2015

The Impact of Motorcycles on Air Quality and Climate Change: a Study on the Potential of Two-Wheeled Electric Vehicles

Chad Redman
Claremont McKenna College

CLAREMEONT MCKENNA COLLEGE

The Impact of Motorcycles on Air Quality and Climate Change: a Study on the Potential of Two-Wheeled Electric Vehicles

SUBMITTED TO

Professor Emil Morhardt

AND

DEAN NICHOLAS WARNER

BY

Chad Redman

for

SENIOR THESIS

Spring 2015
April 27

TABLE OF CONTENTS

Acknowledgements

I would like to take this opportunity to express my extreme gratitude to Professor Emil Morhardt for his guidance toward the completion of this senior thesis. His support has enhanced my college career from the very start, and has not wavered over the past four years. Furthermore, I would like to thank my friends and family for their continual moral encouragement as I composed this paper. Finally, to all the Claremont McKenna College staff and faculty, I thank you for all your effort within the CMC community.

Abstract

The auto industry produces a significant amount of air pollution the world over, and thereby contributes to climate change. As a major component within the auto industry, the motorcycle industry has a great responsibility to minimize its emissions. This study examines powered two wheelers (PTWs) in the European Union to assess the impact made by the motorcycle industry, and the potential for improvement. Reduction of air pollution would be possible by intensifying emissions regulations, which are much less stringent for PTWs than for light-duty vehicles such as passenger cars. However, a more comprehensive strategy to limit the motorcycle industry's air pollution lies in the deployment of electric PTWs. The state of electric PTWs is not yet advanced enough to replace internal combustion motorcycles and mopeds, but they have achieved performance levels that demonstrates electric technology will soon make a significant impact on the motorcycle industry. Upon concluding that electric PTWs are viable and may soon become widely used, this study develops a framework to model the total air pollution created by the motorcycle industry, accounting for varying levels of electric PTW deployment.

Introduction

Proliferating automobile use and accelerating global climate change are inextricably linked phenomenon (Uherek *el al.*). The reason for this, simply stated, is that the current automotive industry is one of the main drivers of global climate change (Unger *et al.*). One highly visible piece of evidence demonstrating the damage done by automobiles is urban air pollution, costing the United States $53 billion dollars each year in damages (Mashayekh *et al.*). The evidence for a connection between vehicular emissions and climate change is so strong that even automotive manufacturers expend significant time and effort attempting to mitigate their impact. In particular, research and development on emissions control technology has been prioritized in recent design efforts (Kolk and Levy, 171-193). Public policy in the United States and around the globe indicates that lawmakers take seriously the effects on climate of the automotive industry; perhaps nowhere better exemplifies this political recognition than in the state of California, where emissions regulations and low-emission vehicle subsidies have led the United States (EPA.gov). In addition to a $7,500 federal tax credit for the purchase of an electric vehicle, California offers up to a $2,500 tax credit, along with use of HOV lanes and other supporting policies (EnergyCenter.org).

While the automotive industry is a broad and diverse group composed of many different types of machines, it can be coarsely organized into categories such as heavy-duty vehicles, light-duty vehicles, and powered two wheelers (PTWs). Heavy-duty vehicles include the trucks that transport goods on and off road all around the world; most of these vehicles are commercially owned and operated. Heavy-duty vehicles are typically subject to different regulations than common cars and other light-duty vehicles

(Uherek *et al.*). They are often powered by diesel engines, which exhibit unique emissions characteristics (Uherek *et al.*). Based on these parameters, heavy-duty vehicles represent a classification of machine with high potential for reducing the automotive industry's contribution to air pollution (Uherek *et al.*). However, the emissions from heavy-duty vehicles tend to be diffuse, as these machines are used to cover long distances and are likely to avoid densely packed urban areas.

Light-duty vehicles are the most familiar sight on the road here in the United States. These cars, vans, pickups, and SUVs are primarily purchased for personal transportation, and are subject to highly standardized and stringent emissions controls. As a result of existing regulations pertaining to light-duty vehicles, enhancing the fuel efficiency and reducing emissions from these machines is relatively challenging, especially in relation to other types of vehicles within the automotive industry (TransportPolicy.net). Instead, focusing on reducing the number of light-duty vehicles on the road may be the most efficient course of action to alleviate environmental pressures created by this category of machine. Reduction in light-duty vehicle numbers can be accomplished in several ways, common methods including the creation of high occupancy vehicle lanes and public transportation lines.

PTWs, or generally motorized vehicles with two or three wheels, represent an interesting section of the automotive industry. Although in the United States PTWs do not come close to matching the prevalence of light-duty vehicles, one visit to several of the major cities in Europe and Asia makes it clear that PTWs are hugely important to the global automotive industry. For instance, several Asian countries such as Thailand are home to millions of registered PTWs, most falling into the moped category and used primarily for short-distance urban travel. In Thailand, well over half of all registered vehicles are PTWs, nearly 20 million vehicles in total (AJTPweb.org). Similarly, in Italy, there are 8.6 million PTWs on the road, 2.2 million of those being mopeds expressly designed for limited range urban use (U.S. Commercial Service). While PTWs are an important factor in the automotive industry, they are relatively lightly regulated. This implies that a significant source of air pollution is relatively under-attended by public policy. For example, the European Union regulates several exhaust constituents to a lesser degree in PTW emissions compared to light-duty vehicle emissions. Current standards in the EU for light-duty vehicles and PTWs can be found in Table 1 (TransportPolicy.net). Given the relaxed nature of PTW emissions standards in major regions like the EU, there is ample room for improvement on this portion of the automotive industry; PTWs are a low hanging fruit for any effort to reduce air pollution, particularly in densely populated urban areas. Fortunately, one solution which has seen limited implementation in other areas due to inherent shortcomings has great potential for a PTW platform – electric drivetrains.

In the interest of reducing the environmental impact of the transportation industry, this paper assesses the prospect of introducing electric PTWs into dense urban areas where PTW use is historically prolific. Specifically, areas of study will be located in the European Union due to the availability of reliable and abundant data, the existence of heavy PTW use, and clear public policy regarding emissions. Preliminary information will be provided on the motorcycle industry at large, followed by a look into the performance characteristics of internal combustion PTWs. The subsequent section of the paper will consider whether an electric PTW platform is a viable solution for the needs of individuals who rely on internal combustion PTWs in their daily lives. Concluding discussion will propose a model for calculating the effects of transitioning to electric PTWs, focusing on air pollution and several related factors.

Light-Duty Vehicle, Motorcycle, and Moped Emissions Regulations in the European Union					
Vehicle Category	Carbon Monoxide	Hydrocarbon	Nitrogen Oxides	Particulate Matter	Particle Number
Light-Duty Vehicle	1.00	0.10	0.06	0.005	6.00E+11
Motorcycle	1.14	0.38	0.07	N/A	N/A
Moped	1.00	0.63	0.17	N/A	N/A

Table 1 This table displays the emission controls on light-duty vehicles and two classes of PTW, motorcycles and mopeds (TransportPolicy.net). Mopeds are defined as having a designed speed of less than 45 km/h and a cylinder capacity of no more than 50 cubic centimeters. Standard motorcycles exceed one or both of these parameters. Each of the pollutants included in the chart are measured as components of the exhaust from road-going vehicles.

Understanding the Motorcycle Industry

Studying the global motorcycle industry presents a daunting challenge. The industry is complex and widespread, making it difficult to construct valid, sweeping conclusions. As such, this paper focuses on a particular section of the global motorcycle industry – the European Union. In many ways, the EU is a convenient sample to examine within the motorcycle industry; it includes several countries with significant and long standing powered two wheeler populations, large scale production, detailed and standardized emissions regulations, and reliable and extensive data regarding the local motorcycle industry. The high level of PTW use within dense EU urban areas is especially useful.

The motorcycle industry within the European Union is well documented. All member countries included, there are about 33 million registered PTWs in the EU (U.S. Commercial Service). The largest PTW users are Italy, Germany, Spain, and France, totaling almost 20 million registered motorcycles as a collective (U.S. Commercial Service). A large portion of the 33 million total PTWs on the road in the EU belong to the moped classification, approximately 11 million in total (U.S. Commercial Service).

Growth patterns are essential for painting a full picture of the motorcycle industry in the European Union. Knowing the total number of registered PTWs in the EU means little without understanding how that total has changed over time. The most recent data on PTW registrations reports almost 1.1 million newly registered motorcycles and mopeds in 2014 (EAMM). France, Italy, and Germany issued the highest numbers of new registrations, accounting for over half of the 1.1 million total (EAMM). Though Europe is home to a significantly large PTW population, its growth rate has fallen dramatically from previous years. For context, the year 2007 witnessed a peek in EU PTW registrations, with over 2.4 million PTWs added to the road (EAMM). While the EU motorcycle industry has seen an enormous 55% decline in annual registrations since 2007, there is evidence that the situation has stabilized; for the first time in seven years, consistency was achieved on a year to year basis. Between 2013 and 2014, very little change occurred in the total number of PTW registrations. Figure 1 and Figure 2 display detailed data on PTW registrations by country, along with historical EU-wide data (EAMM).

Reviewing the number of registered PTWs in the European Union is useful, but other metrics can also build an understanding the motorcycle industry. Registration information primarily indicates how prolific PTW use is among consumers, and the trends that they follow. Producers have another important perspective on the landscape of the EU motorcycle industry, and their behavior may be an indication of how the motorcycle industry performs as an economic entity.

In total, the motorcycle industry contributes around 35 billion USD to the EU annually (EAMM). Unsurprisingly, the EU motorcycle market is dominated by suppliers from Italy, Germany, Spain, and France. Italy, in particular, is the largest producer of PTWs in the EU; during 2011, Italy produced 414 thousand PTWs, over half of total EU output (U.S. Commercial Service). Major brands like Ducati, BMW, KTM, Piaggio, and several more are a result of EU production, and demand for these products in the global motorcycle market makes the motorcycle industry an important economic factor within the EU. Unfortunately, sales within the EU have followed the trend of new registrations closely, falling dramatically in recent years. For example, Italian sales fell by 29% going into 2011, with market revenue declining below 4 billion USD (Euromonitor.com). Counteracting this downsize in the domestic Italian PTW market was an increase in foreign demand, helping to support Italian producers while economic turmoil diminished sales at home (Euromonitor.com). In short, the market for new motorcycles and mopeds throughout the EU has suffered in the years following the Great Recession, with domestic producers turning largely to exports for financial support; only recently have sales ceased to fall in member countries.

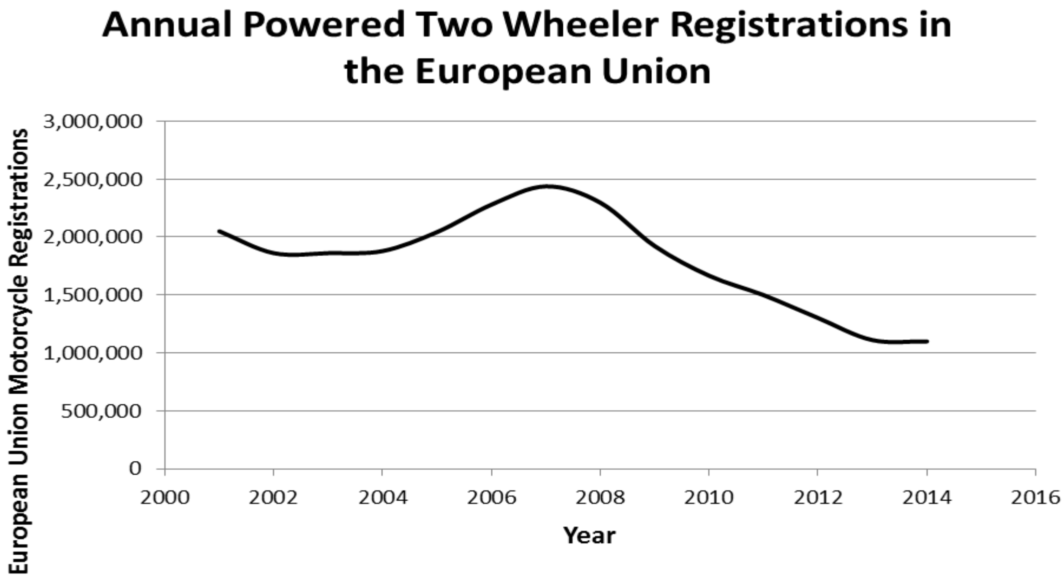

Figure 1 This trend shows annual PTW registrations in the EU from 2001 to 2014 (EAMM). Important features include the sharp decline from 2007 to 2013, as well as the renewed stability from 2013 to 2014.

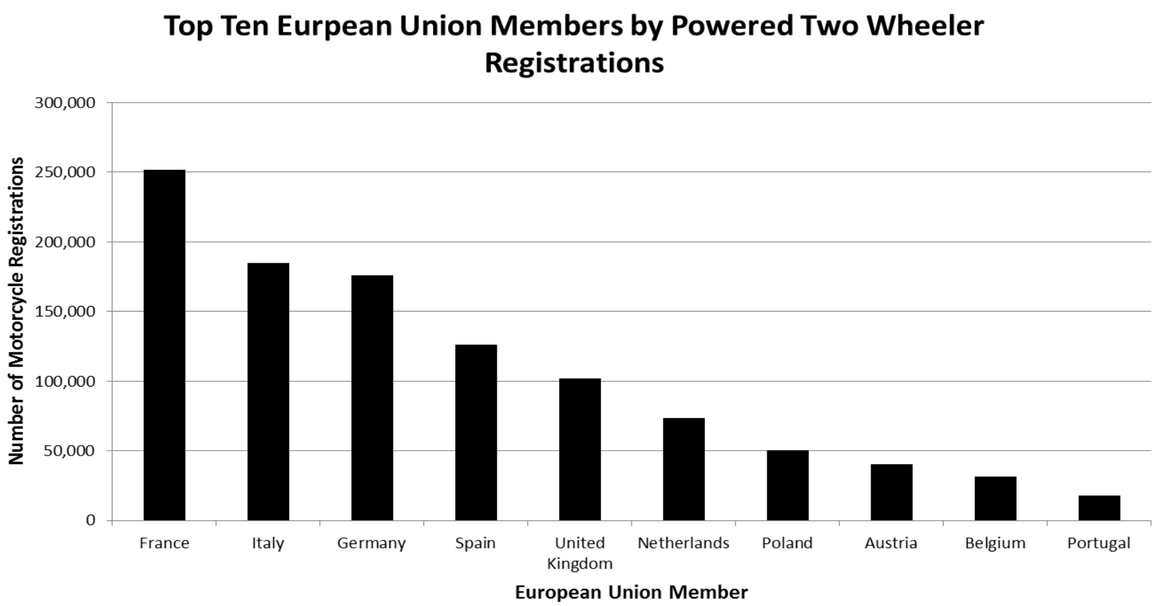

Figure 2 Above are the ten top countries in the EU for PTW registrations in 2014 (EAMM). These registrations include both mopeds and motorcycles. Interestingly, the top four countries are also the top four producers of European motorcycles.

Characteristics of Street Powered Two Wheelers and the Regulations Which Govern them

The purpose of this study is to examine how motorcycles contribute to climate change through air pollution, and the potential for electric motorcycles to mitigate that effect. Therefore, some information is required concerning the nature of powered two wheelers on the road today. At present, the size of the electric motorcycle fleet is nominal, and therefore emphasis will be placed on internal combustion motorcycles. In the European Union, road-going PTWs fall into one of two classifications: mopeds or motorcycles. This distinction can be misleading, as the physical shape is sometimes quite similar. Instead, moped and motorcycle categories are defined by engine size and top speed. Mopeds in the EU have a designed top speed not exceeding 45 km/h, and a cylinder volume of 50 cubic centimeters or less (TransportPolicy.net). Motorcycles exceed one or both of these parameters according to EU legal definitions (TransportPolicy.net).

There are substantial legal implications based on the differentiation between moped and motorcycle in the EU. For example, emissions regulations applied to each category are markedly different. Table 1 presents the limits in the EU on various pollutants produced by light-duty vehicles and PTWs. Interestingly, while CO restrictions are tighter for mopeds, hydrocarbon and NO_x limits are more stringent for motorcycles (TransportPolicy.net). Likely, this is a product of the different emissions characteristics of four and two-stroke engines; two-stroke engines are common in mopeds, while almost all motorcycles are powered by four-stroke engines (Tsai *et al.*). More important than this variation among different PTWs is the gap in emissions standards from light-duty vehicles to both styles of PTW; light-duty vehicles adhere to significantly tighter regulations. Simply bringing PTW regulations up to par would likely result in a large reduction in PTW emissions. Furthermore, licenses to ride PTWs in various EU countries frequently dictate what engine capacity an individual can legally operate. In the UK, for instance, PTW licenses are issued in four stages: AM, A1, A2, and A (gov.uk). AM status clears an individual for operating a moped, A1 license holders may ride up to a 125cc motorcycle, and so on up to the unrestricted A license (gov.uk).

Legal definitions provide a useful framework for categorizing different PTWs, but what is most important is the performance and functionality of various PTW types. Here, extensive discussion could outline the different uses of all the different styles, brands, shapes and sizes of PTWs, but in the interest of simplicity the same moped-motorcycle dichotomy will be used. One critical factor which effects consumer usage of PTWs is the designed range of the moped or motorcycle. Typically, mopeds have somewhat limited ranges, restricting their use to within urban areas. For example, the Piaggio Zip 50 was the top selling model in France in 2012; this moped has a range of approximately 300 kilometers before running out of fuel (Piaggio.com). In contrast, the top selling PTW in Germany was the BMW R 1200 GS, a large motorcycle with a range of nearly 500 kilometers (BMW-motorrad.co.uk). Range is not the only characteristic of mopeds that confines them to urban areas. Legally, mopeds in the EU have a top speed of no more than 45 km/h, insufficient for long range travel or use on most major highways. The Zip 50 is propelled to this speed limit by a 3.4 horsepower internal combustion engine (Piaggio.com). Taken as a counter example, the R 1200 GS has a designed top speed of over 200 km/h, driven by a 125 horsepower engine (bmw-motorrad.co.uk).

Extensive research has focused on discovering the composition of emissions from internal combustion PTW engines of all shapes, sizes, and ages. Perhaps the most significant finding from these studies has been that some of the most harmful components in PTW exhaust are unregulated. For example, volatile organic compounds are present in substantial volumes in exhaust from new and used PTWs (Tsai *et al.*). Volatile organic compounds pose a range of health concerns from minor irritation to serious organ damage, while also doing environmental damage by degrading plant life and contributing to smog (EPA.gov). One study found that major volatile organic compounds in PTW emissions included 2-methylpentane, 3-methylpentane, and isopentane (Tsai *et al.*). Interestingly, far higher volatile organic compound concentrations are found in used PTWs as compared to new PTWs. Some of this disparity can be explained by improved powertrains and exhaust systems that mitigate or contain emissions, but the trend indicates that an aging motorcycle or moped will add progressively more to air pollution. Additional unregulated, harmful emissions from PTWs can be found in Table 2 (Clairotte *et al.*). Table 2 data were collected from two different styles of moped engine. One of the engines was aspirated using a carburetor, while the other used direct injection. Detailed quantities of several pollutants are displayed, including some volatile organic compounds.

Certainly, the performance characteristics of mopeds and motorcycles have a strong impact on their functionality. Motorcycles are used within cities and urban areas, but what portion of their life is spent on longer trips would be difficult to ascertain. It is more important to recognize that moped class PTWs are almost wholly used within dense urban regions. Therefore, the 11 million mopeds registered in the EU focus their contribution to air pollution on the most highly populated areas. Furthermore, the relatively short range use of mopeds invites the introduction of a different kind of PTW which produces minimal air pollution – electric motorcycles.

Unregulated Compounds in Powered Two Wheeler Exhaust in the European Union

		Carbureted		Direct Injected	
Emission Category	Emission Type	Cold Phase	Hot Phase	Cold Phase	Hot Phase
Gaseous Emissions (mg/kg)	CO_2 (g/kg)	47.1	40.2	48.3	42.2
	NH_3	2.03	6.39	0.16	0.13
	HCN	0.94	1.10	0.62	0.38
	CH_4	53.8	87.8	13.6	7.9
	HCHO (formaldehyde)	22.5	16.3	27.4	26.9
	CH_3CHO (acetaldehyde)	24.2	18.4	42.6	38.8
	Benzene group	303	104	177	119
	Naphthalene group	1.43	0.46	1.61	1.11
	Phenanthrene	0.083	0.030	0.017	0.032
Particulate Emissions (mg/kg)	Organic Aerosol Mass	189	24	139	223
	Nitrate Aerosol Mass	0.104	0.011	0.146	0.282
	Chloride Aerosol Mass	0.021	0.005	0.012	0.019
	Black Carbon Mass	0.91	0.47	1.60	1.37
	Particulate Volume (mm^3/km^3)	19.9	3.5	19.8	28.2
	Particulate Quantity (number/km)	3.7810E+12	1.8210E+12	9.1000E+14	8.8100E+12

Table 2 These data were collected using two different styles of internal combustion engine, carbureted and direct injected. Both engines were 50cc capacity and designed to power mopeds (Clairotte *et al.*). Samples of exhaust were examined during two different phases, cold and hot. The cold phase is unregulated in the EU and is intended to warm up the engine for the hot phase. Data collected for the hot phase is representative of operating conditions for the engines. All emission types listed are present in significant amounts in PTW exhaust, but are entirely unregulated by EU emissions standards for PTWs.

Characteristics of Electric Powered Two Wheelers and the Prospect of Large Scale Deployment

Electric Powered Two Wheelers are not yet prolific, but there are a handful of manufacturers currently producing electric motorcycles and mopeds. Moreover, several major motorcycle manufacturers are developing electric motorcycles for the future. Zero Motorcycles is perhaps the most successful electric motorcycle manufacturer, selling units across North America, Europe, and Asia. Other manufacturers such as Harley Davidson and KTM have released limited production and concept electric PTWs, demonstrating anticipation within the motorcycle industry for strong growth in electric PTW sales. In the European Union, 1.3% of all powered two wheeler sales for 2011 were electric, primarily in the moped category (U.S. Commercial Service).

Electric vehicles as a group tend to exhibit outstanding power characteristics. Electric motors have the advantage of producing 100% of their potential torque from a stationary position, allowing electric vehicles to accelerate rapidly compared to an equivalent internal combustion vehicle. Electric PTWs are no exception, offering an exciting user experience. Additionally, the use of computer electronics to control these motors permits near limitless influence over power development and delivery. For instance, electric motors can be switched from highly aggressive settings to docile settings on the fly, depending on road conditions and user preference. In short, power and speed are in no short supply when it comes to electric powered two wheelers. An added and understated benefit of electric drivetrains is realized in cost of ownership and reliability; electricity is far cheaper than gasoline, and the mostly solid-state construction of an electric drivetrain renders it highly resilient. Electric vehicles do not require fragile hardware such as a clutch, transmission, or internal combustion engine, and hence rarely encounter mechanical failure. Current electric PTWs are rated for lifespans well exceeding those of PTWs driven by internal combustion engines. Unfortunately, there are some major shortcomings affiliated with electric PTWs which makes them ill-suited for some consumers.

In order for electric PTW platforms to reduce the auto industry's contribution to air pollution, they must first be advanced to a level at which they satisfy the needs of consumers and compete in performance and cost with their internal combustion counterparts. Currently, the major pitfalls of electric PTWs are range and sticker price. Battery technology has hampered all forms of electric vehicles, and in PTWs the weighty, bulky, and expensive nature of batteries is particularly egregious. Zero Motorcycles' models make for a useful comparison with their internal combustion motorcycle competition. The greatest range advertised by Zero is accomplished by their SR model, achieving a range of just under 300km (ZeroMotorcycles.com). However, this range is only attained in low speed, urban conditions. The SR model cuts its range in half to 150km on an open highway (ZeroMotorcycles.com). Once the SR's battery has been depleted, it will require up to 10.5 hours of charging to reach 95% capacity (ZeroMotorcycles.com). In the motorcycle category, electric PTWs fall far short of their competition for long distance travel. Purchase price, too, can be an obstacle to the entry of electric motorcycles into the market. Zero's RT is listed at $19,840, far more expensive than most of its competition (ZeroMotorcycles.com). Clearly, electric PTWs will be more effective in dense urban areas, as their range will be more competitive with moped substitutes.

A few companies have become well known in niche markets for their electric mopeds. One such company is Govecs, based in Munich. Govecs manufactures four products on its electric moped line, the GO! S2.4 model boasting the longest estimated range of 100km (Govecs.com). With a charge time of 5 hours, this falls short of popular mopeds such as Piaggio's Zip 50, but makes the GO! S2.4 adequate for most daily commutes within dense urban areas. Therefore, Govecs has developed an electric PTW that satisfies the performance needs of consumers who currently operate 11 million mopeds within the EU. However, Govecs still suffers from the high cost of electric drivetrains, with the GO! S2.4 retailing at around $5,500 compared to the Zip 50 for around $2,000.

In many ways, it is unsurprising that the EU has not yet witnessed a large expansion of the electric PTW market. Current electric motorcycles lack sufficient range to provide consumers with the level of flexibility that internal combustion motorcycles afford. The moped sector is much more promising, with brands like Govecs producing electric mopeds that meet the performance needs of those using internal combustion mopeds. However, in both cases, purchase price of electric PTWs far exceeds the gas powered counterpart. Over the course of the vehicle's useful life, the minimal operating cost of electric bikes might well offset this initial investment, but consumers will tend to forego this long-term perspective in favor of saving several thousand dollars up front. Therefore, the current state of electric PTWs is not strongly conducive to debunking internal combustion vehicles. Ultimately, producers still need to rely on subsidies and a consumer base that is attracted to environmentally friendly vehicles, confining electric PTWs to a niche market until performance and price advances are made.

The Impact of Introducing Electric Powered Two Wheelers – a Framework

Electric powered two wheelers may not be prepared for prime time in the motorcycle industry, but it seems clear that they are poised to become competitive with segments of the market in the near future. Battery technology advancements will continue to increase performance and decrease price, making first electric mopeds, then electric motorcycles competitive with internal combustion models. In preparation, it is useful to consider what impact electric PTWs will have as they begin to replace traditional gas powered two wheelers. Air pollution throughout the European Union, and predominantly within dense urban areas, is produced in no small part by PTWs; quantifying the expected decrease in harmful emissions as electric platforms become prolific may help to accelerate the transition. Calculating a tangible benefit will give consumers, producers, and policymakers added incentive for promoting electric PTWs.

A number of considerations will need to be included in a model for calculating PTW emissions and how they will change over time. As with most models, more data, information, and detail will produce increasingly reliable predictions. To begin, any model calculating PTW emissions into the future will need to account for the number of PTWs currently on the road. In the EU, this data is relatively accessible, but in other regions of the world it may be more difficult to come by. Additionally, this component would become more useful with distinctions between style, brand, power, age, and other characteristics which define the varied and unique PTWs now in use. Any distinctions that are drawn should be maintained for all data collected in the model.

Upon establishing the number of PTWs presently in operation, information will need to be obtained on each individual vehicle. First, the quantity of emissions per kilometer travelled by each PTW must be determined. Specifically, it may prove useful to determine emission levels of as many different pollutants as possible. For example, in the EU pollutants such as carbon monoxide and nitrogen oxides are regulated, but many other compounds including volatile organic compounds are found in PTW exhaust. It would be prudent, therefore, to include quantities of both regulated and nonregulated pollutants. The more detailed the information collected on exhaust composition and quantity, the more accurately this model can predict levels of all pollutants in future years. Accompanying this data, the model must include the number of kilometers traveled by each of the PTWs annually. Here, discriminating between the various styles of PTW is critical, as not all kilometers traveled will contribute equally to air pollution. For instance, the engine of a moped traveling ten kilometers will likely be running for more time than a motorcycle traveling the same distance, as the moped moves slower and urban traffic stops frequently.

Industry data will be necessary to make accurate predictions of the air pollution produced by a PTW fleet in any country or region. In particular, sales and retirement rates of PTWs will allow the model to track the number of PTWs over time. Sales throughout a region represent the number of each distinct type of PTW being added to the fleet each year. Vehicle retirement introduces a shrinkage factor to the population. PTWs could be retired due to age, obsolescence, or damage, and different types of PTWs may have longer or shorter lifespans. Importantly, electric PTWs likely have much longer lives than internal combustion PTWs as their drivetrains degrade much more slowly. With factors included in the model for annual additions to and subtractions from the fleet, net growth of the total number of PTWs in operation is a simple calculation away.

The way in which electric PTWs become involved in this model is more obscure. In essence, the variable in this model which a user can adjust is the rate at which electric motorcycles are introduced into the motorcycle industry. For example, this independent variable could be set as high as the total number of annual sales. Under these conditions, internal combustion PTWs are taken completely out of production. Each year, the model would add this number of electric motorcycles and mopeds to the mixture of PTW styles in the fleet. On the other end of the spectrum, the model could be set to add zero electric bikes to the system, and emissions predictions would be based exclusively on internal combustion PTWs. The rate at which electric technology will be introduced is a whole other topic, requiring its own sophisticated estimations to accurately predict.

As electric powered two wheelers become active in the population, they will bring with them a few unique considerations that must be accounted for. Because these vehicles are not powered by typical fossil fuels, they do not directly contribute to air pollution. Instead, it is likely that the generator providing electric PTWs with power produces air pollution. For example, if the electrons which charge the battery of an electric moped in downtown London are generated by a coal burning power plant, then some percentage of air pollution from that plant must be assigned to the particular moped. A model for calculating PTW-produced air pollution must include this consideration. However, in many cases the power plant in question may be emissions-free. Wind, geothermal, solar, and even nuclear fission generation could provide electric PTWs with pollution free electricity. Therefore, the mix of energy production technologies used within the region of study should influence the model. For added complexity, energy production in any given region is likely to change over time, perhaps becoming more and more sustainable.

In order to construct a comprehensive model of the air pollution for which PTWs are responsible, a few final touches need to be added. It is critical that the full lifecycle of each vehicle be included. This entails the emissions produced during the manufacture of the PTW, as well as those produced in the disposal or recycling of the PTW. Furthermore, a large network of supporting industries exists to serve PTW consumers and producers. For example, aftermarket components are shipped to all corners of the world to customize PTWs. The emissions from such enterprises should not go unchecked. Finally, certain unique situations may arise which require adjusting the emissions levels of individual PTWs. Electric vehicles batteries, for instance, may become a major component of the power grid, functioning as storage for electricity while the vehicle is not in use. If this is the case, then electric PTWs would effectively reduce the net air pollution they are responsible for.

This framework provides a guide for the construction of a model with which a researcher might predict the contribution of PTWs to air pollution, and by extension climate change itself. Many of the considerations detailed above may prove too difficult to collect reliable data on, but the more points a model can encompass the more accurate it will become. Predicting various scenarios for PTW air pollution years into the future has the potential to demonstrate what a positive effect electric PTWs will have. This tangible evidence will increase the incentive for users and producers to shift their focus onto electric platforms, as well as spurring policy to advance electric PTW consumption.

Conclusion

Global climate change is a serious threat to humanity. Anthropogenic contributions to this phenomenon may take many forms, but the auto industry is one of the most blatant. Therefore, all sectors of the auto industry must take part in alleviating the negative externalities produced by their vehicles. The motorcycle industry is no exception.

With a large presence in several major regions around the globe, the motorcycle industry is vast enough to create positive change by reducing its air pollution footprint. Current emissions regulations placed on powered two wheelers are not limiting enough, falling short of standards for light-duty vehicles in the European Union. In practice, PTWs release several hazardous compounds into the atmosphere, most of which go unrestricted by legislation. By updating regulations to match light-duty vehicle criteria, PTW manufacturers would be forced to innovate methods for reducing their products' harmful emissions. Dense urban areas receive a large portion of the total air pollution created by PTWs, and this presents an excellent opportunity for the motorcycle industry.

Thanks to the short range travel common among urban riders, electric motorcycles and mopeds have reached a point where they can realistically satisfy the performance requirements of these consumers. It would be feasible to replace internal combustion PTWs with electric versions for those riding primarily in town. By doing so, the motorcycle industry could eliminate the majority of its emissions, significantly reducing its effect on anthropogenic climate change.

Unfortunately, electric powertrains likely need to be developed farther before extensive deployment can take place. The cost of electric PTWs currently puts them out of competition with internal combustion options, carrying a much loftier price tag. More advanced battery technology will help to drive this price down and make electric bikes more accessible. Additionally, as the range and performance of electric platforms increases, they will become ever-increasingly competitive with gas powered motorcycles and mopeds all around the world.

In the meantime, it is important to prepare for the transition to electric PTWs and help the process along. Governmental influence should be used to promote electric motorcycles and mopeds; subsidies of all forms will encourage development and get electric bikes up to par, attracting consumers to the technology. Additionally, pressure from more strict emissions regulations will make electric platforms more attractive for producers under pressure to meet difficult technical challenges. Ultimately, all reasonable action should be taken to promote the promising electric revolution that is coming for motorcycles.

Works Cited

"An Introduction to Indoor Air Quality (IAQ): Volatile Organic Compounds (VOCs)." *EPA.gov*. United States Environmental Protection Agency, 9 July 2012. Web. 5 Apr. 2015.

Clairotte, M., T.W. Adam, R. Chirico, B. Giechaskiel, U. Manfredi, M. Elsasser, M. Sklorz, P.F. DeCarlo, M.F. Heringa, R. Zimmermann, G. Martini, A. Krasenbrink, A. Vicet, E. Tournié, A.S.H. Prévôt, and C. Astorga. “Online Characterization of Regulated and Unregulated Gaseous and Particulate Exhaust Emissions from Two-Stroke Mopeds: A Chemometric Approach.” *Analytica Chemica Acta* 717 (2012): 28-38. Print.

"Clean Vehicle Rebate Project." *EnergyCenter.org*. Center for Sustainable Energy, 1 Jan. 2015. Web. 2 Apr. 2015.

"Emission Standards Reference Guide." *EPA.gov*. United States Environmental Protection Agency, 18 Dec. 2012. Web. 27 Mar. 2015.

European Association of Motorcycle Manufacturers. Powered Two Wheeler Registrations in EU and EFTA Countries 2014 Statistical Release. N.p.: The Motorcycle Industry in Europe, 2014. Web.

"European Union." *TransportPolicy.net*. TransportPolicy.net, 1 Aug. 2013. Web. 25 Mar. 2015.

"GO! S2.4." *Govecs.com*. GOVECS GmbH, 1 Jan. 2015. Web. 4 Apr. 2015.

Kolk, Ans, and David Levy. "Multinationals and Global Climate Change: Issues for the Automotive and Oil Industries." Ed. William Newburry. Multinationals, Environment, and Global Competition. Vol. 9. Bingley: Emerald Group Limited, 2004. 171-93. Print.

Mashayekh, Yeganeh, Paulina Jaramillo, Constantine Samaras, Chris Hendrickson, Michael Blackhurst, Heather MacLean, and Scott Matthews. "Potentials for Sustainable Transportation in Cities to Alleviate Climate Change Impacts." *Environmental Science and Technology* 46 (2012): 2529-2537. Print.

"Motorcycles, Bicycles and Other Transport Equipment in Italy: ISIC 359." *Euromonitor.com*. Euromonitor, 1 Jan. 2015. Web. 18 Apr. 2015.

"R 1200 GS." *BMW-Motorrad.co.uk*. BMW-Motorrad.co.uk, 1 Jan. 2015. Web. 29 Mar. 2015.

"Riding a Motorcycle, Moped or Motor Tricycle." *Gov.uk*. Gov.uk, 27 Mar. 2015. Web. 9 Apr. 2015.

"Road Transport of Thailand." *AJTPweb.org*. Asean Japan Transportation Partnership, 1 Jan. 2014. Web. 25 Apr. 2015.

Tsai, Jiun-Horng, Yu-Yin Liu, Chang-Yu Yang, Hung-Lung Chiang, and Li-Peng Chang. "Volatile Organic Profiles and Photochemical Potentials from Motorcycle Engine Exhaust." *Journal of the Air & Waste Management Association* 53.5 (2012): 516-522. Print.

Uherek, Elmar, Tomas Halenka, Jens Borken-Kleefeld, Yves Balkanski, Terje Berntsen, Carlos Borrego, Michael Gauss, Peter Hoor, Katarzyna Juda-Rezler, Jos Lelieveld, Dimitrios Melas, Kristin Rypdal, and Stephan Schmid. "Transport Impacts on Atmosphere and Climate: Land Transport." *Atmospheric Environment* 40 (2010): 4772-4816. Print.

Unger, Nadine, Tami Bond, James Wang, Dorothy Koch, Surabi Menon, Drew Shindell, and Susanne Bauer. "Attribution of Climate Forcing to Economic Sectors." *Proceedings of the National Academy of Sciences* 107.8 (2010): 3382-3387. Print.

U.S. Commercial Service. U.S. Commercial Service Resource Guide for the European Motorcycle Industry. N.p.: U.S. Commercial Service, 2014. Print.

"Zero SR." *ZeroMotorcycles.com*. Zero Motorcycles, 1 Jan. 2015. Web. 3 Apr. 2015.

"Zip 50 2T." *Piaggio.com*. Piaggio, 1 Jan. 2015. Web. 30 Mar. 2015.