area, including topics such as optimizing the layout of charging stations [22], improving the electric grid system, among others.

5. End of Life

This phase of the vehicle lifecycle has the least contribution to the total cradle to grave emissions. This is estimated to be approx. 1 tonne of CO_2 emissions [6]. Additionally, there isn't a large gap between the End of Life emissions between ICEVs and BEVs, assuming that the batteries can be reused. Generally, when gasoline cars reach the end of their use phase, they are disassembled for parts and materials that are either reused or recycled; a small remnant of the vehicle is sent to a landfill. Most parts on a BEV can be recycled/reused in a similar way. The biggest concern for BEVs is the lithium-ion battery pack. These may also be reused, recycled, sent to a landfill and the toxic chemicals can be disposed of responsibly.

Battery life, maintenance, and poor resale value have been cited as potential disadvantages of EVs, but there is little evidence of EV owners facing these issues [9]. Most EV batteries are capable of lasting for 8-10 years before their performance drops to around 70% (or less) of what it was when new [15]. For vehicular emission calculations, we attribute all the global warming emissions of battery manufacturing to the first use of the battery (on the vehicle), but reusing or recycling it would reduce the emissions and energy expenditure, as shown in Fig. 6 [23]. The battery pack may be used for power storage for homes and businesses (where energy density is not as critical of a factor as for EVs).

Making batteries with recycling options (during the production phase) can reduce global warming emissions of batteries downstream. Many companies recycle lithium-ion batteries for small electronics, but the batteries needed for vehicles are much larger. There are currently two major companies that are capable of recycling lithium-ion batteries at vehicle sizes [15]. Being able to recycle batteries would prove to be an advantage in the long term. Metals from the used battery pack can be readily recycled. This, in turn, would reduce the need for mining new metals for producing new battery packs. This would also help in reducing the burden on the mains supply during peak hours. A study carried out by Drabik and Rizos [23] corroborates this proposition. The study looked at different scenarios for reusing battery packs and for recycling its materials. It predicted that by 2040, the EU economy can save up to €2.6 Billion by recycling battery packs and reducing the need for raw materials during battery manufacturing. In addition to this, the economy can create thousands of new jobs (12,105 to 15,131 by the year 2040). The EU can also save up to 200,000-1.2 Million tonnes of CO_2-equivalent emissions by 2040 in the process. This model can readily be implemented around the world, which would accelerate the growth of this sector.

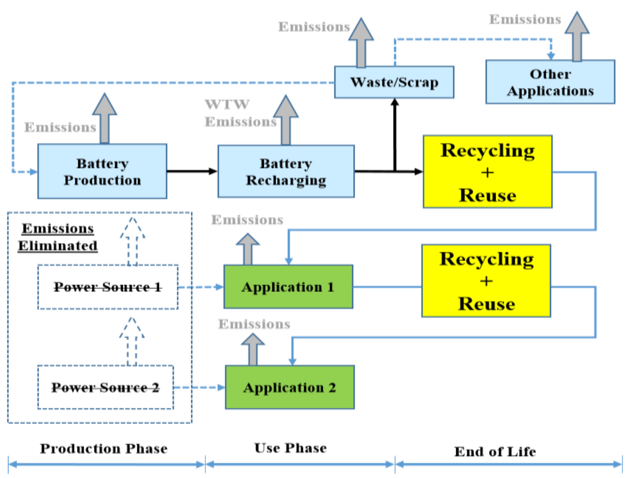

Fig. 6. Energy and Emissions offset by means of reuse and recycling of vehicle battery pack

Battery manufacturers are also looking at ways to replace lithium-ion battery technology, including sodium-ion batteries and solid-state batteries, each of which would pose a unique challenge at the end of vehicle's use phase [15].

6. Electricity Generation and Emission Regulations around the world

According to the US Energy Information Administration, as of January 2015 fossil fuels meet 82% of US energy demand. Other countries over the world show similar trends. The shift toward renewables has been slow, as seen from Table 1, which gives stats about different sources of energy generation in the world. It is worth noting that the table presents data on a percentage basis; however, the total electricity production (absolute value) has been increasing year on year.

Oil remained the world's leading fuel, accounting for 32.9% of global energy consumption in 2015. Roughly 63% of oil consumption is from the transport sector. Oil substitution is not yet imminent and is not expected to reach more than 5% for the next five years [24]. The United States is currently on track to consume approx. 22 million barrels of oil every day by 2035 [2].

Table 1. Energy Consumption distribution based on the Source; from 2005-2015 over the World [23]

Source of Energy	Percentage of the total Energy Consumption		
	2005	2010	2015
Oil	35.9	33.5	32.9
Coal	28.6	29.8	29.2
Natural Gas	22.9	23.7	23.9
Nuclear	5.7	5.1	4.4
Hydro	6.1	6.4	6.8
Wind	0.2	0.6	1.4
Solar	1.0	0.1	0.5
Other (renewables)	0.5	0.7	0.9

It has been asserted that the fossil fuel reserves might reduce in the next few decades, thereby making oil and coal more expensive, which would inadvertently push the economy towards cleaner sources of energy. However, Covert et al. conducted an economic analysis [16] which concluded that in the absence of strong external influences (technological advancements, government policies, etc.) the cost of fossil fuels isn't likely to increase drastically. The reserves of Oil and Natural gas have, in fact, steadily increased from 1980 to 2015, whereas, the reserves of coal have been on a steady decline. The study also compared the projected cost of battery packs on BEVs with the projected cost of an equivalent barrel of oil in 2020. The results show that the oil prices would have to be $115 per barrel for electric vehicles to become cost-competitive with internal combustion engines. In reality, the projected cost of an oil barrel is likely to be $55 in 2020.

6.1 Miles per Gallon Equivalent

Miles per Gallon Equivalent (MPG_{ghg}) rating [6] gives the number of miles that an ICEV can travel on a gallon of fuel for it to produce the same amount of WTW emissions as a BEV. This isn't a comparison between BEVs and ICEVs, but instead is a comparison between the sources of energy (electricity for a BEV, gasoline/diesel for an ICEV) for assessing their GWP. A baseline MPG_{ghg} rating would be the actual value that an ICEV can travel on a gallon of diesel/petrol. Table 2 gives the MPG_{ghg} values for different sources of energy. Oil and coal tend to be the most polluting sources of energy for a BEV and offer no advantage over a conventional ICEV. Renewable energy sources are far cleaner and offer more than 90% reduction in emissions.

Table 2. Well-to-Wheels BEV Miles per Gallon Equivalent (MPG_{ghg}) based on the method of Electricity Generation [6]

Source of Energy	Gasoline Vehicle Emissions Equivalent for a BEV (MPG_{ghg})	Emission Reduction Compared to an Average New 2014 Gasoline Car
Oil	29	0%
Coal	29	1%
Natural Gas	58	51%
Geothermal	310	91%
Solar	350	92%
Nuclear	2300	99%
Wind	2500	99%
Hydro	5100	99%

MPG_{ghg} value for a BEV differs from region to region, based on the mix of electricity generation sources used (generally, grids use a combination of sources based on the availability of resources, cost of generation, Government regulations, etc.). The Miles per Gallon Equivalent for an electricity grid with a mix of the power sources $(MPG_{ghg})_{Total}$ can be expressed as the weighted average of the miles per gallon from each source.

$$(MPG_{ghg})_{Total} = \sum_{i=1}^{n} \frac{W_i * (MPG_{ghg})_i}{W_i} \quad ..(2)$$

Where:
$(MPG_{ghg})_i$ = Miles per gallon equivalent for the ith power source
W_i = Relative weight of the ith power source, depending on its contribution to the total energy generation
n = Total number of power generation sources

Regions where the $(MPG_{ghg})_{Total}$ rating is low would be poor candidates for BEV adoption. Even if the $(MPG_{ghg})_{Total}$ rating is slightly greater than the baseline, overall, the BEVs would end up being a worse choice due to the additional costs of infrastructure development that would be needed for mass adoption. Ji et al. studied the emissions and health impacts from EV use in China [25]. They found that the emission and environmental health impacts for EVs were greater than comparable ICEVs for both, gasoline and diesel vehicles. Even though the combustion emissions from ICEVs are closer to population centres, for most cities in China, primary environmental health impacts per passenger-km were greater for BEVs than for gasoline cars (3.6x on average) and diesel cars (2.5x on average) and equal to diesel buses.

Hence, without sufficient developments in renewable energy technology, the current trend of electricity generation and vehicular emissions are likely to continue. The method of electricity generation greatly affects the global warming emissions of electric vehicles both w.r.t. their manufacturing and use phase. A heavy push is needed towards the use of renewable energy in order to reduce the global warming potential of EVs. For example, the lifecycle GHG emissions for a midsize BEV powered using a predominantly renewable energy electricity grid would be 42% lower than a BEV powered by the current average US energy grid [6].

6.2 Emission Reduction and Regulation Initiatives

Many developed and developing countries around the world have been taking initiatives to reduce their reliance on fossil fuels and to promote the use of EVs. These include global initiatives such as the Paris Climate Accord (for combating the disastrous effects of climate change) which aims at capping the global temperature rise below 2ºC for this century [26]. This goal translates to adding financial incentives, new technology frameworks and promoting public awareness; these initiatives inevitably trickle down to the transportation sector. The EU has been tightening its emission norms and imposing penalties on car manufacturers if their cars fail to limit the tailpipe emissions below the dictated limits. In 2015, the EU set an emission target of 130g of CO_2 per km for all vehicles. The average emission of a new car sold in 2017 was 118.5g, well under the 2015 limit. The 2015 target corresponds to fuel consumption of around 5.6 litres per 100km of petrol or 4.9 litres per 100km of diesel. For 2020, the EU has set a target of 95g for the fleet average emissions for all new cars sold, which corresponds to 4.1 litres per 100km on petrol and 3.6 litres per 100km on diesel [3]. OEMs deal with these emissions in three ways: Increasing the fuel efficiency of internal combustion engines, introducing hybrid vehicles and BEVs to their fleet and introducing tertiary ways to avoid energy waste in the vehicular system (e.g.: regenerative breaking).

The in the UK, the Department of Transport introduced a timeline for the introduction of electric vehicles in 2008, which banks on the introduction of EVs in the market with higher ranges and on a reduction in the cost of battery packs in the near future. The aim of the proposal is to shift towards a predominantly electric fleet of cars by 2030 [9]. Countries like Germany and India have set similar targets for themselves. Governments also provide subsidies to car owners in order to promote EV use, which has proven to be effective.

7. Conclusion and Further Work

Widespread adoption of EVs is an important step toward creating a sustainable future for the transportation sector. They present an excellent and competitive choice in terms of driving performance, comfort and cost savings (throughout their use phase) compared with traditional ICEVs. Based on the emission data estimates, EVs are a much better choice, despite having a higher carbon footprint during the production phase. However, the emission reduction from EVs heavily depends on the electricity grid mix. Popularising EVs would require additional infrastructural development for public charging and further work on developing battery packs that offer greater ranges. It is likely that EV adoption is likely to follow a technology adoption curve similar to Amara's law.

In absence of Government initiatives, it is unlikely that the trend of high fossil fuel use would change (especially since companies have a vested interest in maintaining their current operations and maximising their profits), and the transportation sector would continue to be the largest contributor to GHG emissions (at least till 2025). The initiatives like the Carbon credit system need to be re-engineered so as to remain viable and to support sustainability in the economy [27]. Additionally, a push towards renewable sources of energy is vital for reducing the total GHG emissions from the transportation sector.

All the perceived disadvantages of EVs can be offset by means of additional research in areas like battery technology, recycling methodologies, financial incentivising and vehicle engineering along with an added emphasis on infrastructure setup and public awareness.

Abbreviations

CO_2	Carbon Dioxide
GHG	Greenhouse Gas
EV	Electric Vehicle
BEV	Battery Electric Vehicle
MHEV	Mild Hybrid Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
OEM	Original Equipment Manufacturer
CoG	Centre of Gravity
MPG	Miles per Gallon
MPG_{ghg}	Miles per Gallon equivalent Greenhouse gas emissions
GWP	Global Warming Potential
UCS	Union of Concerned Scientists (USA)
WTW	Well-to-Wheels
WTT	Well-to-Tank
TTW	Tank-to-Wheels
NASA	National Aeronautical Space Administration (USA)
BRIC	Brazil, Russia, India and China
SUV	Sport Utility Vehicle
kWh	kilo Watt-hour

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