University of South Wales

Feasibility Study into the Market and Developing Technologies of Electric Motorbikes

BSc Mechanical Engineering

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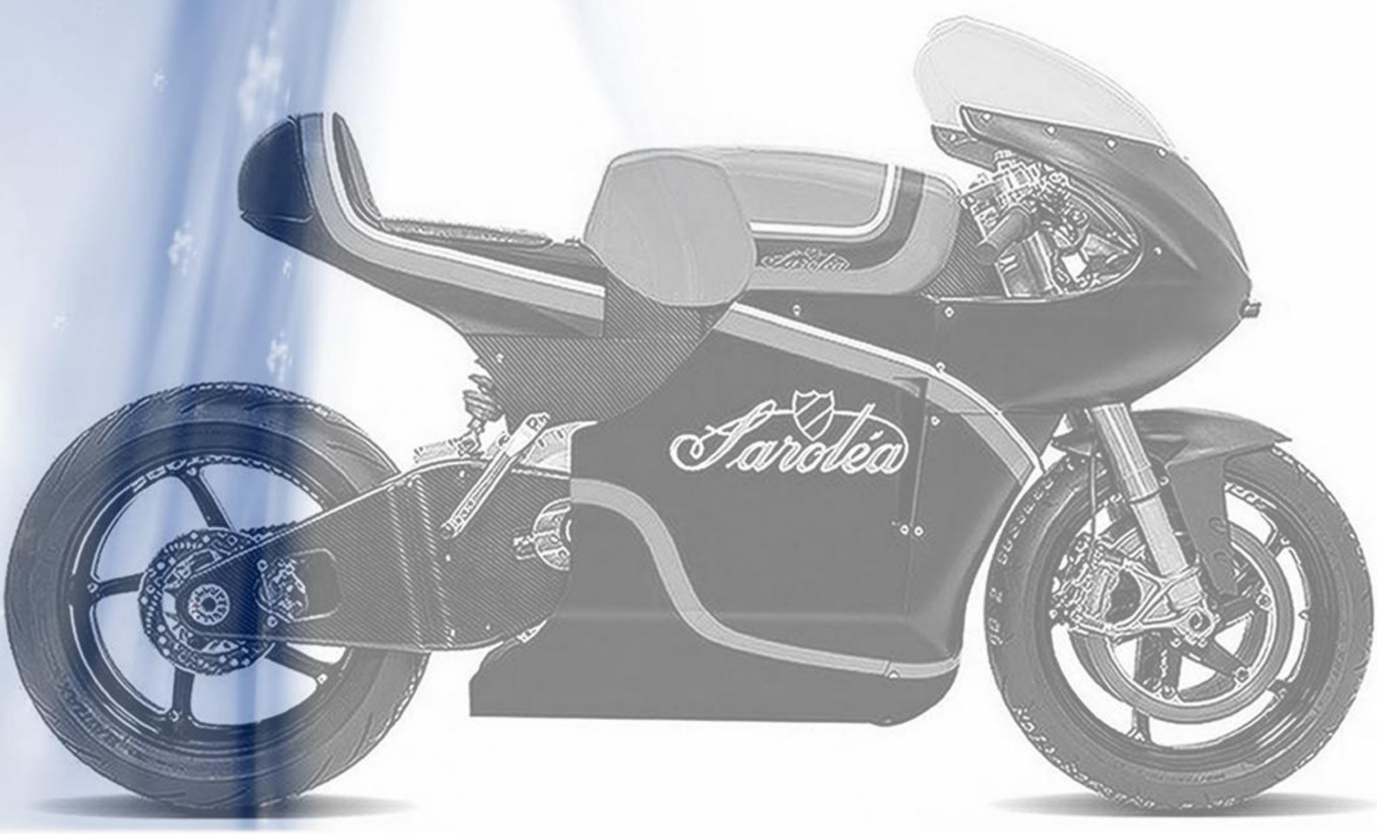

Acknowledgements

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Ted Dillard for granting permission to use his material and any party that contributed to the publication of his most revered work, *'Power in Flux – The History of Electric Motorcycles.'* This proved to be a fascinating and invaluable resource, opening up the world of the electric motorbike, kick starting this project and maintaining the pursuit of research throughout. His enthusiasm for the subject has prompted an insatiable desire to purchase an electric motorbike.

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Abstract

This report focuses on three main areas of the electric motorcycle in an attempt to determine its feasibility. The current market availability indicates 26 individual manufacturers of varying size that produce electric motorcycles of equally varied design. Zero, Energica and BMW Motorrad's C-Evolution is discussed in detail including specification of all models available from these manufacturers. The developing technologies are also discussed in depth and key developments of crucial components are identified to highlight the improving feasibility over time.

Finally the electric motorcycle market is discussed on a national, continental and global scale in an effort to illustrate past, present and future trends. It shows that in all these areas the market will expand as expected but gradually. Consumers are apprehensive about range, infrastructural support and price. Government Incentives are identified as the most crucial tool for initiating a larger uptake of not just electric motorcycles but all EVs. An analysis of the data showed that electric scooters will dominate the forthcoming sales majority because of their affordability and portability in urban areas. Electric motorcycles are not popular enough to become a feasible means of travel, despite the established manufacturers efforts due to their currently high prices and mind set of riders that require extra mileage. Feasibility is concluded to be challenging in the future but an inevitability due to the attitudes towards climate change and zero emissions transport.

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Table 1) – List of Report Abbreviations

ABS	Anti-Lock Brakes
BEV	Battery Electric Vehicle
Bhp	Brake horse power
CAGR	Compound Annual Growth Rate
CS	Charging Station
EAPC	Electrically Assisted Pedal Cycles
EICMA	Esposizione Internazionale Ciclo, Motociclo e Accessori (International Exhibition of Bicycles, Motorcycles and Accessories)
EV	Electric Vehicle
EV-MC	Electric Vehicle Motorcycle
FCEV	Fuel Cell Electric Vehicle
GBP	Great British Pounds
HEV	Hybrid Electric Vehicle
HH	Household
ICE	Internal Combustion Engine
k/mph	Kilometres/Miles per hour
KERS	Kinetic Energy Recovery System
Kg	Kilograms
kWh	Kilowatt hour
Li-Ion	Lithium Ion
Li-Poly	Lithium Polymer
Li-S	Lithium Sulfur
MCIA	Motorcycle Industry Association
MOT (Test)	Ministry of Transport (Test)
NiMH	Nickel-Metal Hydride
Nm	Newton metres
NMC	Lithium Nickel Cobalt Manganese Oxide
PHEV	Plug-In Hybrid Electric Vehicle
SORN	Statutory Off Road Notice
TWD	Taiwanese Dollars
ULEV	Ultra-Low Emission Vehicle
USD	United States Dollars

1.0 Introduction

1.1 Background Theory

With the aggressive technological advancement of HEV, BEV and PHEV cars, petrol and diesel only powered vehicle sales will inevitably decline up to and ultimately cease in 2040 for the UK & France. Linked to an estimated 40,000 premature deaths per year in the UK, the harmful levels of nitrogen oxides in the atmosphere are well above the 40µg/m³ average in the majority of major UK cities and towns topping out at 62µg/m³, although Greater London Area has a level as high as 96µg/m³. *(BBC News. 2017)* Authority's areas are actively looking for ways to reduce the levels of harmful pollutants in our environment; a most recent example is the introduction of a 'toxic tax' in Central London area. From October 23rd 2017 for petrol and diesel vehicles registered before 2006 driving Monday – Friday 7am – 6pm will have to pay £10 to do so, in addition to the pre-existing congestion charge at £11.50. These are purely for permission to drive into the centre of the capital.

As a result, all industries that have a heavy reliance on diesel/petrol use are looking to alternative sources of energy to reduce the long-term damage done to the environment, mitigating climate change. Governments are incentivising the public with special grants of up to £4,000 to make electric vehicles more affordable, and a diesel scrappage scheme of up to an additional £2,000 to encourage people to rid their old polluting vehicles. Electric motorcycles are also included in these measures and are eligible for grants of up to £1,500 off the list price. Businesses and industry are experiencing similar incentives to support development by means of 'The Faraday Challenge.' Announced late July 2017, it commits £246m over four years into the battery storage and vehicle electrification market. Part of the Governments Industrial Strategy Challenge Fund, it provides an opportunity for businesses to win investment into projects designed to ease the introduction of EVs and construct the necessary infrastructure to maintain it. *(Edmonds, S. & Dr Wise, A. 2017)*

Included in, and a side effect of these industry developments is the motorcycle, it too is seeing technology introduced which was not available several years ago. These new technologies will be explored in this report along with an assessment of the time delay between applications from four-wheel vehicles to two wheel vehicles.

Unless explicitly stated, the terms 'motorcycle' and 'EV-MC' will include all methods of road legal two wheel transport. This is to help distinguish between the popular 'e-bikes' or 'pedelecs' as they have become known. GOV.UK refers to them as EAPC's and they are defined as:

- Maximum motor power of 250 watts
- Should not be able to propel the bike when travelling more than 15.5mph
- Must have pedals to offer propulsion

As a result, anything that does not meet this criteria is considered a motorcycle/moped/scooter and requires a license, registration and taxing for road use. It is these machines that are the focus of this report and the feasibility of their electrification that comprise it.

Feasibility – 'The state or degree of being easily or conveniently done.'
(Oxford Dictionaries. 2018)

The structure of this report is broken down into the following three main sections with sub-sections in each.

1. The first begins with an analysis of the current market. Three manufacturers and their model line-up, specifications and optional extras are detailed which, can have a significant effect on the usability of the machine. Failed start-up companies are documented too including discussions as to the reasons why and barriers precluding successful development.
2. Developing Technologies is the next focus where new industry developments that benefit the evolution of EV-MCs are discussed. Batteries, motors, regenerative braking and infrastructural developments are the main topics here.
3. Finally, the fluctuation of how many EV-MCs have been sold this year by measure of registrations made nationally and in the previous decade is explored. The likely future sales growth and predicted circumstances of the electric motorbike within the U.K. will be discussed and establishing how far behind the EV-MC industry lags compared to the electric car, is of particular interest. Attention is paid to the South East Asian market since this is where the highest percentage of global sales occurs too, with reference made to the global motorcycle market.

1.2 Brief History

1.2.1 – Summary

References to Electric Motorcycles have appeared several times in the experimental context since the earliest known mention of them in the late 1860s but not until 1996 did they endure mass production. This is courtesy of Peugeot with their 'Scoot'Elec', which was in production for a decade; a small 3.8hp electric motor powered the scooter up to a maximum speed of 28mph good for a 25-mile range. Though it is felt that it arrived too early to the market and only a few thousand were sold. *(Oortwijn, J. 2011)* Partly due to critics reviews who said it 'produced a chorus of yawns.' *(New Atlas Team. 2010)*

A handful of bikes were built over the late 90's and into the 2000's like the Scoot'Elec previously mentioned and the EMB Lectra VR24, but Dillard claims in 2017 that no vehicle was more potent in exposing the general public to the capabilities of electric drivetrains than the Killacycle. Powered by the same batteries found in DeWalt power tools' it stunned crowds with a quarter mile time of 7.824 seconds at 168mph in Arizona in 2007. It was the first electric vehicle ever to exceed 150mph and break the 8-second barrier in drag racing.

Dillard validates an old saying that 'there's no bad press,' after sensationalised coverage of a clip where its rider Bill Dube

1.2.2 – Timeline

Late 1860s: Earliest references to electric motorcycles can be found in patents.

1911: Electric motorcycle available according to early Popular Mechanics article.

1920s: Ransomes, current makers of forklifts, explored the use of an electric powered motorcycle. This and other developments helped pave the way for the company to use electric mining cars and lorries.

Early 1940s: Fuel rationing in United States caused Earle Williams to convert a motorcycle to electric power. This became the basis for the formation of the ParCar from the Marketeer Company.

1941: Fuel rationing in Occupied Europe encouraged an Austrian company by the name of Socovel to create a small electric motorcycle. Approximately 400 were manufactured.

1967: First Fuel Cell powered electric motorcycle created by Karl Kordesch at Union Carbide debuts. Demonstrated the feasibility of fuel cells as a power source. This particular fuel cell was an alkaline fuel cell that operated with hydrazine, a rocket fuel propellant.

1967: "Papoose" moped sized electric motorcycle prototype is created by Indian Motorcycle Company under the direction of performed a televised burnout on the Killacycle and subsequently had a minor bump with a minivan, bringing confirmation to a wide audience that electric vehicles as they knew were now, not slow but very powerful.

Aside from the remarkable achievements laid down by the Killacycle, from the late 1990's to late 2000's the idea of an electric motorbike lay dormant and unattended. In 2009 American manufacturer 'Brammo,' produced and sold few models of the Enertia concept they had recently debuted before moving onto the 'Empulse R' the following year, now sold by 'Victory Motorcycles'. Since then, the last eight years have seen an unprecedented rise in the number of EV-MC variants available from a range of manufacturers. All 26 of those listed in section 2.0 have emerged within this short period in comparison to only two that were introduced in the late 90's.

Interestingly, parallels can be drawn between these circumstances and the enormous influence of Tesla on the electric vehicle market during this time. In late 2008 the 'Model S' was announced and in 2010 the company went public at $17/share. 200,000 sales later and as of March 2018, it stands at $257/share *(Plus500. 2017).* Almost certainly their evolution has had a distinct impact on implementing this ideology into the motorcycle market.

Floyd Clymer.

Early 1970s: Aurenthetic Charger moped sized mini bike (small motorcycle) sold.

1973: Mike Corbin sets first electric motorcycle land speed record of 101 mph.

1974: Corbin-Gentry Inc. begins sale of street legal electric motorcycles. Professor Charles E. MacArthur makes first electric vehicle ascent on Mt. Washington, NH using a Corbin Electric motorcycle. The event evolved into an annual rally called the "Mt Washington Alternative Vehicle Regatta".

1978: Electric Harley Davidson MK2 created by Transitron manufactured in Honolulu, Hawaii.

1988: Eyeball Engineering creates KawaSHOCKi electric drag bike and is featured in a major magazine.

1996: Peugeot Scoot'Elec released first mass production of an electric motorbike.

Late 1990s: EMB Lectra VR24 electric motorbike created by Scott Cronk and EMB. Pioneered the use of variable reluctance motors (hence the VR) and marketed as street legal.

2000: Killacycle makes record run of 152 mph (245 km/h) at 9.4 s quarter mile (400-metre) time at Woodburn Drags 2000, OR.

2007: A123 Li-Ion cell-powered Killacycle makes new quarter mile (400-metre) record of 7.824 seconds and 168 mph (270 km/h) in Phoenix, AZ at AHDR. *(Dillard, T. 2013)*

1.3 Literature Review

Very little has been discussed on the collaborative subjects explored in this report, and attempts to determine the feasibility of an EV-MC are rare. Despite this, the direction of the market for sales of electric motorbikes is predictable and current circumstances outlined in the U.K. in section 2.1 represent a microcosm of a global trend. As the entire automotive sector looks for alternative sources of energy the most heavily invested in is electric propulsion. With the likes of Tesla, leading the way in technological advancements and capability the growing popularity of this alternative fuel type is impossible to ignore.

Other industry experts share this opinion and it is clear that it is a prediction hard to disagree with. Market Researcher Technavio estimates that in terms of units the EV-MC market will grow at a global CAGR of 41.8% during the period 2017-2021 *(Technavio. 2017)* and a major industry player recently announced plans that support this prediction. At the end of 2017, Yamaha Motor's new president Yoshihiro Hidaka announced plans to introduce more powerful electric models range, by production methods involving robotics and 'labour-saving technologies' presenting a unique opportunity for growth. *(Nikkei. 2017)*

By contrast, Ducati on the other hand feel differently. Company CEO Claudio Domenicali believes the battery technology is not suitable yet and that their density needs to be addressed before they consider an electric bike. A concept bike was produced called the 'Ducati Zero Concept' in 2016, in partnership with a Polytechnic School of Design based in Milan *(Ramsey, J. 2017)* proving that electrification of a Ducati is, of course, possible. At the 2017 Frankfurt Motor Show however, VW Group Chairman Matthias Mueller broke the news that every VW group brand will have an electric model by 2030, this deadline is the main point here. Regardless of Domenicali's views, Ducati, owned by VW will have no choice but to produce an electric variant by 2030. Being the world-renowned sports and superbike manufacturer that Ducati are, this will bear a heavy influence over the nature of the motorcycle market and the decisions of others to follow suit.

In 2015, Martin Weiss concluded that: *'Our findings suggest that electric two-wheelers can make urban transportation more sustainable. However, immediate market potential exists only for e-bikes; persisting price differentials and the absence of an obvious additional use value appear to present a barrier for the market penetration of mid-size and large electric two-wheelers,'* citing battery costs as the main reason behind the large-scale market penetration. As well as making urban transportation more sustainable and environmentally friendly, EV-MCs have also proved effective in making cities safer to live in.

In 2014, the Los Angeles Police Department evaluated the possibility of employing a fleet of 100 Zero MMX motorcycles, touting the silence as the most desirable attribute. With their officers given a tactical advantage while on district patrol, they will no doubt prove more effective at reducing crime. This point in case has been proven in the Colombian capital of Bogota where one hundred of the Zero MMX's have been deployed. Abe Askenazi who is Chief Technology Officer for Zero Motorcycles says the crime rate there is now measurably falling, after the city's mayor issued an order for more sustainable transport. *(Stewart, J. 2014)*

Through the breadth of research carried out for this report, only one other feasibility study of EV-MCs was found. Produced by Yoshimoto Matsuda of Kawasaki Heavy Industries in 2014, Kobe, it explores the design and evaluation strategies required to produce a prototype model in the technical climate of the time. The prototype was designed to mimic equivalent 600cc ICE sport bikes and the specification was 219kg curb weight, PMAC motor, 5.2kWh Li-Ion battery pack, four-speed transmission with reverse drive limited to 5kph with a quick charge ability.

The prototype bike was subject to rigorous testing and development; dropped three times each side and from a 3.5m height onto its battery pack directly onto a triangular fixture to test for durability, which it survived with no issues. The power train was fully submerged in water, and exposed to a pressure washer to determine its waterproofing abilities; it was also contained in a small box for one year and cycled at high voltage to calculate the deterioration of the battery. It was found that 20% capacity had been lost over 2,500 cycles. Public-Road Tests were also performed to determine the practical feasibility of the bike. This intense string of testing methods found that there were no major issues in the technological climate of 2014 and the design, construction and evaluation proved relatively simple, but that the lack of charging facilities was a barrier preventing widespread adoption.

Every car manufacturer has been given emissions targets in the European Union and according to the PA Consulting Group, seven are set to miss their 2021 EU CO^2 emissions targets (BMW, VW, Daimler, FCA (Fiat Chrysler), PSA (Peugeot, Citroen and Opel), Hyundai-Kia and Ford). Substantial fines are in place as a consequence with the potential to reach £800million *(Prez, M. 2016).* Motorcycle emissions regulations have reduced considerably since their introduction in 1997 and since 2012, emission measurements were introduced as part of the annual MOT test. Euro 4 regulations apply to all new motorcycles from 2017 and reduces the concentration levels of harmful emissions elements. Nitrogen oxide, carbon monoxide, hydrocarbons and particulate matter limits decreased by 40% and are set to reduce even further with the introduction of Euro 5 legislation *(Transport Policies. 2018).* An analysis of the life cycle of equivalent Fuel Cell Motorcycles, ICE motorcycles and EV-MCs found that the ownership costs per kilometre are largely the same for the latter two, but with reduced climate change effects. 80% and 60% less from renewable and natural gas respectively and still advantageous when charged with electricity produced from coal. *(Cox, B. L., & Mutel, C. L. 2018)*

The Euro 4 regulations represent a cause to which the environmentally friendly lifecycle assessment of EV-MCs is an effect; as opposed to gradual reduction, they offer an immediate solution in their own market space.

1.4 Research Methodology

From the perspective of objectives, the research methodology of this report is secondary and broadly presents itself as exploratory research. This is because there is little common knowledge on the subject of electric motorbike feasibility, and the literature review did not provide enough clarity on the approach of others to the subject. A descriptive study approach was carried out during the 'Current Market Analysis' and 'Developing Technologies' section, in that the feasibility is systematically assessed throughout. Regarding section 1, the information collected was freely available from the manufacturer's websites when referring to make and model statistics.

The final section, 'Previous, Current and Future Market' applies quantitative research methods by obtaining and analysing statistics from credible sources such as GOV.UK, the MCIA and corporate marketing company reports. A questionnaire was produced and distributed via email to 15 dealerships around the country in an attempt to obtain primary, quantitative data for analysis. Despite repeated follow up calls, this proved unsuccessful due to the lack of responses. Journals and technical articles found on Science Direct and SAE Mobilus proved beneficial primarily to sections 2 & 3, and where possible I endeavoured to make sure the recipients study was primary research to avoid the diluting of points made via secondary referencing. A recurring source was the book *'Power in Flux – The History of Electric Motorcycles,'* which provides a backbone of knowledge to the report throughout.

The conclusion required a correlational approach to collectively discuss all the findings from the research and ultimately determine the feasibility level of EV-MCs. It looks to answer whether or not it has a place in the current economic climate and if so, why. *(Kumar, R. 2011)*

2.0 Current Market Analysis

There are wide varieties of different manufacturers that offer EV-MCs currently, with different capabilities. Often, the compromise is between weight, performance and range with adding batteries the only way of simultaneously improving the latter two. Though adding batteries significantly increases weight leading to a more cumbersome ride. Some manufacturers currently are:

Table 2) – Current EV-MC Manufacturers

1. Aero – (Taking pre-orders for E-racer)	14. Lightning
2. Agility Motors	15. Lito
3. ALTA Motors	16. Mission
4. BMW	17. NXT – (Taking pre-orders for 'One')
5. Brutus	18. Peugeot
6. Bultaco	19. Sarolea
7. Energica	20. Super Soco
8. Gogoro	21. Torrot
9. Govecs	22. Vespa – (Taking pre-orders for Elettrica)
10. Harley Davidson – (Taking pre-orders for Livewire)	23. Victory (Acquired Brammo)
11. Johammer	24. VMoto
12. KTM	25. Voltron
13. Lacama – (Taking pre-orders Italian Volt)	26. Zero Motorcycles

Three of these manufacturers and their respective models will be explored in this section, to highlight the variety available to the consumer and different approaches to EV-MC design.

2.1 Typical Design layout

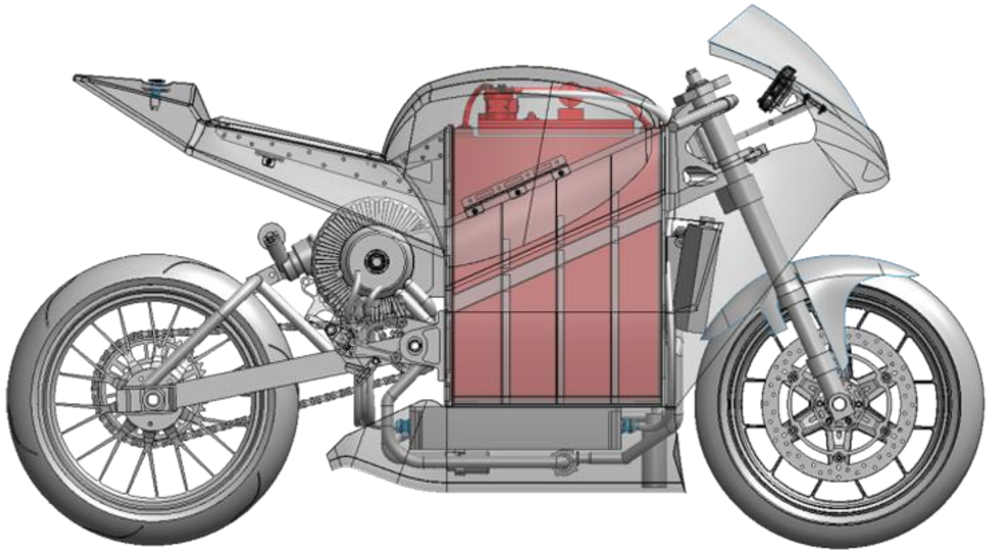


Figure 1) – The Electric Motorcycle of Universite de Sherbrooke (EMUS)

(Rafferty, T. 2017)

Figure 2) – Kawasaki Ninja 300R Cross Section

(Motogokil. 2014)

Figure 1) above illustrates the typical design layout of an electric motorbike. The majority of key features remain the same to a conventional petrol-powered bike in terms of style, components and hand controls. The only noticeable differences are the lack of exhaust (therefore noise), gear and brake lever, functioning much the same as the traditional 'twist-and-go' motorbikes.

Due to the far higher torque levels produced from the electric motors, comparable ICE driven transmissions prove to be a weaker application and unreliable in handling the power delivery. This idea has been tried and tested though and is discussed in section 3.2. The major changes occur internally where the entire fuel tank and centre of gravity is focused around the substantial battery packs represented by the red shaded area. Energy storage now spans the height of the machine as opposed to the small tank found at the middle top on the 300R. A much smaller motor sits behind the batteries just underneath the seat perhaps sacrificing under seat storage, instead of occupying the large space just behind the radiator.

Both the EMUS model and the Saietta R below are built this way but the Saietta's batteries are tilted. This allows a tighter wheelbase, which is good for manoeuvrability and battery size. The engineering complexity is evident here too, the sheer number of different components required to produce a petrol-powered motorbike compared to an electric variant is huge. For reference, the Vectrix VX-1 electric scooter is composed of 250 parts compared with 2,500 for an ICE equivalent.

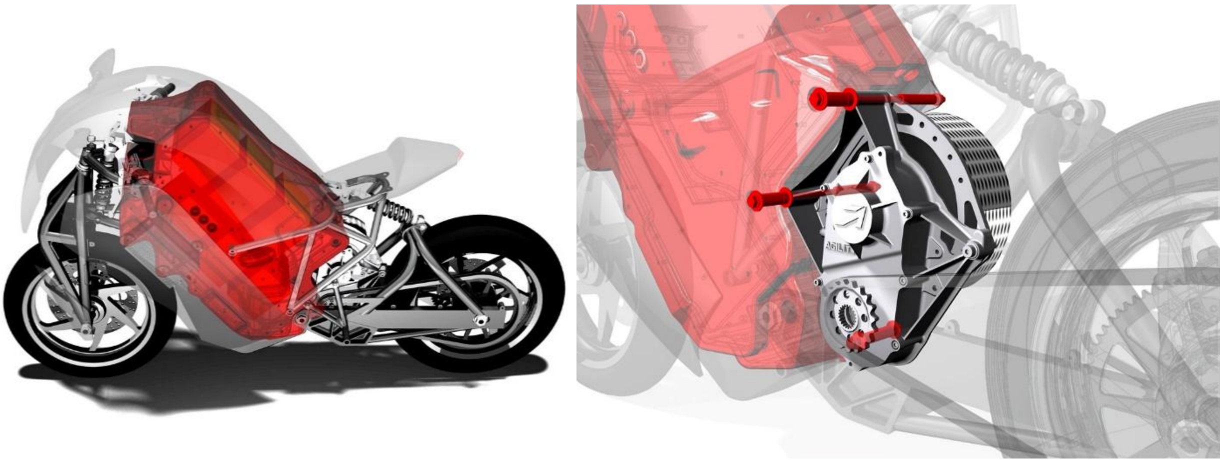


Figure 3) – Agility Motors 2008 Saietta R

(Saietta Group Limited. 2015)

Figure 3) shows the unconventional design of the Saietta R. As we can see the motor and gearbox mechanism positioned neatly between the battery pack and close to the rear wheel where drive originates. The EMUS and Saietta both share this component layout and are typical of electric motorbike design. Indicative of the rapid evolution of battery storage technology, the successor to the Saietta R is Agility Motors' 2017 NGS, which doubles the battery capacity of the Saietta R but within similar dimensions.

2.2 Zero motorcycles

Based in California and started by former NASA Engineer and keen bicycle enthusiast Neal Saiki, Zero motorcycles are an American EV-MC manufacturer that has grown steadily since inception in 2006. Now internationally established and generally considered by critics as one of the companies at the forefront of EV-MC development, they currently offer four models (SR, DSR, FX & FXS) with a different size battery pack for each. In a step forward for consumer convenience, accessories are available that can increase mileage or reduce charge time significantly. The following pages show the specification of these models.

The array of available battery capacities and duo of optional performance extras demonstrate a willingness to cater to all kinds of customer using the same base model. Having this awareness is crucial to attract a wide range of consumers with different demands who may prefer higher power as opposed to extended range, or simply have a lower budget. They are powered by NMC Lithium-ion batteries produced by Farasis Energy in California. The same battery packs are found in the Chevrolet Volt and Nissan Leaf and are some of the most compact and highest outputting batteries in the industry. These are used in tandem with a Motenergy ME0913 air-cooled PMAC motors. Motor types will be explored and explained in section 3.0. A Kevlar belt drives the rear wheel which lasts up to 40,000 miles on all Zero models. *(Dillard, T. 2017)*

The figures in red include the optional power tank accessory fitted (provides power increase), which costs an additional $2,895. Figures in blue include the optional charge tank accessory fitted (provides range increase), which costs an additional $2,295. Only one of these can be fitted at any one time.

The DSR is billed as the more capable touring bike of the range with a longer suspension travel and rugged dirt-ready tires. The slightly altered design comes at a sacrifice in terms of range, weight and performance though.

The FX and FXS models offer 3.6 kWh modular batteries, which output the same power and range as the larger 7.2kWh units when two are combined, but are removable and can be charged at home or in work if the commute is short enough to last the distance. An extra 3.6 kWh module costs $2,895 so that once depleted the replacement can be fit and depleted module recharged. There is also a quick charging option available for all models too for an extra $600. The FX/FXS is a minimalist dedicated off road supermoto, identifiable by the slimmer body, high front fender and thin spoke wheels with rugged tires.

2.2.1 – Zero SR

Figure 4) – Zero SR

(Rubalcaba, A. 2014)

Battery Capacity (kWh)	7.2	13.0	14.4
Range (miles) (Urban & Motorway)	60 N/A	108 138	120 150
Peak Power (bhp)	34	60	70
Peak torque (Nm)	106	110	157
Charge Time (hours:minutes)	5:12 1:30 N/A	8:54 2:18 11:18	9:48 2:30 12:06
Top Speed (mph)	91	98	102
Curb Weight (kg)	142 N/A	185 205	188 208
Charging Method	HH & CS	HH & CS	HH & CS
Price ($)	10,995	13,995	16,495

2.2.2 – FX/FXS

Figure 5) – Zero FX

(Allen, J. 2017)

2.2.3 – DSR

Figure 6) – Zero DSR

(Brown, B. 2017)

Battery Capacity (kWh)	3.6 modular	7.2	7.2	13.0	14.4
Range (miles) (Urban & Motorway)	27	54	53 N/A	95 121	105 132
Peak Power (bhp)	27	46	34	60	70
Peak torque (Nm)	106	106	106	110	116
Charge Time (hours:minutes)	5:06	9:42	5:12 1:30 N/A	8:54 2:20 11:18	9:48 2:30 12:06
Top Speed (mph)	85	85	91	98	102
Curb Weight (kg)	114	131	144 N/A	187 207	190 210
Charging Method	HH	HH	HH & CS	HH & CS	HH & CS
Price ($)	8,495	10,495	10,995	13,995	16,495

2.3 BMW

2.3.1 – C-Evolution

One of the industries major players BMW released their first EV-MC, the C-Evolution in 2014, and are the first of large manufacturers to do so. Their reputation and high consumer focus on urban mobility places the C-Evolution as one of the fastest growing EV-MCs today, particularly since the model was refreshed in 2017 to accommodate two license categories.

Some of the optional extras include luggage accessories, heated grips, covers etc. Also an AC quick charging cable, which can reduce charge times up to 25% and is compatible with conventional 3 pin plugs at home as well as public charging points. As before, figures in blue represent this reduction. It is also equipped with a limited speed reverse gear to aid slow speed parking and manoeuvrability of its high 275kg weight.

The drivetrain is comprised of a liquid cooled surface mounted PMAC electric motor and air cooled Li-Ion batteries. Four riding modes offer the user different styles depending on their mood, road, eco pro, dynamic and sail, which eliminates all regenerative braking allowing the bike to coast much more easily. *(BMW. 2018)*

Figure 7) – BMW C Evolution

(Lunes, Á. G. 2016)

Battery Capacity (kWh)	12.7
Range (miles) (Urban and Motorway)	99
Peak Power (bhp)	46
Peak torque (Nm)	72
Charge Time (hours:minutes)	2:53 / 3:50 – 80% 3:23 / 4:30 – 100%
Top Speed (mph)	75
Curb Weight (kg)	275
Charging Method	HH & CS
Price (£)	12,350

2.4 Energica

'Energica Motor Company S.p.A. is the first Italian manufacturer of super sport electric motorcycles. Energica Motor Company, headquartered in historic Modena, Italy, is the sustainable subsidiary of CRP Group – a pioneer in the world of international motorsports and a hub of excellence for its state-of-the-art technologies.' (Energica. 2017)

Acting under the name 'CRP Racing,' their first prototype the eCRP1.0 was revealed in 2010 at the 'Cleaner Racing Conference' in Birmingham by Lord Drayson. Officially formed in 2014 and bolstered by the remaining two subsidiaries of the CRP Group (CRP USA & CRP Mecannica), Energica have been developing EV-MCs since 2008 and have delivered three different models into the market. Unlike Zero Motorcycles, they do not offer any accessories that affect the powertrain capabilities of their motorcycles.

Their latest introduction is the Esseesse9, which was revealed at the EICMA show in 2017. Key features on this new model are the introduction of eABS, which is a system responsible for limiting the amount of regenerative torque used to recharge the battery pack for when conditions are slippery, to stop the back wheel locking up under deceleration.

Four riding modes are available (Urban, Eco, Rain & Sport) with four regenerative maps available for the braking system too. Like the C-Evolution, it too has a park assistant mode, which aids the rider to move forward and reverse at a steady and controllable 1.74mph, a very useful feature uncommon on petrol-powered bikes apart from larger touring bikes. *(Milbank, J. 2017)*

The performance levels and exquisite design backed by an experienced mother company allow Energica to market their machines as an 'exotic' European hand-built machine not accessible to any buyer or rider. Appealing to a very different bracket of enthusiast with deeper pockets and a desire for the unique. *(Dillard, T. 2017)*

The Eva and Ego are representative of the previous point, finely polished examples taking design cues from modern day superbikes and street fighters but equipped with cutting edge motor and battery technology. All of the Energica motors are oil cooled permanent magnet AC motors and they are fit to all three models, this works in tandem with the 11.7kWh lithium polymer battery packs. The substantial power and top speed of the Ego is what deserved it the title of Motorbike of the Year in 2017.

2.4.1 – Eva

Figure 8) – Energica Eva

(Visordown. 2015)

2.4.2 – Ego

Figure 9) – Energica Ego

(Kane, M. 2014)

	Eva	Ego
Battery Capacity (kWh)	11.7	11.7
Range (miles) (City and Motorway)	125	93
Peak Power (bhp)	109	145
Peak torque (Nm)	180	200
Charge Time (hours:minutes)	0:30 – 85% 3:30 – 100%	0:30 – 85% 3:30 – 100%
Top Speed (mph)	125	150
Curb Weight (kg)	258	258
Charging Method	HH & CS	HH & CS
Price (£)	27,999	24,999

2.4.3 – Esseesse9

Figure 10) – Energica Esseesse9

(Fiorentini, D. 2018)

Battery Capacity (kWh)	11.7
Range (miles) (City and Motorway)	93
Peak Power (bhp)	109
Peak torque (Nm)	180
Charge Time (hours:minutes)	0:30 – 85% 3:30 – 100%
Top Speed (mph)	125
Curb Weight (kg)	N/A
Charging Method	HH & CS
Price (£)	23,999

2.5 Failed Projects

Two examples of manufacturers facing difficulties in the development of EV-MCs are Vectrix and Vigo. Vectrix, a producer of electric scooters, filed for bankruptcy then liquidation, in 2009 and 2014 respectively. Vigo was a start-up company that failed to raise the required funds through an Indiegogo campaign.

2.5.1 – Vectrix

Vectrix introduced their first electric scooter, the VX-1 in 2006, with impressive statistics for the time. It utilised a 3.7kWh NiMH battery that could reach 65 miles on a single charge and travel over 60mph. Dillard reports that Vectrix built 2,002 of the $12,000 model by 2008 but only sold 123, resulting in $819,000 in sales and a $54million loss. Shortly before bankruptcy in 2009 their own take on an electric superbike was displayed at the EICMA show, they committed to produce it based on 500 deposits initially but this was soon lowered to 200. Under new parent company 'Gold Peak,' the following 3 years involved periods of updating the VX-1 with a more modern Lithium-ion battery unit and suffering manufacturing problems with the revised VX-1, the VX-2.

Figure 11) – Vectrix VX-1

(Motorstown. Unknown)

This accompanied with continuing support for owners suffering problems with their original VX-1 units paved the way to their slow decline. After a loss of European dealerships in 2013, they filed for liquidation the following year and ceased all operations. *(Wikipedia. 2018)*

2.5.2 – Vigo

Vigo, failed to reach their £240,000 start-up goal, only £27,326 was raised which is little over 11% of the target. Although personally I believe that the company set itself unrealistic goals. The Vigo website claims the motorbike would achieve a range of up to 400 miles, which is an unprecedented distance on a single charge even for a car in the current technological climate. Put into context, the range declared for the EV-MCs previously explored are on average 107 miles. Tesla's currently longest ranging vehicle the Model S 100 D can only manage 335 miles. To achieve such a range clearly requires technology ahead of our time, couple this with the claimed top speed of 180mph and the primitive promotional video found on the homepage, this certainly has the feel of a product 'too good to be true,' which has now been 'temporarily suspended' as of April 2nd 2017. They cite, 'inability to disclose information, legal complexities, setbacks and other matters' as well as the lack of funding, the reasons for the projects suspension. *(Sergeev, T. 2017)*

Figure 12) – Vigo Superbike Render

(Sergeev, T. 2017)

2.6 EV-MC Maintenance

One overlooked concept of EV-MCs is the manufacturers ability to provide service and firmware upgrades online. Allowing the user to download and install them themselves. Although Dillard argues that, this could present a potential threat to the traditional dealership network, because of the return-ability of customers to dealerships with gasoline bikes, generally providing more revenue to them. It has been implemented nonetheless with the Brammo model line-up and Zero. Overall, the running and maintenance costs of all EVs including EV-MCs are significantly less than their petrol counterparts. Although there is a higher initial outlay of RRP and home charging equipment must be installed, the government incentives are there in an attempt to offset these costs. *(Reichmuth, D. 2017)*

3.0 Developing Technologies

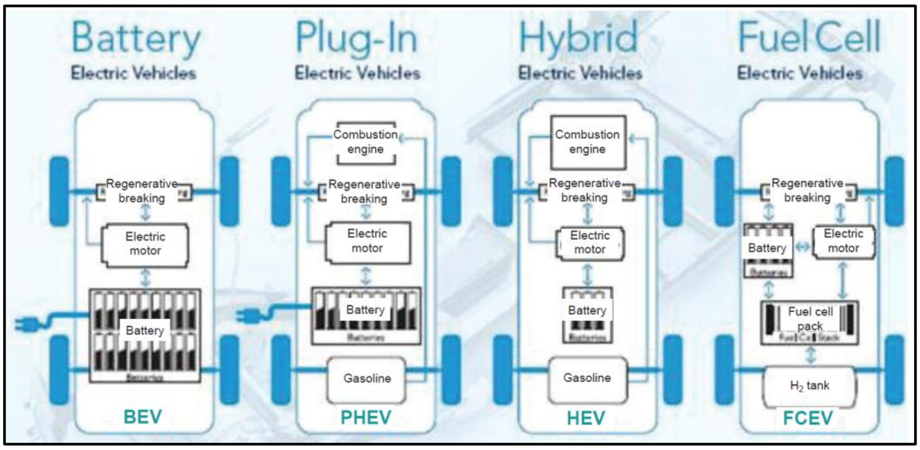


Figure 13) – Diagram of Electric Vehicle Hardware

(Saisirirata, P. et al. 2013)

Figure (13) illustrates the differences between the terms associated with EVs today. We can see that the BEV and PHEV are the only vehicles with the ability to be charged traditionally by plugging in. Where-as HEV and FCEV are not, using either the fuel cell/combustion engine or electric motor, or a combination of both. All variants utilise the regenerative braking feature to re-charge the battery pack.

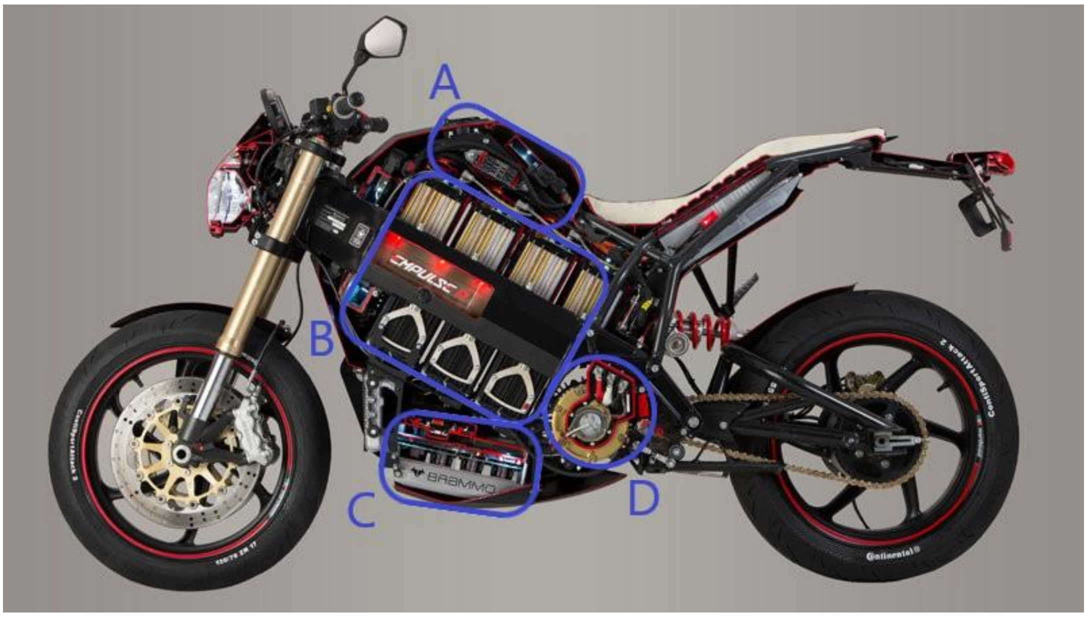


Figure 14) – 2013 Brammo Empulse R Cutaway

(After Yoney, D. 2015)

Figure 14) provides an excellent insight into how various components are positioned within the confined available space under the rider. B, D and regenerative braking which encompasses all A, B, C & D components will be discussed at length in the following sub-sections.

Components:
A – Battery Management System
B – Battery Pack
C – Motor Controller
D – Motor

All EV-MCs are reminiscent of the BEV category in figure 13), although experimental work has been carried out on PHEV layouts with greatly improved acceleration & range. See *(Asaei, B., & Habibidoost, M. 2017) & (Bureš, Z., & Franc, V. 2009)*

3.1 Battery Technology

Battery Packs provide the source of power distributed through the controller to the motor for propulsion. Four types of battery stand out as being of significant importance to the development of this component.

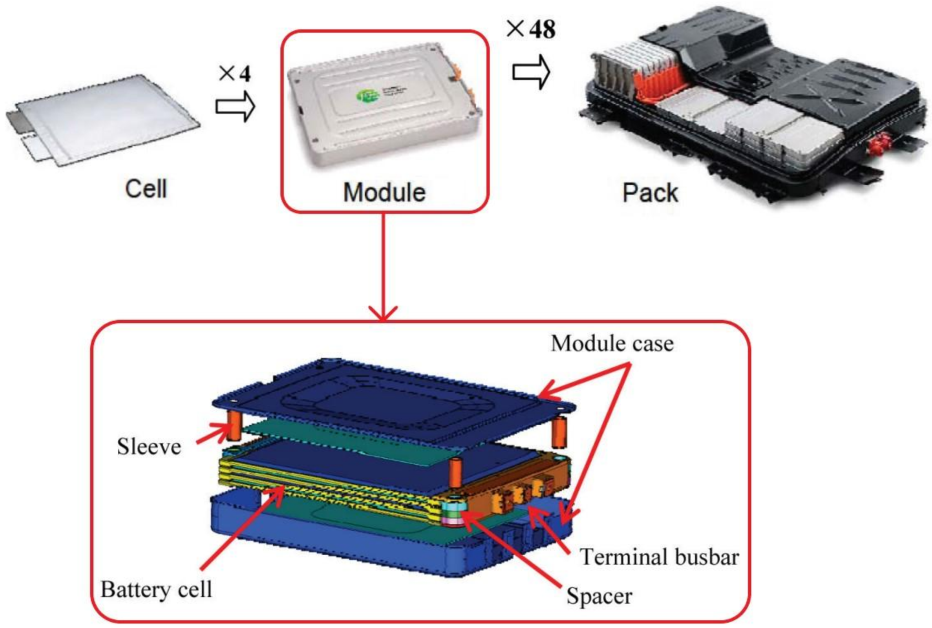


Figure 15) – Nissan Leaf Battery Pack Architecture

(After Kinoshita, Y. et al. 2013)

Figure 15) is representative of the typical battery pack arrangement found in modern electric vehicles, with varying types of cell material and module numbers. Using the Nissan Leaf as a reference for battery discussion is appropriate due to the transferrable knowledge that can be applied to EV-MCs, through Nissans research and development into the technology.

3.1.1 – Nickel-Metal Hydride

NiMH cells have an alkaline electrolyte, usually potassium hydroxide. This solution allows the flow of electrical energy through the cell material. The positive Electrode is Nickel Hydroxide and the Negative electrode is hydrogen ions or protons. The hydrogen ions are stored in a metal hydride structure that is the electrode *(Omega Omega. 2017).* These replaced Ni-CD batteries where the negative electrode was cadmium based.

Nickel-metal Hydride batteries have a huge application of uses from household items such as digital cameras, GPS units, mp3 players etc. to vehicles like the Toyota Prius. Since their introduction in 1991, they have endured significant developments in terms of their capabilities. Early variants of the Vectrix VX-1 were fitted with NiMH batteries as discussed in section 3.5 and more than 10 million hybrid vehicles currently utilise one, offering a wide operational temperature range, high energy density and very long service life. Although EV-MC manufacturers favourably choose Lithium-Ion due to its strengths over NiMH and in light of consumer demands from an EV, NiMH continues to be a strong and sensible choice for energy storage under continuous development. *(Lin, S-K. 2016)*

3.1.2 – Lithium-Ion

Li-Ion batteries are capable of holding much higher densities of energy than NiMH, making it possible to reduce the battery size considerably.

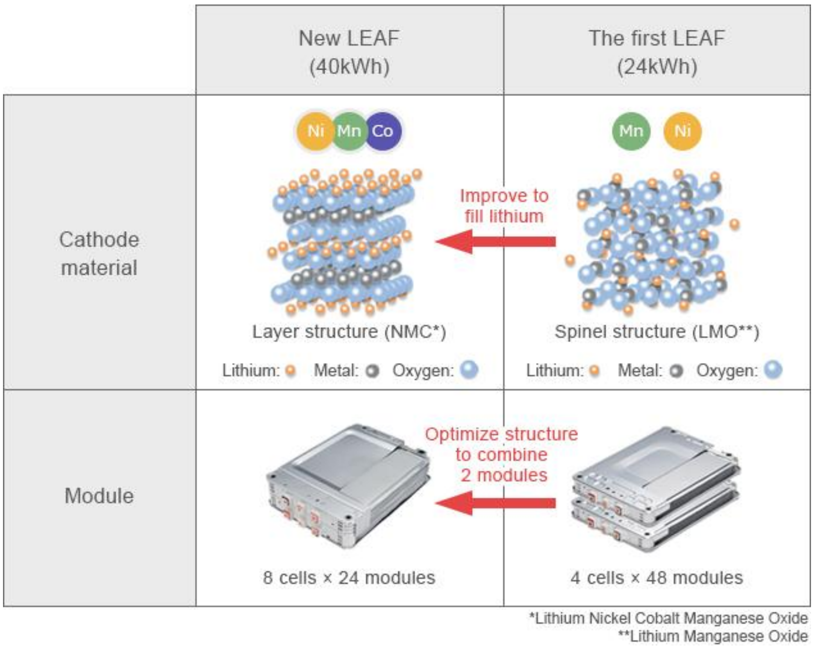


Figure 16) – Nissan Leaf Li-Ion Development

(Nissan Global. 2018)

Since the introduction of the leaf in 2010, the original battery pack construction has changed considerably. The addition of Nickel and Cobalt to the cathode material has boosted the power output by 16 kWh, and doubled the range from 200km to 400km by allowing more Lithium into the laminated cell structure. The Zero SR and Brammo Empulse R use this NMC Li-Ion battery cell composition.

Benefits to using a Li-Ion battery pack over a NiMH are the efficiency and heat generation. A study by Kent, A. et al. in 2009 where the characteristics of the two battery packs were compared, found that the Li-Ion battery exhibits 5% higher efficiency levels that the equivalent NiMH. This is down to the inherently higher internal resistance of the NiMH, which consequently leads to increased generation of heat. Equivalent size NiMH and Li-Ion batteries can give 2200mAh and 1500mAh respectively, demonstrating a higher capacity for NiMH. Although it can only deliver 1.2V compared to Li-Ion cells 3.7V, is another characteristic that makes it a more powerful battery type, and currently, distinguishes it as a manufacturer's battery of choice.

3.1.3 – Lithium Polymer

'A lithium polymer cell is made by laminating together five thin materials including an insulator, a lithium foil anode, a solid conductive polymer electrolyte, a metal oxide cathode and a current collector. The total thickness of this all-solid laminate is less than 100 microns (0.004 inches) and it is wound into a prismatic shape to form an electrochemical cell (EC)'

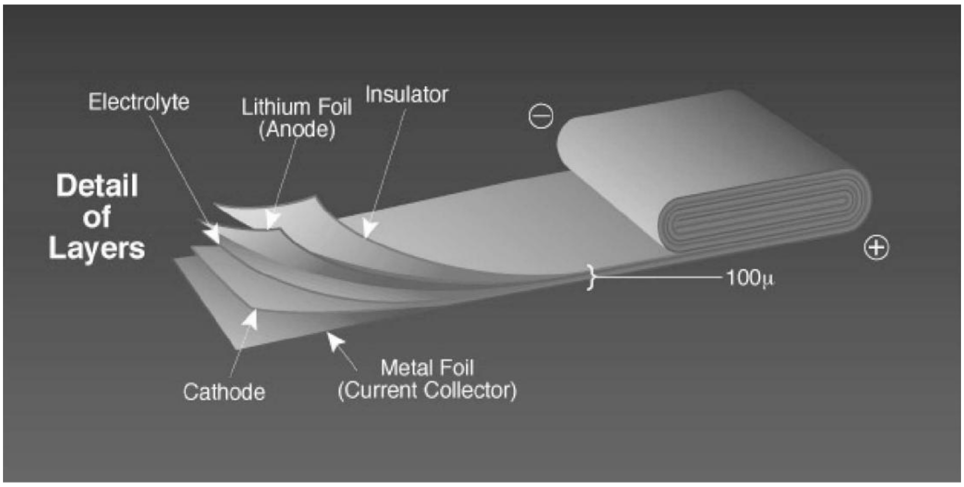


Figure 17) – Lithium Polymer Cell

(St-Pierre, C. 2000)

This solid conductive polymer is what differentiates a Li-Poly battery cell from the previous two, which have fluid electrolytes between layers instead. Allowing for the higher density using a solid electrolyte puts these battery cells among the most power and energy-dense available as well as being significantly less expensive to produce than other chemistry. Where power and weight are of particular concern, as is the case with EV-MCs, Li-Poly cells are perfect for application due to their high discharge rates. Another advantage is that manufacturers are not bound by standard cell formats, with high volume any reasonable size can be produced economically. *(Battery University Group. 2010)*

Although a major drawback is the volatility of these cells. Early on in their adoption this was down to simple quality control issues, as well as over-charging/discharging would lead to potential combustion. With improved quality control measures over time, manufacturers like Energica and Voltron have successfully implemented this battery type into their EV-MCs.

3.1.4 – Lithim-Sulfur

Lithium-Sulfur is a state-of-the-art battery technology, which has the ability to store an incredible 540Wh per kilo, more than double that of Li-Poly cells. Nagata, H. & Chikuse Y. found in October 2016 this cell level energy density when measuring it over 100 cycles at 25°C. This is encouraging when considering the more than sufficient application for electric vehicles. Sulfur is a cheap element to obtain but despite this promising discovery, the developments are not without drawbacks. Disadvantages are the capacity fading after moderate cycling, high electrical resistance and self-discharge which is down to the so-called shuttle effect.

'Generated at the cathode, these long-chain polysulfides with high mobility can migrate to the lithium anode where they are reduced to the insoluble Li2S and the short-chain soluble poly-sulfides. Once they are concentrated at the anode side, the short-chain polysulfides can diffuse back to the cathode side and will be re-oxidized into the original long-chain ones, thus creating a so-called shuttle effect. This shuttle effect results in the low utilization of active materials, poor coulombic efficiency and degradation of the lithium anode' (Wang, Q. 2014)

Using a hybrid electrolyte, Wang, Q. et al. was able to eliminate this shuttle effect over dozens of cycles.

However, despite being in its early development, Li-S is a promising prospect for the automotive sector. With the ability to hold more than twice as much energy per kilo, this could have a major impact on the 'range anxiety' experienced by EV motorists of today. With further testing of the hybrid electrolyte over at least a thousand cycles to match real world usability of a typical battery cell, there is a real prospect that EV-MCs could endure significantly increased range compared to their petrol-powered counterparts. Only a battery pack such as this could ever allow the up to 400-mile range figure quoted by the lead engineer of the Vigo project to become a reality.

Table 3) – Battery Cell Level Characteristic Comparison

	NiMH	Li-Ion	Li-Poly	Li-S
Nominal Cell Voltage (V)	1.25	3.6	3.7	1.7-2.5
Cycle Durability (Cycles)	500-1,000	1,000-2,000	<1,000	100
Energy/Weight (Wh/kg)	100	160	200	540
Energy/Price (Wh/$)	1.40	2.8-5	2.8-5	N/A

(Artiuch, J. 2007)

Dillard says a motorcycle pack needs to be able to deliver power. Discharge rates, in the battery world, are given as a C-Rate, and a typical lithium-ion battery gets ratings of C2-C4, for the sake of discussion. Radio control model batteries (Li-Poly), as used in model aircraft, cars and boats, are rated much higher – C20 – C40, and, because of nature of the chemistry, are also considerably more apt to catch fire and explode. To compete with "Sport" gas bikes, an electric motorcycle, can demand anywhere from 400A to 600A to the motor, pulling discharge at a starting point of C10, if not C20 for smaller packs. While electric cars certainly benefit from smaller, more energy and power-dense battery chemistry, motorcycles are the acid test of battery performance.

3.1.5 – Giga Factory

Tesla's new Gigafactory began construction on June 1st 2014; currently the facility has a footprint of more than 1.9million square feet, with 2.5 times that across several floors. Tesla's ultimate goal is to produce a mass-market affordable electric car, and through the construction of the largest building in the world (even larger than the sum of all lithium-ion factories in the world), this goal will be brought much nearer to reality by manufacturing in the parameters of economies of scale. To emphasise the true scale, company CEO Elon Musk can be quoted as saying 'it's aligned on true north so we can actually map out where the equipment is going to be by GPS.' It will also be completely self-sustaining via use of geothermal wind and solar power and is forecast for completion in 2020. *(Tesla.com. 2017)*

The price of battery packs has long been one of the primary reasons for the high price of all electric vehicles, including EV-MCs, but with a facility of this size prices will soon fall. Tesla expects its own battery prices will reduce by roughly 30% by eliminating waste and tidying up the supply chain. *(Desjardins, J. 2016)*

Figure 18) – Tesla Gigafactory, Nevada

(Tesla.com. 2017)

3.2 Motor Types

A common misconception is that the recent industrial enthusiasm for EV drivetrain technology means that it is a relatively new one. Although it actually pre dates petroleum power and has existed in motor form since the mid 1800's. *'The electric motor is based on the interaction between electric and magnetic phenomena. In a simplified representation, the motor is composed of coils (the rotor) arranged on top of fixed magnets (the stator). A magnetic field is generated around the coils when electric current flows through it, which interacts with the field of the magnets causing the coils to turn. The coils will not stop turning when a current reversal is applied at a determined frequency. When a shaft is coupled to these coils movement is transferred to the outside of the structure.' (World Pumps. 2016)*

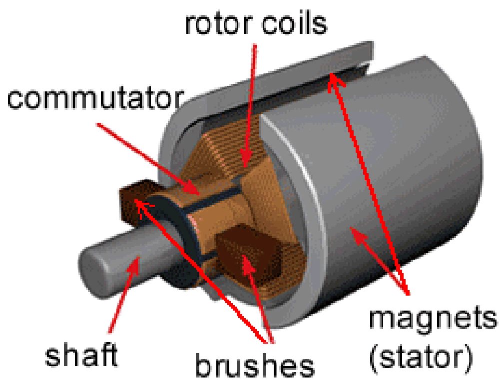


Figure 19) – Basic components of DC Electric Motor

(Zekan, J. Unknown)

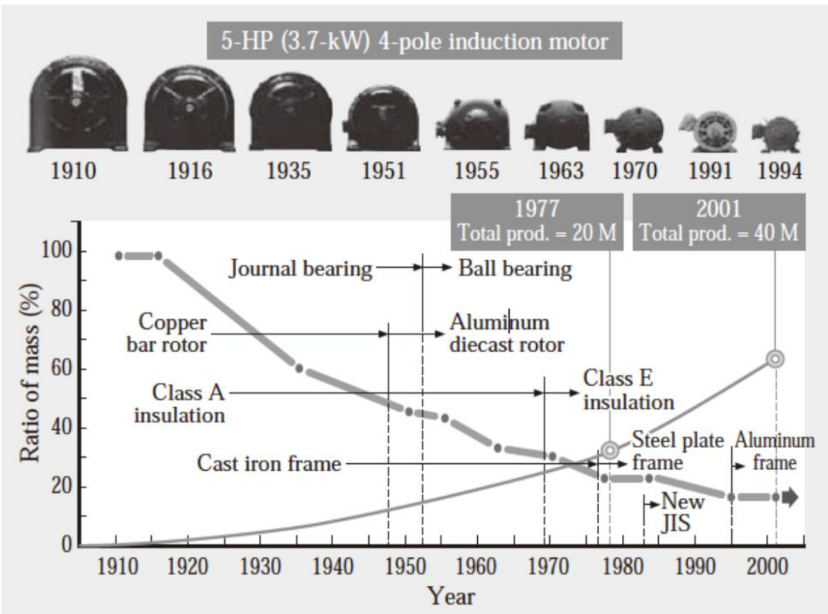


Figure 20) – Hitachi Electric Motor Size Reduction Over Time

(Dillard, T. 2017)

This basic principle of causing motion due to the interaction between electric and magnetic phenomena has remained very much unchanged since its founding. Primary alterations to the manifestation of the principle have been the size of the device itself. Figure 20) from Hitachi's History of Motor Development demonstrates this, the 1910; 5bhp model weighed 150kg at 40cm wide while a prototype shown in 2010 was only 10kg with one third of the volume. A modern motor can produce the same amount of power as one from 1910 but the efficiency of today's motors has dramatically increased and can manage 97-98%. Comparatively the best of today's Internal Combustion Engines can only manage 45%. *(Economist Editor. 2017)*

3.2.1 – DC Motor

Figure 19) is representative of a basic DC motor, the inefficiencies of this design lie in the use of copper coils in the rotor, which generate heat as a current passes through. The other inefficiency is the use of carbon brushes, which make contact with the commutator to keep the current flowing in the same direction. These brushes are unreliable, also generate heat, and wear out over time as a result. Typical characteristics of DC motors include a high starting torque, poor speed regulation and no load operation, which can prove to be a personal safety hazard.

The Reason for this is that the torque produced is proportional to the square of the current passing through the armature. Effectively as the motor is started and armature resistance is low, the supply voltage drives the whole current through it resulting in a high starting torque. A load must be applied as a means of regulating the speed otherwise at no load the motor would simply runaway and burn out.

3.2.2 – PMAC Motor

Brushless AC & PM Synchronous are also other names for a Permanent Magnet Alternating Current Motor. These are the most popularly adopted in the automotive industry because of the ability to regulate the load; they have been fitted to the Zero and Energica models explored in section 2.0. The difference in construction is the replacement of the current carrying coils in the rotor with permanent magnets and the magnets in the stator with coil windings. Brushes are eliminated and instead of applying direct current through these, it is an alternating current directed through opposing pairs of coil windings in the stator. This is done at a frequency defined by a controller, which in turn governs the rotating speed of the magnets (rotor), hence the term 'PM Synchronous.'

Immediately this is a direct improvement over the conventional DC motor due to the removal of the brushes, which produce heat and friction. The other benefit is that permanent magnets are by definition, permanent and not subject to failure except in cases of magnet abuse and overheating. *(Murphy, J. 2012)*

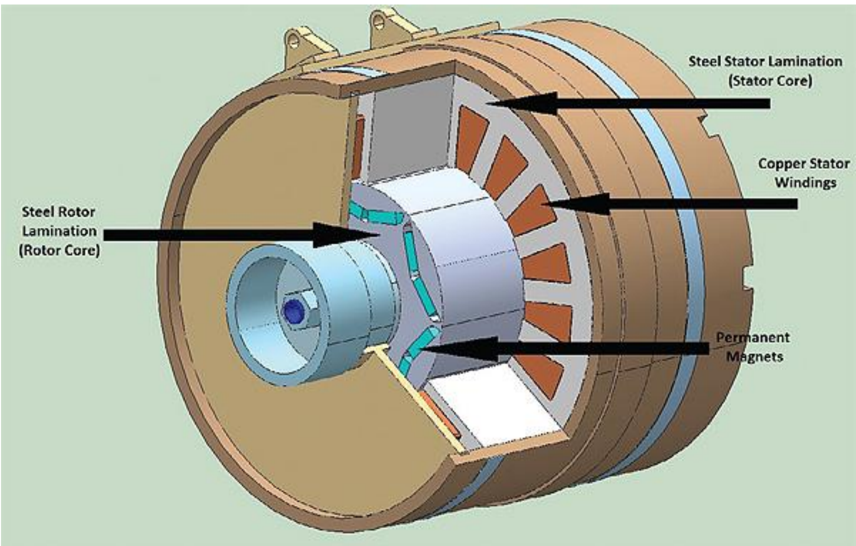


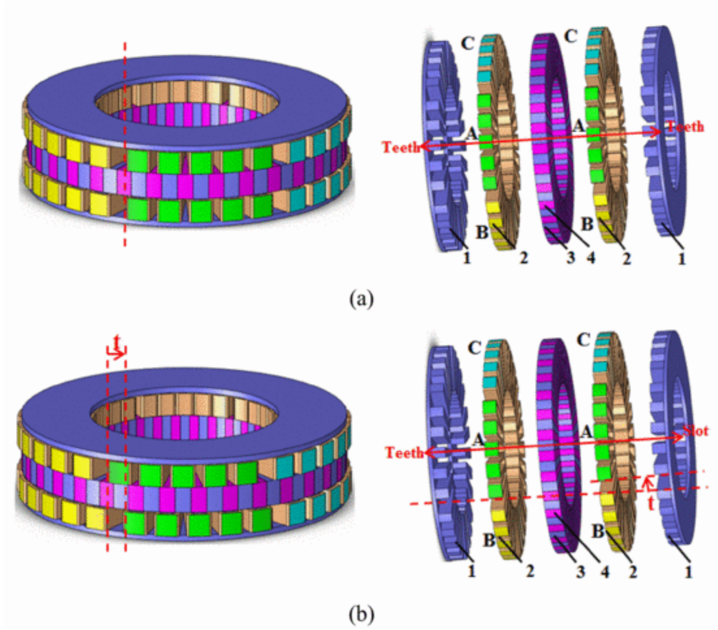
Figure 21) – Components of PMAC Motor

(MCT Editor. 2014)

3.2.3 – PMAC Motor Developments

Another way of improving the PMAC motor is to use 'rare earth' magnet material, which has much stronger magnetic field intensity when compared with traditional ferrite magnets. This increases the overall power of the motor. Three of the most popular are dysprosium, neodymium and samarium cobalt. They are one third to two times more intense than the abundantly available ferrite metals used in cheaper applications of the design. Rare earth magnets are the most effective way of increasing the power of the motor but are very expensive and not as abundantly available as the ferrite metals. China possess 96% of global availability of rare-earth material and 2011 saw a 600% rise in their prices due to reductions in export quotas there. According to the 'Information Office of the State Council the People's Republic of China, Situation and Policies of China's Rare Earth Industry,' *'the current price of some REEs is too low to reflect their value, does not represent the shortage of the resources and does not compensate the environmental damage.' (Riba, J-R. et al. 2016)*

This has led to the development of alternative magnet arrangements with abundantly available ferrite metals, in an attempt to reproduce the performance standards of those motors with rare-earth materials.



(a) Basic model.

(b) Proposed model.

1-Stator.

2-Phase-group winding.

3-Rotor pole.

4-Ferrite permanent magnet.

t – Stator offset

Figure 22) – Alternative dual stator arrangement

(Wenliang, Z. et al. 2013)

Figure 22) shows an arrangement of teeth found on a pair of stators. Arrangement (b) is offset by one tooth's width as represented by t. This simple modification resulted in a higher torque density and motor efficiency when compared to arrangement (a), characteristic of rare-earth motors. Not only this, but the resulting interaction of the combined magnetic field in arrangement (b) effectively nullified any cogging torque and torque ripple, reducing both considerably by 91.4% and 92% respectively. These are undesirable effects of the interaction between the two magnetic fields of a motor and are defined as:

Cogging Torque – The attraction/interaction of the magnetic poles to the teeth (steel structure) of the laminations within an un-energized motor.

Torque Ripple – The variance of the torque of the energized motor with a constant current, which are related in position independent of magnitude or direction. *(Hurley, G. 2014)*

3.2.4 – Electric Motor Transmissions

There are many disputed reasons for and against the necessity for a transmission on any electric vehicle. Brammo, one of the first American manufacturers to release an EV-MC in the U.S. in 2008 are also the first and still the only EV-MC manufacturer to equip their models with one. Bought by Polaris industries in 2015 who own the Victory and Indian motorcycle companies, Victory continue to sell Brammo's Empulse R with the 6-speed transmission it was designed with, seen below in figure 23). This addition appeals to the more authentic, traditional motorbike rider who will appreciate the like for like functionality of conventional ICE machines. Although EV purists might argue that it detracts from the uniqueness of the way an electric powertrain delivers its power. Brian Wismann, a designer at Brammo said, '*Electric motorcycle design has always been a bit of a balancing act in direct drive systems where great acceleration performance comes at the expense of low top-end speed. The Integrated Electric Transmission is a mechatronic propulsion unit that emulates the feeling and performance of a traditional internal combustion engine, with a specially developed electric motor, clutch and gear shift, that enables Brammo motorcycles to accelerate hard from the line up to a high top speed, something that is just not possible to achieve with a single ratio electric motorcycle*' *(Siler, W. 2011)*

Figure 23) – Brammo Empulse R

(Siahaan, T. 2014)

Brammo stated that to achieve similar performance from an equivalent direct drive system with no transmission the motor would need to be 1.5x the power requirement. *(Design World. 2014)* While a road test by Tom Roderick in 2013 proved that, the Empulse R was by far the faster bike from a standstill and achieved higher top speeds. A detriment was the added 83lbs in weight that it provided and the conclusion that six gears were at least three too many which inhibited each other, due to the vast torque curve of the electric motor. Highlighting this was a fourth gear acceleration test from 55mph where the Zero even proved to be the quicker machine. In terms of price the Zero is $3,000 cheaper too, I would estimate the transmission is at least a quarter of this price difference along with the reputable branded wheels, brakes, forks and shock absorbers.

3.3 Regenerative Braking (KERS)

Regenerative Braking is a system commonly seen on four-wheel electric/gasoline vehicles and has existed for well over a decade, but not on two-wheel vehicles. This is because there has never been a need to recover braking energy on a motorcycle until now.

Regenerative braking is defined by the United States Department of Energy as a system that captures the energy lost during braking by utilizing an electric motor as a generator and storing the energy captured.

The principle is simple; all electric vehicles have batteries, an electric motor and wheels to distribute the power to. With the kinetic energy and momentum that a vehicle has at speed, on deceleration the whole power distribution process is reversed and becomes absorption. The rotation of the wheels turns the electric motor, generating power to charge the batteries. This captured energy can be used to accelerate once more prolonging the range and overall efficiency of the vehicle. Comparable to engine braking, relying solely on the motor to bring the vehicle to a halt is unsubstantial and is the reason traditional mechanical brake discs and pads are fitted for when more rapid deceleration is required and emergencies *(Lampton, C. 2016).* This is also, why regenerative braking will never recover 100% of braking energy. Based on several simulations performed by the Worcester Polytechnic Institute in 2014, disregarding drivetrain and electrical losses, potentially recoverable energy stands at 17% for typical urban driving with maximum energy recapture a primary goal. Two separate studies have successfully improved the energy capture of the regenerative system by adding neodymium magnets to the back of the brake discs, and a coil positioned at set distances from them. See *(Kaul, S. et al. 2013)* & *(Singh, B. et al. 2015)*.

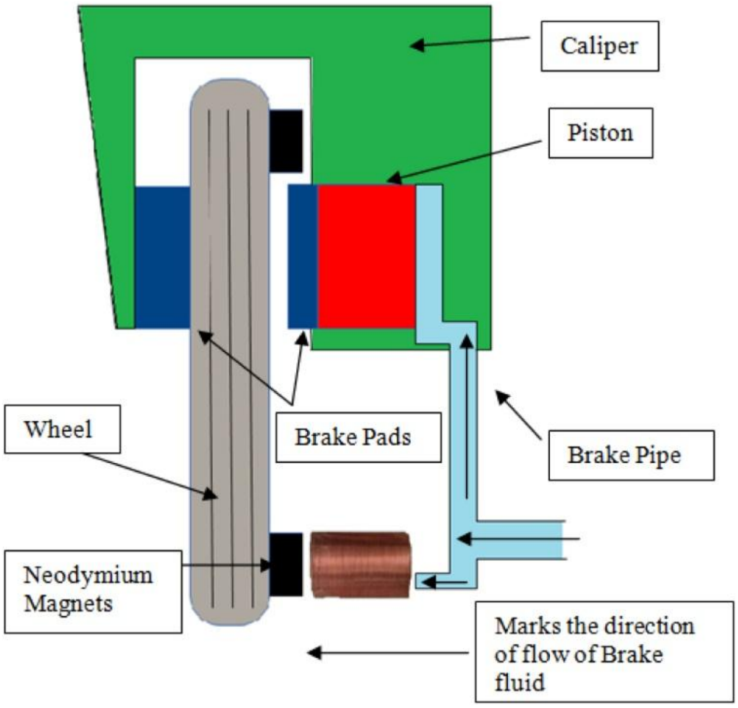


Figure 24) – Brake Disc Regeneration Method *(Kaul, S. et al. 2013)*

Upon testing the design, both studies determined the best distance from the magnet for the coil was 7cm due to the increased intensity of the magnetic field. This induced the largest current through the coil and resulted in overall system efficiency increases of 9.81% and 13.23%. This idea can be easily installed on existing vehicles with very little modification and could be particularly effective on transport where deceleration is timed such as trams and trains.

An even more cost effective way to implement this idea would be to use conventional ferrite magnets that, are not always less effective when compared to rare-earth material as proven in J-R Riba's rare-earth free propulsion study in 2016. Depending on the application, they can be equally as effective. This option is also a potential improvement for PMAC motors as discussed in section 4.2 and simultaneously has the ability to reduce production costs and preserve the remaining quantity of the diminishing rare-earth materials.

3.4 Infrastructure Advancements

3.4.1 – Charging Point Distribution

National EV ownership levels are still in their early days and present a fraction of the U.K.'s total vehicle registrations. However, there are enough to warrant necessary investments in the infrastructure to allay some of the concerns regarding range. EV-MCs are designed to be compatible with public charging points this diagram applies to them too.

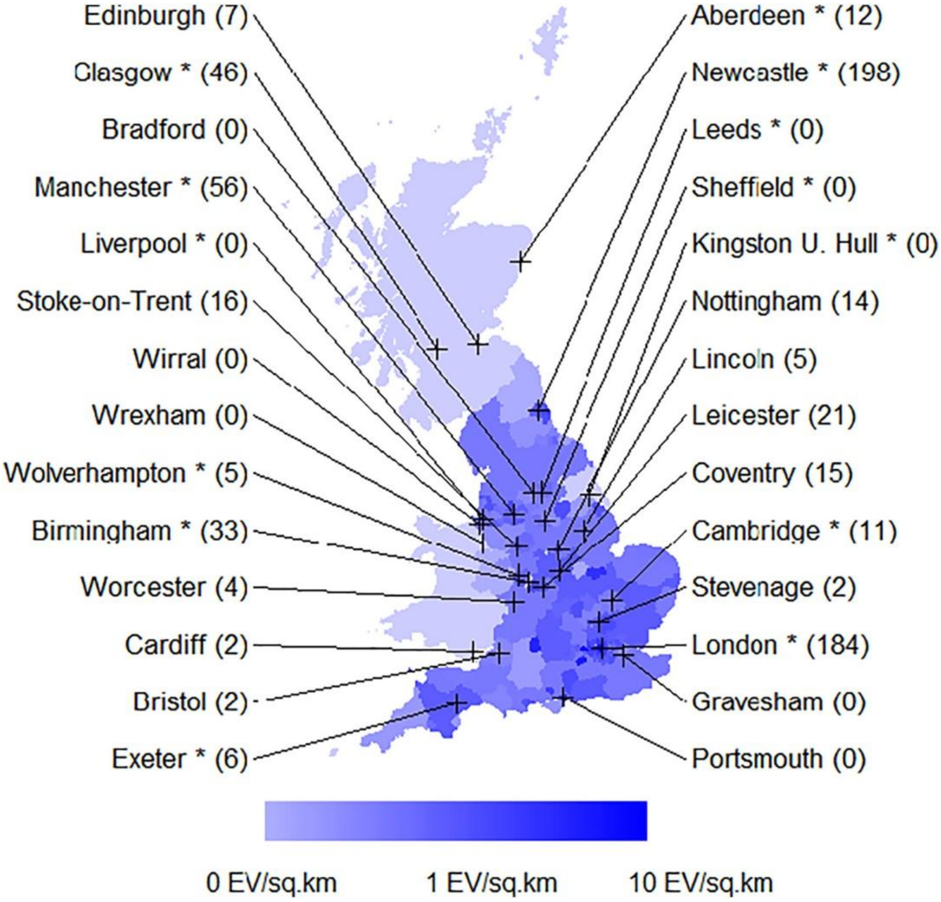


Figure 25) – Charging Points against EV ownership density per city *(Heidrich, 0. et al. 2017)*

Figure 25) indicates each city & their respective number of charging points where an asterisk symbolises a city with a climate change mitigation policy with an EV strategy. Exeter & the surrounding County of Devon stand out as the most concerning location with an increased density of EVs but a poor number of available charging points. Particularly since this is a county that has an EV strategy in place. Newcastle on the other hand is where the Nissan Leaf is produced and so workers at the factory can access discounted leasing deals, which culminates a high density of EV ownership. The Regional council has responded effectively to this awareness and implemented a high number of charging points here. Generally, whether a region has a climate change mitigation policy or not has no effect on the number of implemented charging points, which in turn could inadvertently affect the number of sales.

Currently local strategies are failing to do enough to achieve carbon reduction targets as a result. *(Heidrich, O. et al. 2017)*

It must be considered though the reason a consumer is likely to purchase an EV-MC. Predictably, EV cars are likely to do further journeys than that of an EV-MC because of levels of comfort and vehicle capability. Just as petroleum-powered vehicles are likely to travel further than equivalent motorbikes. Having an awareness of the range capabilities of a car and motorbike separately dictates the acceptable number of charging points within that region. Where range is significantly less on an EV-MC, a potential owner would ensure that there were ample charging facilities present in their daily routine so as not to be caught out by low battery levels, whether through public charging stations or via a household socket.

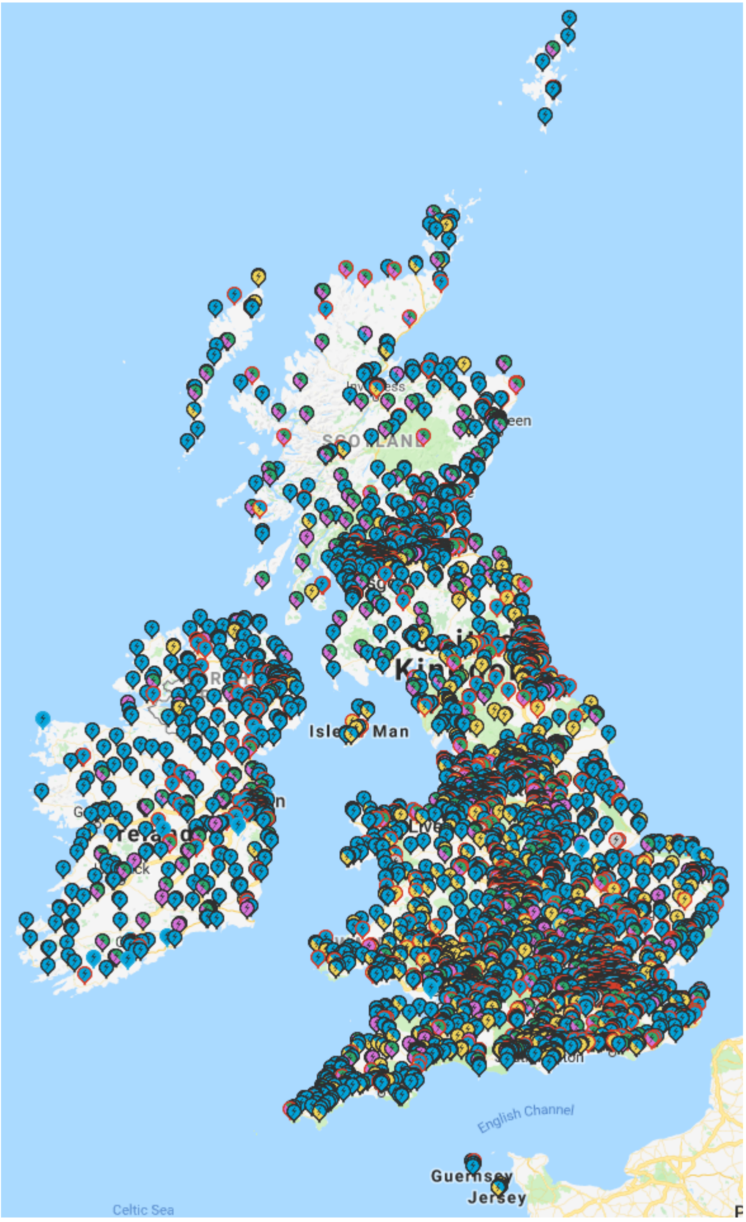


Figure 26) – Zap Map shot of National Charge Points *(Zap Map. 2018)*

Where Regional Authorities are under performing in implementing necessary charging points, this has not stopped a huge variety of businesses installing some of their own such as Supermarkets, car parks, restaurants, hotels, service stations etc. The screenshot to the left is from charging point platform 'Zap Map,' and as of 19/04/2018 is displaying 15,910 charging points over 5,541 locations across the country including Republic of Ireland, of that amount, it states 4,000 are public charge points. When combining the total area of the U.K. (93,627.84mi²) and Republic of Ireland (27,132.56mi²). This equates to one charging location every

21.79 mi² on average.

The distribution is the densest in largely populated areas; with so many points on a single map, it is difficult to illustrate a more accurate national spread without a much larger image. Bournemouth, Bristol, London and Newcastle stand out as the most heavily populate charging locations while the Scottish Highlands and Southern Ireland are lacking. This is due to the difficulty accessing these areas for installation and the low population that live there.

Zap Map has liaised with charging point network providers to integrate live statuses of each charging point so EV owners can check in advance using an app or the website to see if a charge point is free and operational. The community of site users can also update the status of any charge point manually.

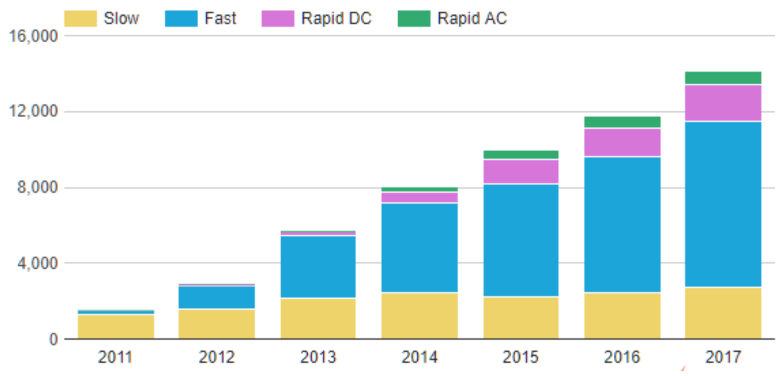


Figure 27) – Annual Charge Point Type Fluctuation

(Newman, C. 2018)

Despite the fact we can infer regional authorities are not doing enough, figure 27) demonstrates a near constant increase in the number of available stations by roughly 2,000 per year since 2013. It has clearly been recognised that user convenience is a priority, due to the equally constant increase in the number of fast charging points as opposed to the plateaued implementation of slow charging points.

3.4.2 – Gogoro Scheme

Gogoro entered the electric scooter market in 2011 and launched in Taipei, Taiwan with an innovative new business model, marketing itself more as an energy company than an EV-MC manufacturer. The principle is simple. A consumer purchases one of their EV-MC scooters and has the choice of several plans where a monthly subscription fee is selected. One of the cheapest options is compared to the most expensive in table 4):

Table 4) – Gogoro Tariff Comparison

Plan Name	Free Solution		Tour Solution	
Monthly Price (Taiwanese Dollars, $) (Equivalent GBP, £)	$399	£9.63	$1199	£28.95
Allowable Mileage	150		1,000	
Extra Mileage (Taiwanese Dollars, $) (Equivalent GBP, £)	$1/km	£0.02/km	$1.5/km	£0.04/km
Performance Improvement Plan (Optional, increases power output)	$249		$249	
Unlimited Battery exchange	✓		✓	
Regular Factory Return Service	X		✓	

(Gogoro.com. 2017)

Figure 28) – Gogoro Scooter, GoStation and Battery Packs

(Lynch, T.W. 2015)

The Scooters are reasonably priced too, at $95,000 to $39,800 TWD (£2290.45 to £959.58) and can travel 60 miles on a full charge while the S performance model can reach 59mph. They currently have 554 GoStations,' across their network which act as the battery equivalent of a fuel station. Riders pull up, remove their depleted/low battery pack and insert them into an empty charge slot in the station before it releases a fully charged one so they may instantly continue the journey. This sidesteps a huge issue in the current EV climate and is an ingenious way of reducing range anxiety amongst consumers. Although it does rely on a variety of factors such as the ratio of scooters to stations within the local area and whether a fully charged one is available or not, it is still a quicker process than refuelling a petrol equivalent scooter.

This also highlights another observation where the whole process of distilling diesel and unleaded petrol, and transporting it to the nearest fuel station outputs and immense amount of carbon dioxide emissions. Comparing this to Electric power, which can be produced at power stations and distributed through the national grid to the GoStations, is much more environmentally friendly and efficient.

There is also the option for riders to purchase charging stations to use at home, both internal and external versions. The external version is Gogoro’s way of incentivising the rider to set up a station at his or her own house, which Gogoro will pay the owner to run. Although these cannot hold as many as the primary GoStations they could be seen as a stepping-stone to anyone travelling through rural areas for example. Currently the company has networks based in Taiwan, Amsterdam, Berlin and Paris with plans to expand further into Western Europe. This has been made increasing likely by a $130 million USD investment at the end of 2015 from Panasonic, the Taiwanese Government and Chairman of the Ruentex Group. *(Tilley, A. 2015)*

4.0 Previous, Current & Future Market

This section will explore three different markets, Global, Continental and National in varying levels of detail due to the limited availability of data; the latter two are the U.K. and South East Asian & Chinese markets.

4.1 South East Asian Market

Less developed countries in South East Asia such as Vietnam and Thailand, rely on affordable, cheap transport as a means of moving about and as such the motorcycle has become arguably the most popular way of achieving this. A study was carried out by the 'Pew Research Centre' in 2014 on the distribution of vehicle ownership amongst the population between 44 countries. It found the following distribution amongst four developed countries compared to four in South East Asia, sorted by motorbike ownership:

Table 5) – Results of Vehicle Ownership Study

	Motorbikes (%)	Cars (%)	Bicycles (%)
Thailand	87	51	74
Vietnam	86	2	67
Indonesia	85	4	65
Malaysia	83	82	53
China	60	17	65
Italy	26	89	63
Germany	16	85	80
U.S.	14	88	53
U.K.	7	74	50

(Poushter, J. 2015)

Interestingly, we can see more than 4/5 of the South East Asian countries have a population that own a motorbike compared to the developed countries which peaks at just over 1/4 of their population. Looking at the distribution of car ownership, a staggeringly low 2% and 4% of the Vietnamese and Indonesian population own cars respectively. Where-as, predictably the four developed countries on the list have much higher distribution of car ownership.

An interesting perspective though is the perception that motorcycle ownership was negatively associated with income in these developing countries, to own a car living in these places is a luxury to be perceived as successful and established. Motorcycles are purchased out of necessity here and play a vital role in sustaining the local economy.

In developed countries like the four mentioned in table 5) it is interpreted as a hobby or recreational activity, and is more an example of available disposable income than a necessity to aid earning one. *(Misra, T. 2015)*

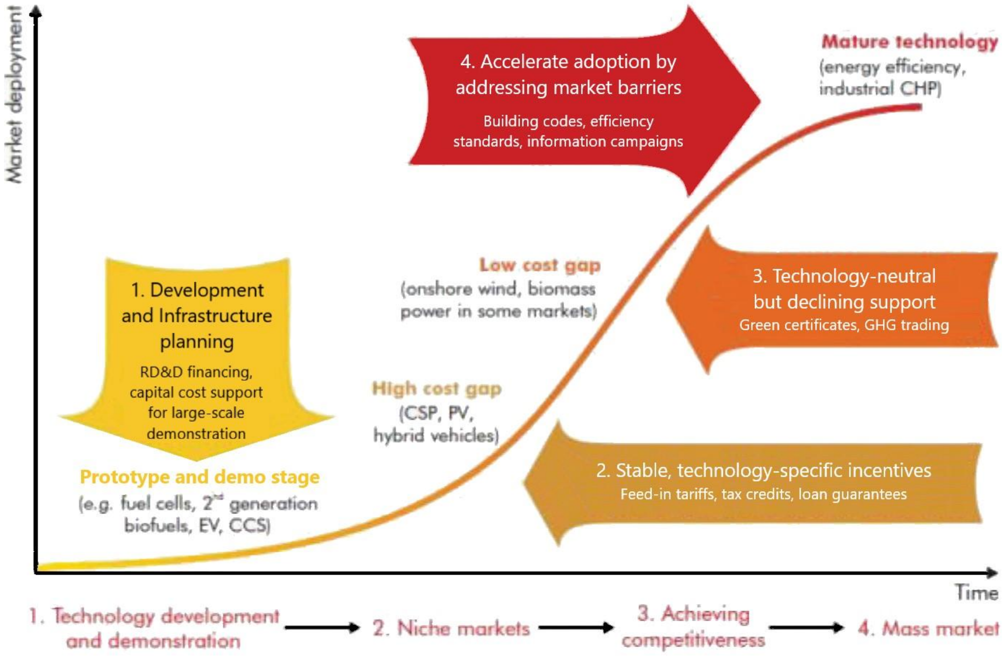
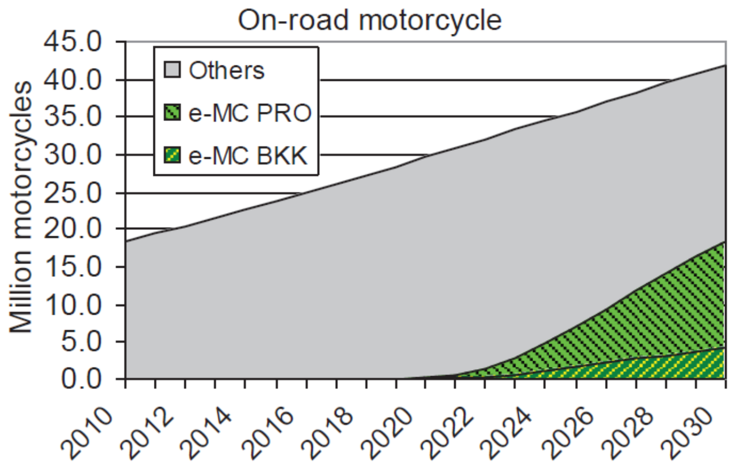


Figure 29) – S-Curve of Market Penetration

(Saisirirata, P. et al. 2013)

A study carried out in 2013 claimed that the sale share of EV-MCs will develop as the S-curve in figure 29) above. Although specifically referring to the development of vehicle electrification in Thailand, it can be applied to all countries currently undertaking the implementation. The 'high cost gap' is indicative of the niche market that EVs are currently available to, and this is reflected even in the most popular, not-so mass produced EV-MCs discussed in section 3.0. At present, in the U.K. we are at stage 2, the stable, technology-specific incentives stage. This can be substantiated by the introduction of 'The Faraday Challenge' in 2017 as discussed in section 2.1 and, the vehicle specific incentives offered by the government to purchase EVs. A survey distributed to 400 residents in Hanoi City in July 2008 determined that this method of incentivising the consumer has been proven to be the most effective way to initiate the uptake of EV-MCs, followed by the developing technology and rising fuel prices. *(Jones, L. R. et al. 2013)*



e-MC PRO:

EV-MC in Provincial Area

e-MC BBK:

EV-MC in Bangkok

Figure 30) – Sales trend for EV-MCs in Thailand

(Saisirirata, P. et al. 2013)

Further into the research it was predicted that EV-MCs will achieve an on-road figure of 18.5million by 2030, equivalent to 44% of total motorcycle registrations in the country. Compared to PHEV and BEV cars which is likely to achieve only 1.1million units, fewer than 6% of all electric capable vehicles.

4.2 Chinese Market

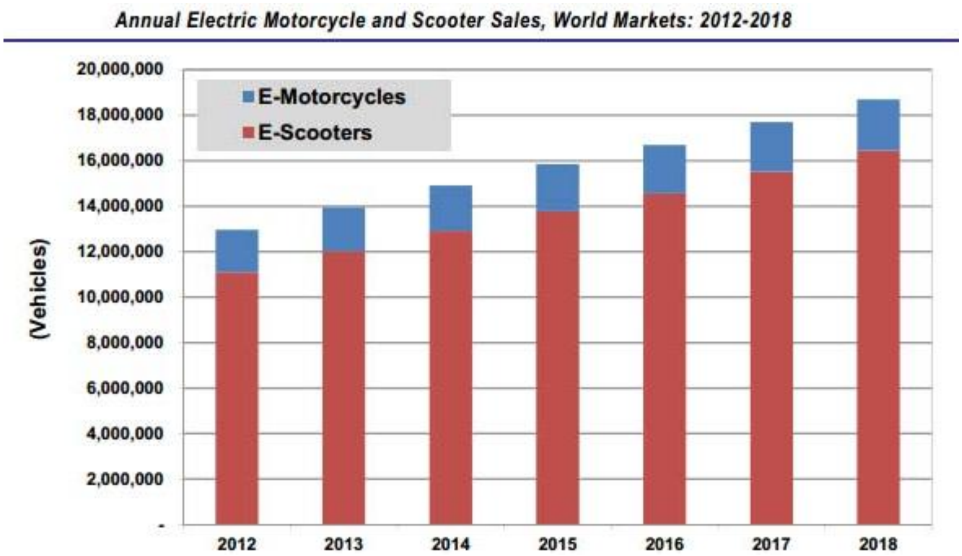


Figure 31) – Annual Fluctuation of Global EV-MC Sales

(Imreh, A. 2017)

Sourced from market research Company 'Pike Research / Navigant' This graph shows a marked increase in the sales of E-Scooters over the past 6 years compared to E-Motorcycles which increase at a fraction over the same period.

The reasons for this 5.2million unit jump in E-Scooter sales stems from the banning of all petrol motorcycles from 90 major Chinese cities, in an attempt to reduce pollution levels, congestion and improve safety. To fill the vacuum left from this ban, vague enforcement of electric bicycle and scooter standards, which are technically classed as 'non-motor' vehicles, saw an explosive growth. In 1998 sales reached 56,000, by 2008 that number exceeded 21million and from figure 31) that trend is set to continue. Chi-Jen Yang refers to this as 'policy accident rather than policy success.'

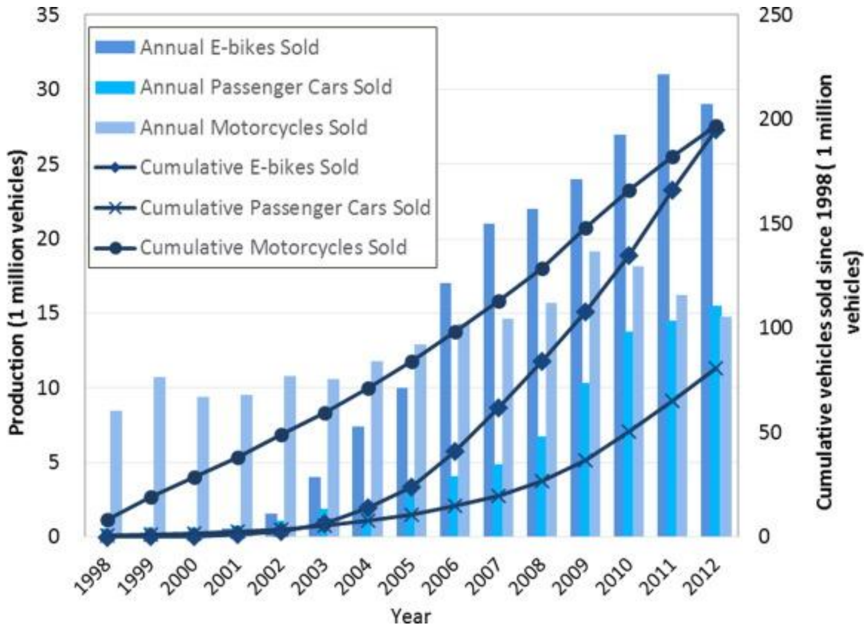


Figure 32) – Vehicle Production & Cumulative Sales Fluctuation for China

(Lin, Z. et al. 2015)

Figure 32) illustrates the scale of the problem with over an estimated 400million E-Bikes and Motorcycles in use today. This unprecedented situation serves as a focal point of research regarding the mismanaging of policy and consequently the managing of the products end of life disposal.

Assessing the global motorcycle market, it is expected that the Asia-Pacific region will continue to dominate representing 84% of all units sold in 2016. This is down to the region being home to the six largest motorcycle markets in the world, China, India, Indonesia, Thailand, Vietnam and Malaysia. By the end of 2017, it is expected that 132million motorbikes will be sold each year at an annual value of $120billion USD. From this we can deduce that the Asia-Pacific motorbike region is worth just shy of $101billion making all of the six major markets, prime candidates for an affordable EV-MC such as the Gogoro discussed earlier, particularly when accounting for the lower levels of income here. *(Kaiser, U. 2015)*

4.3 Global Market (Marketing Reports)

Sources dedicated to the sales of electric motorbikes are difficult to come by. When found they have often been commissioned by large corporate marketing companies carrying out global research, for this reason they are highly priced in the region of $2,500 to $4,500 USD for single user access. While this is a disadvantage and deprives this report of valuable data, the conclusions are freely available and provide an insight to their findings. A few are mentioned below and links to the articles can be found in the references:

Site: Technavio.com

Title: Global High-Performance Electric Motorcycle Market 2017-2021

SKU: IRTNTR14054

Price: $2,500

Summary: ‘Technavio’s *research analysis on the global high-performance electric motorcycle market identifies that the availability of such government subsidies and incentives will be one of the major factors that will have a positive impact on this market’s growth in the coming years. Our market research analysts predict that in terms of units, this market will grow at a CAGR of close to 42% by 2021.*

The development of long mile range motorcycles is one of the key trends that will gain traction in the high-performance electric motorcycle market. OEMs are constantly working on the introduction of battery technology to lower the mile range between the electric motorcycles and ICE-counterparts. One of the major vendors, Zero Motorcycles is working on the development of its battery technology to enhance the mile range of its motorcycles. With such advancements, the demand for high-performance electric motorcycle will increase in the coming years, fuelling market growth.

This market study estimates that in terms of geographic regions, Western Europe will be the major revenue contributor to the high-performance electric motorcycle market throughout the forecast period. The increasing adoption of electric motorcycles and the preference towards the usage of eco-friendly transport due to high demand from the governments and companies in the private sector, will drive the market’s growth in this region.’

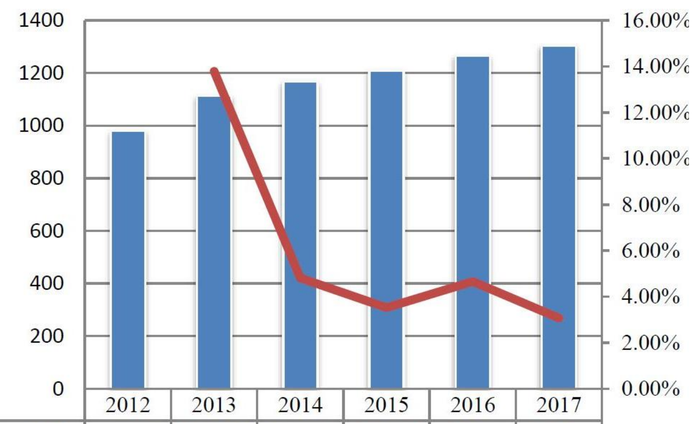
Site: MarketReportsWorld.com

Title: GLOBAL ELECTRIC MOTORCYCLE AND SCOOTER INDUSTRY PRODUCTION, SALES AND CONSUMPTION STATUS AND PROSPECTS PROFESSIONAL MARKET RESEARCH REPORT 2017-2022

SKU: HNY-

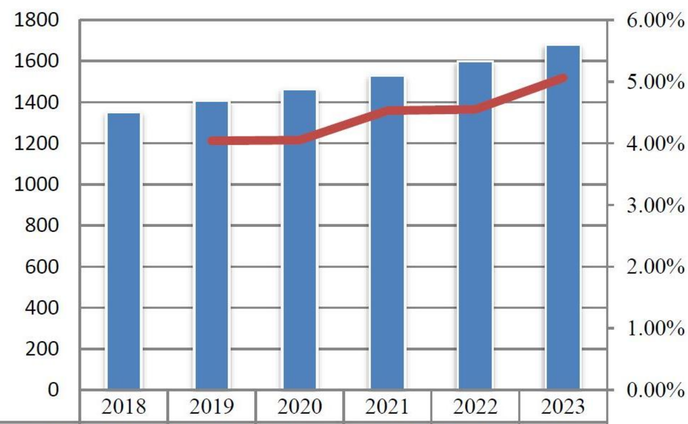
Price: $3,500

Discussion: Although the summary is omitted in this sample report, two figures that are of particular interest that have been freely made available are figures 33) and 34) that show the global revenue fluctuation and percentage increase over time.



	2012	2013	2014	2015	2016	2017
Revenue(Million USD)	980.03	1115.15	1168.81	1210.01	1266.4	1305.28
Revenue Growth Rate		13.79%	4.81%	3.52%	4.66%	3.07%

Figure 33) – Revenue Total and Growth Rate of EV-MC Sales 2012 – 2017



	2018	2019	2020	2021	2022	2023
Revenue(Million USD)	1351.64	1406.22	1463.21	1529.52	1599.13	1679.97
Revenue Growth Rate		4.04%	4.05%	4.53%	4.55%	5.06%

Figure 34) – Revenue Total and Growth Rate of EV-MC Sales 2018 – 2023

Figure 33) shows a sharp decline in growth rate during 2013 to 2014 where the economic recession of 2007-2013 was still affecting the industry. The primary observation here is the constant increase in global revenue from EV-MC sales and a future acceleration of this growth. The market is expected to grow by over 300million USD in the next five years. MarketReportsWorld gather data by conducting annual and quarterly deep interviews with major manufacturers. Government conferences and industry associations are all liaised with and information that is disclosed is then checked with various methods of secondary research.

Site: GlobalMarketInsights.com

Title: Electric Motorcycles & Scooters Market Size By Product (Motorcycles, Scooters), By Battery (SLA, Li-ion, NiMH), Industry Analysis Report, Regional Outlook (U.S., Canada, Germany, UK, France, China, India, Japan, Brazil, Mexico), Growth Potential, Price Trends, Competitive Market Share & Forecast, 2016 – 2024

SKU: GMI128

Price: $4,500

Summary: *‘Electric Motorcycles & Scooters Market size was valued at over USD 25 billion in 2015 and will grow at more than 10% CAGR estimation from 2016 to 2024. Global shipments are projected to surpass 60 million units by 2024. Favourable regulatory climate for pollution control and environment conservation will drive the electric motorcycles & scooters market share from 2016 to 2024. There exist stringent norms across the globe supporting clean energy to improve air quality and overcome dependence on crude oil, thereby reducing green-house gas emissions. Incentives and subsidies are provided to OEMs and customers in order to lower barriers in electric vehicle deployment. Rising adoption of these vehicles owing to benefits such as emission free mobility along with less maintenance as compared to gasoline vehicles will also boost the industry demand.*

Lack of infrastructure for battery charging along with deprived performance of EVs is expected to be a major barrier for the electric motorcycles & scooters industry size. High costs associated with these batteries along with performance restrictions and travelling range pose potential challenge for the suppliers.

Many manufacturers are adopting a combination of direct and indirect distribution channel in order to attract more customers and make distribution simpler. The OEMs are facing challenges of establishing strong distribution network and product customization as the industry is highly competitive, particularly in Asia Pacific. Thus, manufacturers are focusing towards building direct distribution channels through building various B2B customers and adopting e-commerce channels for electric motorcycles & scooter market sales.’

4.4 Statistical Analysis of GOV.uk & MCIA Data

Table 2) from section 2.0 can be used as a guide as to what EV-MCs are currently available to buy on the U.K. market as of 1st April 2018. Manufacturers highlighted in green will be the focus of the following two sub-sections.

Available in the U.K. (green) | Available for pre-order (blue) | Available abroad/importing (yellow)

Table 6) – EV-MC Availability

1. Aero – (Taking pre-orders for E-racer)	14. Lightning
2. Agility Motors	15. Lito
3. ALTA Motors	16. Mission
4. BMW	17. NXT – (Taking pre-orders for 'One')
5. Brutus	18. Peugeot
6. Bultaco	19. Sarolea
7. Energica	20. Super Soco
8. Gogoro	21. Torrot
9. Govecs	22. Vespa – (Taking pre-orders for Elettrica)
10. Harley Davidson – (Taking pre-orders for Livewire)	23. Victory (Acquired Brammo)
11. Johammer	24. VMoto
12. KTM	25. Voltron
13. Lacama – (Taking pre-orders Italian Volt)	26. Zero Motorcycles

4.4.1 – GOV.UK

The government website contains huge amounts of vehicular information dating as far back as 1994 and is all freely available to access. An excel spreadsheet of particular interest is:

VEH0120 – 'Licensed motor bikes, scooters and mopeds by make and model, Great Britain, annually from 1994, quarterly from 2008 Q3; also United Kingdom from 2014,'

Included in this spreadsheet was every single recorded motorbike registration in the country from 1994. It was not in any way arranged by electric propulsion therefore each EV-MC was searched for manually and data extracted to form figure 35) below. Data can be found in Item 1 in the Appendix.

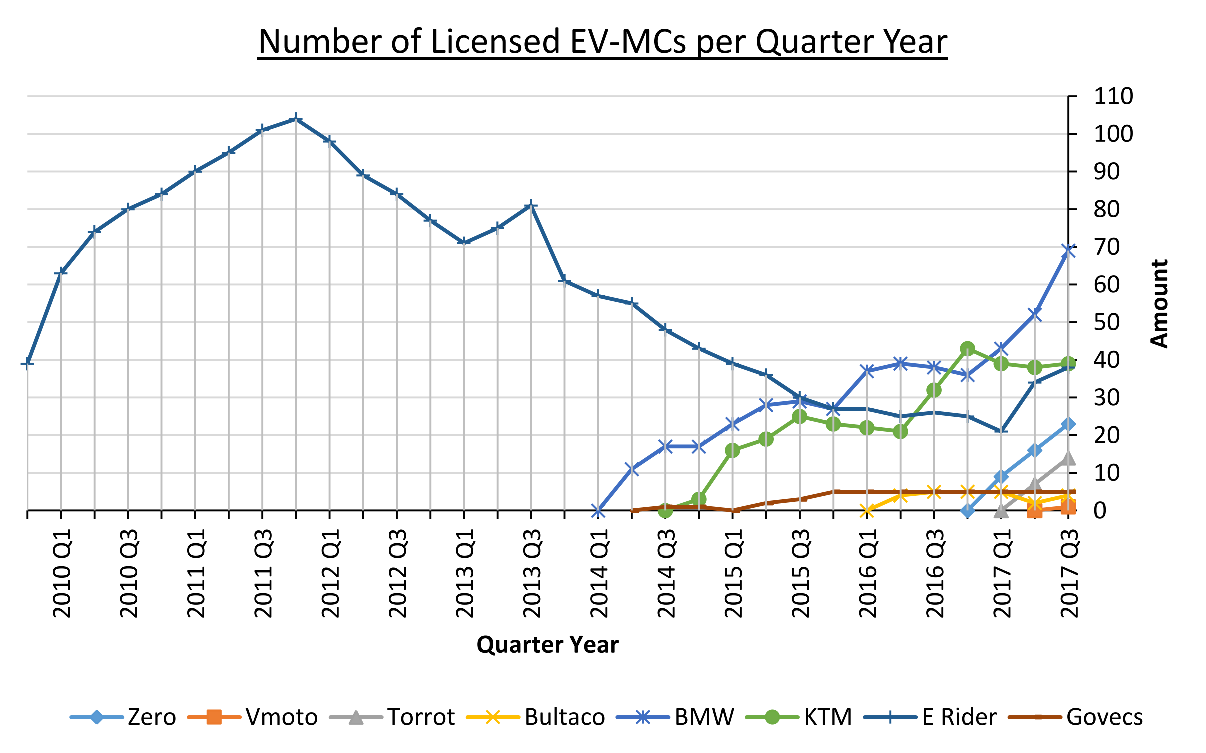


Figure 35) – Graph to show Number of Licensed EV-MCs per Quarter Year

This graph shows the fluctuation over the last eight years in numbers of registered EV-MCs on the road. These can be directly interpreted as purchases and as of quarter 3 2017, all manufacturers have experienced an increase in the number of purchases made. Generally, all have been steadily increasing in numbers since the beginning of 2014. Where numbers reduce is likely to be where the vehicle has been written off or SORN. The spike in sales of the E Rider in the third quarter of 2013 is likely to be down to when Zero released their first motorbike in the U.S., the Zero S that could have revitalised the market.

It was also the period where Mission released their Mission R and RS models in the U.S. too.

So far, the highest number of registrations is for BMW's C Evolution, discussed in section 2.3. A revised version of the popular scooter was unveiled at the start of 2017, implementing consumer feedback such as increasing the range by 37 miles from 62 to 99. This change meant an increase in continuous power output too from 15bhp to 25.5bhp, which places it in the higher A2 license band. The manufacturer offering a lower range, power & category scooter alongside the higher range, power & category version, increasing the size of the customer base, could explain this increase in registrations from 2017. Although these numbers are low, they represent an increasing demand and use of EV-MCs.

Another spreadsheet of particular interest is:

VEH0170 – 'Ultra-low emission vehicles (ULEV) registered for the first time, United Kingdom, quarterly from 2010 Q1'

The data includes all ULEV registrations since 2010. The Department for Transport defines an ULEV as those with significantly lower levels of tailpipe emissions than conventional vehicles; for the purpose of this graph, this includes all fully electric vehicles and vehicles with emissions below 75g/km. Data can be found in item 2 in the appendix.

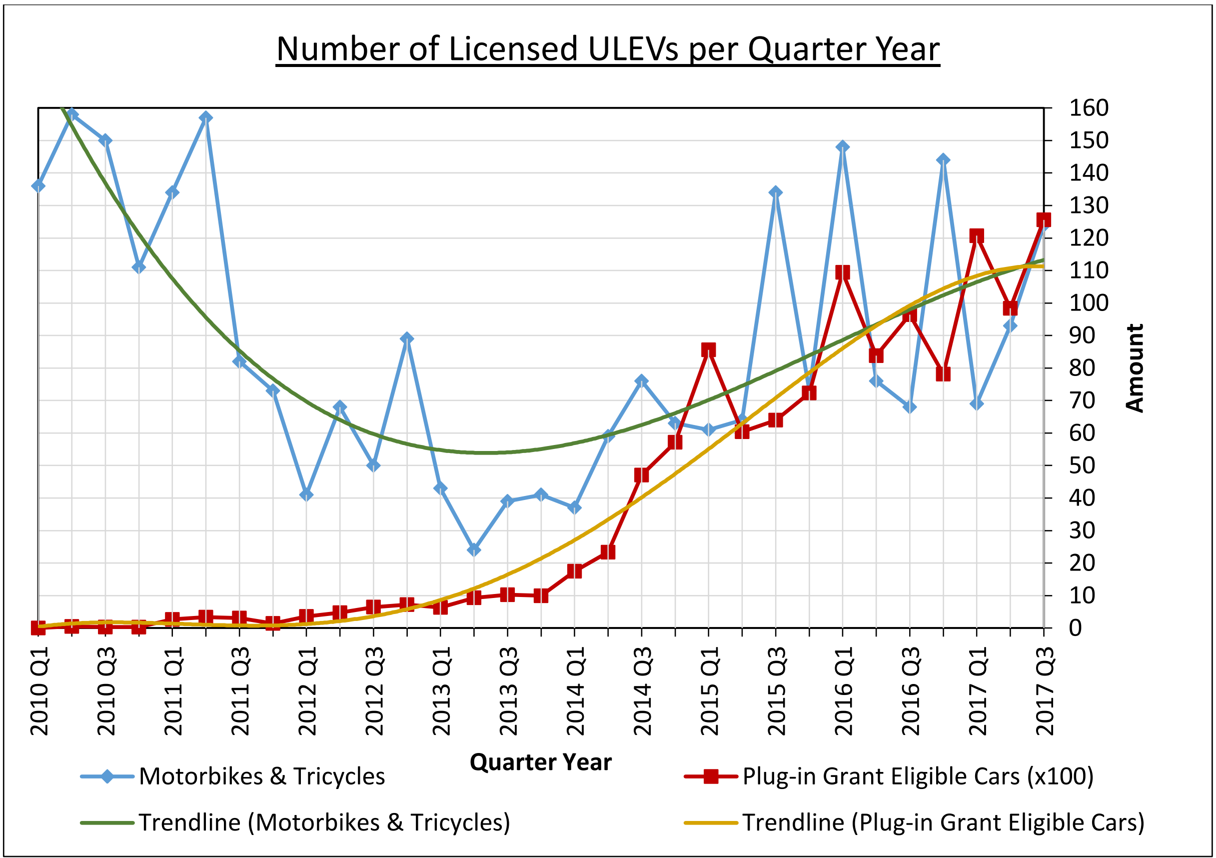


Figure 36) – Graph to show Number of Licensed ULEVs per Quarter Year

Although not dedicated to EV-MCs, it does display an increasing demand for all low emission motorbikes and tricycles since quarter 2 in 2013, also plug-in grant eligible cars. Some of the spikes in registrations coincide with Q1 & Q3; this could be down to the dates that new registration plates are released in the U.K., which is every March and September. This generally increases vehicle value and as such, there is increased numbers at these times of year. The decline from 2010 onwards is considered to be effects of the Great Recession which took place between 2007 and 2013, supported by figure 33) where there is a sharp drop in the revenue growth rate. As a result, this suppressed all electric car sales until economic recovery started to take place in 2014, evidenced by the climb in both sets of data from this point onwards. Although they were available, they had also only recently entered the market in 2010. Had there been no recession, I expect the number of registrations would have grown at a much higher rate for all ULEV vehicles.

4.4.2 – MCIA

The final set of available statistics to explore is that of the MCIA: *'The MCIA has been established for over 100 years and represents approximately 85% of the supply side of the industry; the manufacturers and importers of motorcycles, accessory and component suppliers and companies supplying associated services.'* (MCIA. 2018)

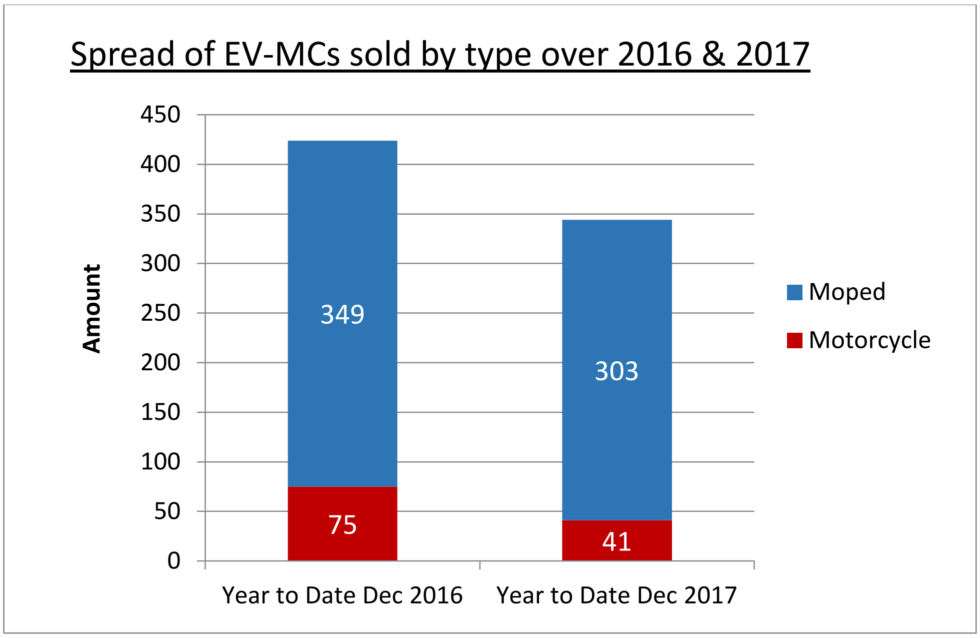


Figure 37) – Graph to show spread of EV-MCs sold by type over 2016 & 2017

The graph above shows a drop in overall sales of 80 units; whilst this is difficult to explain, it could be purely down to a lack of newly released models and reduced publicity.

It also illustrates more evidence to support the fact consumers are more likely to purchase a cheaper, more affordable electric moped as opposed to motorcycles. The data provided by the MCIA also exposed several other manufacturers producing small, compact and even one foldable electric moped, that have not been listed in table 2) or 6) such as:

Table 7) – Extra Electric Moped Manufacturers

1. Di Blasi	6. Juicy Bike	11. Rieju
2. Dayun	7. Kingday	12. Sunra
3. Ebladet Evo	8. Ligier	13. Xinri
4. EvoMotion	9. Lynx	14. Yadea
5. Goodyear	10. Quazzar	

Upon further investigation, it appears that some of these manufacturers are offering two versions of powered, two wheel forms of transport. One that does and one that does not abide by the EAPC restrictions outlined in the introduction (Maximum motor power of 250 watts, should not be able to propel the bike when travelling more than 15.5mph & must have pedals to offer propulsion). They are therefore technically categorised as mopeds and must be categorised as road legal machines requiring a license to ride, road tax (although completely exempt) and an MOT test. Although they do not embody the traditional styling associated with mopeds that most people are familiar with, such as the step through frame design akin to the BMW C-Evolution from section 2.3.

Figure 38) – Di Blasi R70 Folding Moped

(Di Blasi. 2018)

Figure 39) – Ebladet Evo ES17

(Evo Scooters. 2017)

The market is well catered for when it comes to affordable mopeds; even the Bultaco Brinco series bikes have pedals more akin to pedelecs but offer higher power versions that retain the pedals but are subject to normal EV-MC restrictions. This is the reason for the overwhelming majority of electric mopeds presented in figure 37).

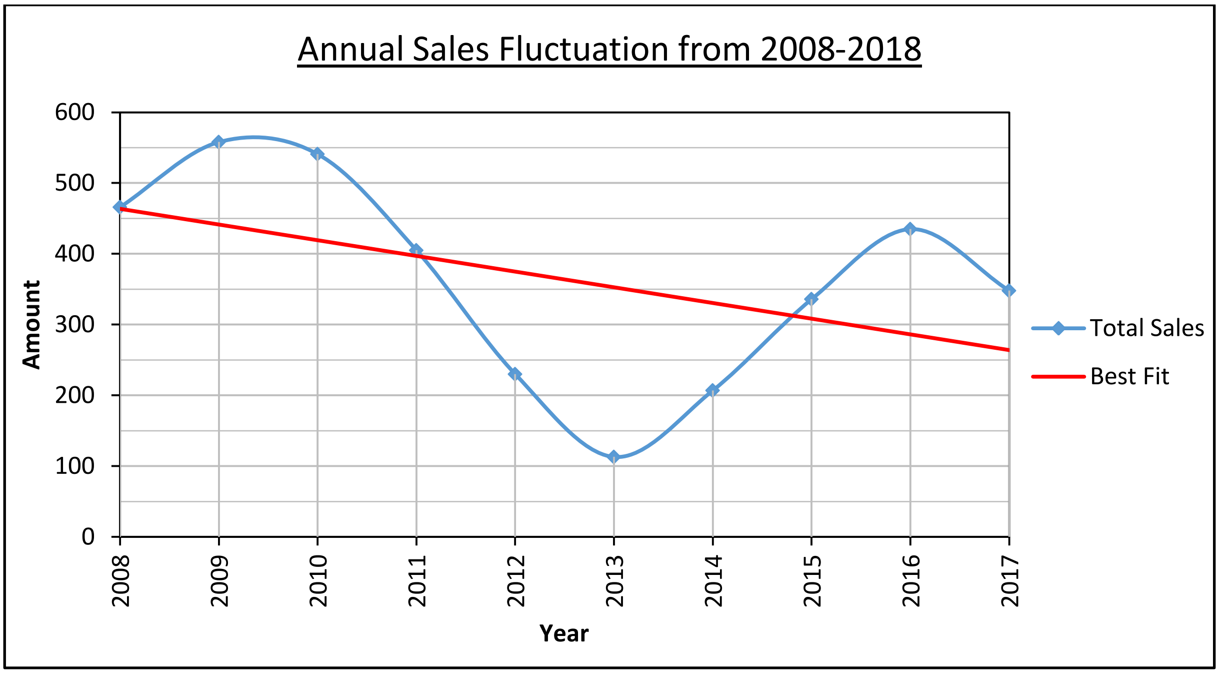


Figure 40) – Historical EV-MC Sales fluctuation from 2008-2018

Annual data was also provided which closely resembles the trend in motorcycle and tricycle ULEV data from figure 36) Contrary to predictions made earlier in the report the overall trend as seen from the best fit line during the last ten years is a distinct decline, more noticeably in 2017 where there was a decline of 87 sales from the previous year. This is an example of the market contracting slightly as the industry struggles to grow. Data for figures 37) and 40) can be found as items 3 and 4 respectively in the appendix.

5.0 Conclusion

5.1 Summary

Exploring the current market has identified an extensive list of companies that produce or are developing EV-MCs. By discussing the approaches of three developed manufacturers to their model line-up, it provides an insight to how well established they currently are, offering a variety of models and options to reduce charging time and/or increase range. This is indicative that range anxiety is very much recognised as a consumer concern that manufacturers are eager to relieve them of. The appeal of an electric motorbike is deemed the usability, reduced noise, low maintenance, running costs, rapid acceleration and uniqueness. Detrimental factors are range, high curb weight, limited third party support and high price, with the latter being the overriding factor even with a government incentive.

The study referred to by Jones, L. R. et al in section 4.1 indicates that tax incentives are the biggest contributing factor in the uptake of EV-MCs, followed by technological developments and increasing fuel prices. This is despite the fact the consumer would save extensively on fuel prices in the long term. Admittedly, while average household income is much lower in Vietnam, those very same factors apply in the U.K. too. While I believe the industry is still in its early stages of development, I expect the national and global EV-MC market to increase in size as supported by the marketing reports, Heather Brown, statistical associate at the MCIA, Ted Dillard and a variety of other experts. More specifically, and though they do not explicitly say, I expect it to increase in proportion to the 1 : 5 motorcycle to scooter ratio shown in figure 37)

This realisation that the increase would be largely down to electric scooters was unexpected, and provides credibility to the view of Martin Weiss outlined in the literature review, *'immediate market potential exists only for e-bikes; persisting price differentials and the absence of an obvious additional use value appear to present a barrier for the market penetration of mid-size and large electric two-wheelers.'* Out of the eight manufacturers in figure 33) the five scooter manufacturers account for the majority of the current EV-MC market and appear to be growing more rapidly than the three motorbike manufacturers. The decision by BMW Motorrad to put the C-Evolution to market in 2014 is telling of that situation. Recognising the increasing popularity for clean, urban mobility, the wealth of resources available to them has positioned the C–Evolution as the single most popular and fastest growing EV-MC in the U.K. Compared to electric motorcycles, increased affordability, manoeuvrability and popularity of electric scooters present themselves as the consumers current EV-MC of choice. This conveniently proves more effective from a political perspective in reducing carbon dioxide levels in built up urban areas, as opposed to the larger, higher powered electric motorcycles that do not commute through these areas. The product is well catered for too, with dozens of independent producers offering their own take on road legal electric two wheelers, highlighted by the MCIA data in table 7)

The failure of Vectrix to continue development of the VX-1 and touted superbike is due to quality control issues which affected dealership relationships, I believe this is because the VX-1 was introduced to the market too early. There was a lack of enthusiasm for such a concept during the early 2000's which meant that, regarding the low purchases that were made, any bad customer experiences would prove to be much more damaging than usual in terms of instilling consumer confidence in the technology. Using the rising popularity of the EV car, the EV-MC market, whilst 100 times smaller, has grown proportionally while simultaneously matching demand capacity. The key was to enter the market during 2013 just as the recession subsided, this was the year that all EV sales nationally began to see increased demand. From this point on, of what little market there was, became too fierce to allow room for any more competition. Signified by the instability of scooter manufacturer sales in figure 35). For the electric motorcycle, there simply is not enough demand with only 41 purchases made in 2017. Supported by the attempts of Vigo during the same year, coupled by the unrealistic performance statistics and lack of project funding quickly led to the projects demise. From the launch of the crowd funding campaign to the projects suspension lasted little over 11 months. This leads to the conclusion that in future I do not expect any new manufacturers to enter the market unless major producers such as Honda, Suzuki, Ducati & Triumph etc. decide the time is right to produce one of their own. This could prove to be within the next two to three years based on several factors. The proposed completion date of the Tesla Giga-Factory in 2020, which will lead to huge reductions in battery costs due to the manufacturing in economies of scale, the news in December 2017 that Yamaha is investing in EV-MC production capability and the release of Harley Davidson's livewire project in 2019. This will have a domino effect on others to follow suit. CEO of Energica Livia Cevolini reportedly said that major manufacturers need sales in the tens of thousands region to justify the costs of mass production and release, which is why in their first year of business she predicted sales in the region of only 500. With the CRP Group backing their production, it would prove easy for Energica to meet unexpected demand. It is in the interest of these major manufacturers to let the market mature more before entering into development and production and based on the findings in this report, I agree.

The developing technology of the industry is paramount to earlier success; part of the objectives was to establish how far behind the electric car that EV-MCs are lagging and to see if there was any delay in implementation of hardware/software from one to the other.

This was a miss-informed assumption based on their comparatively low popularity and upon exploring relevant research, it appears that there is no delay; in fact, the two forms of transport run concurrently in terms of development. Motor and battery development theory is universal to both vehicle types, the two components are interchangeable between vehicle types particularly considering the size of electric motors and that battery packs can be reduced down to modules. Much more so than the parity of components between ICE vehicles and therefore EV-MCs should endure a much more rapid development in drive train technology synonymous with that of EV cars in the future. Consequently, any benefits on performance will prove considerably more effective on EV-MCs due to their inherently lower weight and size difference.

The National charging infrastructure is well established due to the EV car, which is currently 100 times more prevalent than EV-MCs. This acts as a constant enabler for any potential EV-MC customer. With on average one charge location every 21.79mi^2 including Republic of Ireland, the main issue here is the amount of time spent using them. Charge points effectively become car parks while the owner tends to their business, being unlikely that they return at full charge this limits the amount of users that can access them. Fast charger capability serves to improve the delivery of charge but not the availability; the infrastructure will therefore continue to be a disruptive influence on the usability in the future.

Feasibility – 'The state or degree of being easily or conveniently done.'

The purpose of this report was to explore the feasibility of the electric motorcycle by looking into three main areas of the product. By its very nature, trying to electrify the transport industry is a nearly incomprehensible task but substantial investment and political influence has dictated this new direction. By attempting to apply the above definition to EV-MCs the feasibility can be said to be challenging at best, but inevitable.

The progressive uptake will be slow, particularly for motorcycles while more affordable scooters and mopeds will continue to dominate this area in the immediate future.

5.2 Recommendations for Future Study

Future work endeavours to explore the developments made in Battery Management Systems and Motor Controllers and the benefits they could bring to the current EV climate. As well as a more detailed study of the promising new advancements made regarding Li-S battery technology. Fuel cell motorcycles also present a solution to the same problem (i.e. climate change) and should be incorporated in future study considering the zero emissions capability of the incorporated power train. Conducting Primary Research in the form of an unstructured approach to a questionnaire to explore the nature of the market from the consumer's perspective could prove beneficial in uncovering issues that have not been raised in this report. Quantifying those reasons by commonality and associating a priority level to the most frequent would provide an insight to this too.

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8.0 Appendix

Item 1) *Table VEH0120 - Licensed motor bikes, scooters and mopeds by make and model, Great Britain, annually from 1994, quarterly from 2008 Q3; also United Kingdom from 2014 Q4*

Make	Model	17 Q3	17 Q2	17 Q1	16 Q4	16 Q3	16 Q2	16 Q1	15 Q4	15 Q3	15 Q2	15 Q1	14 Q4	14 Q3	14 Q2	14 Q1	13 Q4
Zero	DS ZF13.0	1	1	1													
Zero	DSR ZF13.0	7	4	3													
Zero	DSR ZF13.0 MY 16	1	1														
Zero	FX ZF5.7 MY 15	1	1	1													
Zero	FX ZF6.5 MY 17	1	1														
Zero	FXS ZF6.5	2	2	1													
Zero	FXS ZF6.5 MY 17	3	2														
Zero	SR ZF12.5	1	1	1													
Zero	SR ZF13.0	6	3	2													
VMOTO	SOCO TS 1200 R	1															
Torrot	MUVI	12	5														
Torrot	MUVI CITY	2	2														
Bultaco	BRINCO C	1	1	2	2	2	1										
Bultaco	BRINCO RE	3	1	2	2	2	2										
Bultaco	BRINCO S			1	1	1	1										
BMW	C EVOLUTION	69	52	43	36	38	39	37	27	29	28	23	17	17	11		
KTM	FREERIDE E SM 15	1	1	2	2	1	1	1	1	2							
KTM	FREERIDE E SM 16	4	4	5	5	2	2	2	1	1							
KTM	FREERIDE E XC 15	26	27	25	27	22	12	13	16	19	19	16	3				
KTM	FREERIDE E XC 16	5	6	7	9	7	6	6	5	3							

KTM	FREERIDE E XC 17	3															
Erider	B2000	25	19	5	5	5	5	6	6	7	8	7	10	10	13	14	17
Erider	B3000	4	3	1	1	2	2	2	3	5	5	7	8	11	11	10	12
Erider	Missing	1	4	4	4	4	4	4	4	4	3	3	1	1	3	3	2
Erider	T4000 W88 KMH	8	8	11	14	15	14	15	14	14	20	21	23	25	27	29	28
Erider	THUNDER				1							1	1	1	1	1	2
GOVECS	2E S1.4	1	1	1	1	1	1	1	1	1	1	0					
GOVECS	4E S2.4+	1	1	1	1	1	1	1	1	1							
GOVECS	4E S3.4	1	1	1	1	1	1	1	1	1	1		1	1			
GOVECS	TE T2.4+	1	1	1	1	1	1	1	1								
GOVECS	TE T3.4	1	1	1	1	1	1	1	1								
	Make																
Total	Zero	23	16	9	0												
Total	Vmoto	1	0														
Total	Torrot	14	7	0													
Total	Bultaco	4	2	5	5	5	4	0									
Total	BMW	69	52	43	36	38	39	37	27	29	28	23	17	17	11	0	
Total	KTM	39	38	39	43	32	21	22	23	25	19	16	3	0			
Total	Erider	38	34	21	25	26	25	27	27	30	36	39	43	48	55	57	61
Total	Govecs	5	5	5	5	5	5	5	5	3	2	0	1	1	0		

Continuation of data for Erider from 13 Q3 to 09 Q4

Make	**Model**	**13 Q3**	**13 Q2**	**13 Q1**	**12 Q4**	**12 Q3**	**12 Q2**	**12 Q1**	**11 Q4**	**11 Q3**	**11 Q2**	**11 Q1**	**10 Q4**	**10 Q3**	**10 Q2**	**10 Q1**	**09 Q4**
Erider	B2000	22	20	21	22	23	25	28	26	26	23	20	18	16	16	12	6
Erider	B3000	18	17	16	19	23	24	24	30	30	29	28	28	28	27	27	13
Erider	Missing	4	3	3	3	3	4	5	6	6	6	6	6	5	3	2	1
Erider	T4000 W88 KMH	35	33	29	31	33	34	39	40	37	35	34	29	28	25	19	18
Erider	THUNDER	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	1
	Make																
Total	Erider	81	75	71	77	84	89	98	104	101	95	90	84	80	74	63	39

Item 2) *Table VEH0170 - Ultra-low emission vehicles (ULEV) registered for the first time, United Kingdom, quarterly from 2010 Q1*

Year	Quarter	Plug-in-Grant Eligible Cars	Plug-in-Grant Eligible Cars / 100	Motor cycles & tricycles
2010	Q1	2	0.02	136
2010	Q2	49	0.49	158
2010	Q3	31	0.31	150
2010	Q4	29	0.29	111
2011	Q1	265	2.65	134
2011	Q2	335	3.35	157
2011	Q3	308	3.08	82
2011	Q4	143	1.43	73
2012	Q1	358	3.58	41
2012	Q2	473	4.73	68
2012	Q3	647	6.47	50
2012	Q4	721	7.21	89
2013	Q1	635	6.35	43
2013	Q2	932	9.32	24
2013	Q3	1025	10.25	39
2013	Q4	993	9.93	41
2014	Q1	1748	17.48	37
2014	Q2	2334	23.34	59
2014	Q3	4707	47.07	76
2014	Q4	5716	57.16	63
2015	Q1	8561	85.61	61
2015	Q2	6040	60.4	64
2015	Q3	6397	63.97	134
2015	Q4	7233	72.33	73
2016	Q1	10945	109.45	148
2016	Q2	8380	83.8	76
2016	Q3	9642	96.42	68
2016	Q4	7813	78.13	144
2017	Q1	12070	120.7	69
2017	Q2	9837	98.37	93
2017	Q3	12561	125.61	124

Item 3) *U.K. MCIA EV-MC Make and Model Data*

Make	Model Series	Vehicle Type	Dec 2017	Dec 2016
Artisan	EV	MOPED	24	13
Bultaco	BRINCO C	MOPED	0	2
Bultaco	BRINCO RE	MOPED	2	2
Bultaco	BRINCO S	MOPED	0	1
Di Blasi	R70	MOPED	0	4
Ebladet Evo	ES17	MOPED	4	9
E-Max	80 L	MOPED	1	0
Erider	B2000	MOPED	32	1
Erider	MOPED UNSPEC ELECTRIC SCOOTER	MOPED	2	0
EvoMotion	XR-EM36	MOPED	12	10
EvoMotion	XR-EM44	MOPED	0	2
Goodyear	EGO 2	MOPED	4	0
Juicy Bike	RETRO Li	MOPED	1	0
Kingday	DORA 1200	MOPED	41	4
Kingday	FERRA 5000	MOPED	5	2
Ligier	PULSE 3	MOPED	1	0
Lynx	ZQTD-389	MOPED	0	1
Quazzar	E-DIVINE	MOPED	0	101
Rieju	MIUS 2.0	MOPED	0	1
Sunra	HAWK	MOPED	2	0
Torrot	MUVI CITY	MOPED	2	0
Unspecified	UNSPEC CYCLE	MOPED	15	2
Unspecified Chinese / Asian	MOPED UNSPEC	MOPED	6	2
Unspecified Chinese / Asian	MOPED UNSPEC SCOOTER	MOPED	16	13
Unspecified Other	MOPED UNSPEC	MOPED	3	3
Unspecified Other	MOPED UNSPEC SCOOTER	MOPED	14	8
Vmoto	80 L	MOPED	3	6
Vmoto	MOPED UNSPEC	MOPED	1	0
Vmoto	SOCO TS 1200 R	MOPED	16	0
Xinri	MOPED UNSPEC SCOOTER	MOPED	3	0
Xinri	XR-EM07	MOPED	1	0
Yadea	Z3 MERLIN	MOPED	2	0
Yamaha	ED06 EC-03	MOPED	4	7
Yinhua	TDR 038Z-97	MOPED	0	1
BMW	C EVOLUTION	MOPED	0	11
BMW	C EVOLUTION PLUS	MOPED	38	0
Dayun	DYTDR 605 Z	MOPED	0	28

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Make	Model Series	Vehicle Type	Dec 2017	Dec 2016
E-Max	110 S	MOPED	0	1
E-Max	120 L	MOPED	1	0
Scutum	S02	MOPED	9	106
Torrot	MUVI	MOPED	21	0
Unspecified Chinese / Asian	M/C UNSPEC SCOOTER	MOPED	9	0
Unspecified Other	M/C UNSPEC SCOOTER	MOPED	0	1
Vectrix	VX-1	MOPED	0	2
Vmoto	120 L	MOPED	3	3
Vmoto	120 LD PLUS	MOPED	2	0
Vmoto	120 L PLUS	MOPED	3	2
Electric Motion	EM 5.7	MOTORCYCLE	5	8
Energica	M/C UNSPEC	MOTORCYCLE	1	3
KTM	FREERIDE E SM	MOTORCYCLE	0	5
KTM	FREERIDE E XC	MOTORCYCLE	11	31
Unspecified Chinese / Asian	M/C UNSPEC	MOTORCYCLE	2	1
Unspecified Other	M/C UNSPEC TRAIL/ENDURO	MOTORCYCLE	1	2
Yamakoyo	YM 2000 DT-02	MOTORCYCLE	1	0
Zero	DSP ZF11.4	MOTORCYCLE	0	7
Zero	DSR ZF13.0	MOTORCYCLE	11	6
Zero	DS ZF13.0	MOTORCYCLE	1	0
Zero	FXS ZF6.5	MOTORCYCLE	3	4
Zero	FX ZF6.5 MY 17	MOTORCYCLE	2	0
Zero	M/C UNSPEC	MOTORCYCLE	0	5
Zero	SR ZF12.5	MOTORCYCLE	0	2
Zero	SR ZF13.0	MOTORCYCLE	3	1
		Total	344	493
		Total Moped	303	349
		Total Motorcycle	41	75

Item 4) *U.K. MCIA Total Annual EV-MC Sales*

2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
466	558	541	405	230	113	207	336	435	348