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Contributions of Zero Emissions Motorcycles for Demand Forecast

Please see the attached documents for inputs on potential contributions of zero emissions motorcycles for the IEPR.
Thank you!

Additional submitted attachment is included below.

A Review and Assessment of the Environmental Impacts of Lithium-ion Battery Electric Motorcycles

September 24, 2018

San José State University | DEPARTMENT OF ENVIRONMENTAL STUDIES

MINETA
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Executive Summary

This report reviews and assesses the environmental and economic benefits of Lithium-ion Battery Electric Motorcycles (ZEM). The goal was to review the scientific literature on the greenhouse gas benefits from electric motorcycle adoption and growth. The key findings from the report are:

- The per-mile avoided greenhouse gas (GHG) emissions from driving an electric Zero Emission Motorcycle (ZEM) versus a gasoline powered ICE motorcycle is 46% in California, and this reduction will increase as more renewables are added to the electricity grid.
- The annual avoided greenhouse gas (GHG) emissions from the use of ZEM instead of Internal Combustion Engines (ICE) Motorcycle by 2040 is 2.35 million metric tons CO_2e at 0.6% adoption, 4.7 million metric tons CO_2e at 1.2% adoption, and 47 million metric tons CO_2e at 10% adoption.
- The monetized social benefits from displacing this amount of GHG emissions are $73 million to 2.8 billion dollars by 2040 depending on the rate of ZEM adoption.
- Criteria air pollutants avoided with ZEM adoption are NO_x and VOCs. According to the California Air Resource Board, the entire fleet of gas motorcycles produces 16% more than entire fleet of cars in 2017, yet VMT are 100 times less.
- Smog forming NO_x and hydrocarbon emissions are 0.8 grams per mile for ICE motorcycles, compared to zero for ZEMs. Any upstream emissions associated with electricity will decrease as more renewable energy is integrated into the electricity grid.
- The economic savings associated with individual ownership of ZEM can be $360 per year with a simple payback time of 5.95 years. Payback is much faster if ZEM vs ICE maintenance is considered.
- Reduced need for area to park ZEMs is about 13% compared to the parking space needed for a compact automobile.

Acronyms used throughout the report

- BAU - Business as Usual
- CARB – California Air Resources Board
- DOT – U.S. Department of Transportation
- EPA – U.S. Environmental Protection Agency
- EV – Electric Vehicle
- EM – Electric Motorcycles
- GHG – Greenhouse gas
- ICE – Internal Combustion Engine
- NHTSA – National Highway Traffic Safety Administration
- PM – Particulate matter
- ROI – Return on Investment
- VMT – Vehicle Miles Traveled
- WTP – Well-to-pump
- WTW – Well-to-wheels
- ZEM – Zero emission motorcycle

Disclaimer and Financial Disclosure

This independent research review and report was made possible by a private grant from Zero Motorcycles, Inc. The authors reviewed the best available scholarly and technical research related to the scope of work to ensure the accuracy of all economic, infrastructure and environmental performance claims in the report. The authors have no financial stakes in the manufacturing industries reviewed in this report and no financial interest in Zero Motorcycles, Inc.

A Review and Assessment of the Environmental Impacts of Lithium-ion Battery Electric Motorcycles

1. Introduction

The purpose of this report is to review, document, and assess the environmental and economic benefits and impacts of electric motorcycle adoption and growth. The use of the conventional fossil-fueled powered internal combustion engine (ICE) for personal mobility is a leading contributor to air pollution and greenhouse gas (GHG) emissions, and is linked to other impacts across the supply chain related to producing fuels and vehicles. In general, a shift from ICEs towards electric vehicles (EVs) will improve the overall environmental performance, including lower air pollution, water use, and GHG emissions associated with transportation. One vehicle that is undergoing a technological shift from the ICE to an EV is the electric motorcycle (EM). Today, lithium-ion batteries and electric motors in zero emissions motorcycles (ZEMs) are replacing ICE motorcycles.

The environmental benefits of customers switching from ZEMs to ICEMs are not straightforward, since vehicles also cause "cradle-to-grave" or "life cycle" impacts from the materials and processes used to manufacture them, as well as consequences of the sources of energy used to power the vehicles. There are also some tradeoffs related to other environmental performance metrics and the spatial distribution of impacts as emissions move from tailpipes to electric power plants. In this report, we compare conventional forms of personal mobility to ZEMs. Our emphasis is on the environmental costs and benefits of shifting toward EVs generally, but we also point more specifically to the benefits of higher rates of ZEM adoption. The goal is to create awareness, dispel common myths, and offer consumers information that can inform potential customers' decisions about the consequences of purchasing and otherwise supporting consumer use of electric motorcycles. We have utilized this information in this report to help dispel misinformed myths about electric vehicles. Our information comes from findings in peer-reviewed research. The environmental benefits and tradeoffs are not always intuitive, so our approach aims to makes commensurate comparisons between conventional vehicles and ZEMs. These metrics are used to inform implications for several scenarios we simulate for motorcycle adoption to estimate the broader benefits and costs of this shift to ZEMs.

Box 1. Types of motorized vehicles defined in transportation research

The scope of this report is light-duty vehicles and motorcycles used for personal mobility. The two types of motorcycles reviewed are those powered by electric motors (ZEMs) and gasoline powered ICEs. Heavy-duty vehicles, used for moving freight or other cargo (including people in the case of buses), are not detailed in this report.

Light-duty vehicles – for personal mobility: Light-duty gasoline passenger cars, Light-duty diesel passenger cars, Light-duty electric passenger cars, Light-duty gasoline trucks, Light-duty diesel trucks.

Motorcycles – for personal mobility, assumed to have pollution control equipment: Gasoline fueled Internal Combustion Engines (ICE) motorcycles and electric powered Zero Emissions Motorcycles (ZEMs).

2. The environmental impacts of transportation vehicles

The majority of impacts from conventional fossil-fuel vehicles come from direct emissions from combustion and fueling, as well as impacts associated with the manufacturing of liquid fuels.[1] Combustion of fossil fuels accounts for more than 90% of air pollution.[2] Criteria air pollutant emissions are those that lead to exposures that can have public health impacts such as increased incidences of respiratory illnesses, pulmonary function, low birth rates, and infant mortality.[3] The annual monetary costs of air pollution in the USA are estimated to be nearly $150 billion according to some researchers due to high rates of morbidity and mortality.[4] Exposures to particulate matter ($PM_{2.5}$) of around 2.5 microns in size are linked to 3.45 million premature deaths annually worldwide.[5] The most relevant criteria air pollutants for motorcycles are nitrogen oxides (NO_x), reactive organic gases, carbon monoxide (CO), and particulate matter (PM).

Motorcycles powered by internal combustion engines (ICEs) emit a disproportionate amount of air pollution in some places. Data from the California Air Resources Board (CARB) show that the entire fleet of motorcycles in the state emit 16% more air pollution than the entire fleet of automobiles.[6] In the worse case scenario this means that ICE motorcycles are more than 30 times more polluting than cars. This reflects the fact that air pollution standards for ICE motorcycles have seen little change over the past twenty years.[7]

ICE motorcycles powered also emit higher rates of GHGs such as CO_2, CH_4 and N_2O due to engine conversion inefficiencies. When combusted, the global warming potential of CH_4 is 25 times that of carbon dioxide, N_2O is higher at 298.[8] Burning transportation fuels contributed 27% to overall GHGs in the USA in 2015.[9]

Water use and impacts to water quality occurs throughout the life cycle of fossil fuels, from extraction through refining. Ethanol, added to gasoline to help it burn cleaner with fewer GHG emissions, uses more water

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[1] Hill, J., Polasky, S., and Nelson, E. (2009). "Climate Change and Health Costs of Air Emissions from Biofuels and Gasoline." Proceedings of the National Academy of Sciences 106: 2077–2082.

[2] U.S. EPA. (2011). The Benefits and Costs of the Clean Air Act. Office of Air and Radiation, March 2011.

[3] Casey, J. A., Karasek, D., Ogburn, E. L., Goin, D. E., Dang, K., Braveman, P. A., & Morello-Frosch, R. (2018). Coal and oil power plant retirements in California associated with reduced preterm birth among populations nearby. *American Journal of Epidemiology*. 187(8): 1586–1594.

[4] Jaramillo, P., and Muller, N. Z. (2016). "Air Pollution Emissions and Damages from Energy Production in the US: 2002–2011." Energy Policy, 90, 202–211.

[5] Zhang, Q., Jiang, X., Tong, D., Davis, S. J., Zhao, H., Geng, G., and Ni, R. (2017). Transboundary Health Impacts of Transported Global Air Pollution and International Trade. Nature, 543(7647), 705–709.

[6] California Air Resources Board. (2018). Mobile Source Emissions Inventory. https://www.arb.ca.gov/msei/categories.htm

[7] California Air Resources Board. (2018). On-road Motorcycle Rule-making Kickoff. April 11, 2018. https://www.arb.ca.gov/msprog/motcycle/a.pdf

[8] U.S. EPA. (2017). "Understanding Global Warming Potentials." Retrieved October 29, 2017. https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

[9] U.S. EPA. (2017). Sources of Greenhouse Gas Emissions. Retrieved October 5, 2017. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

than any other energy source and is also linked to water pollution issues such as eutrophication.[10] Many researchers distinguish between water withdrawals and consumption. Sometimes water withdrawn is taken, but never returned to the source; this water is consumed. Other times water is withdrawn and returned to where it was taken with minimal quality impacts. Water use from electricity generation is more difficult to quantify and generalize about because there are a variety of different combustion efficiencies, cooling technologies, and contexts for water use. Average water per unit energy for any given region's electricity, will be product of the mix of generation sources. The highest water withdrawals per unit of energy are for thermo-electric power plants with a once-through cooling design fed with coal, biomass, nuclear or natural gas fuels. Over 40% of freshwater withdrawals in the USA are for thermoelectric power.[11] The lowest water withdrawals are for electricity from photovoltaics.[12] Much like GHGs, water use varies with the geography of electricity.[13] Electricity's impacts are

Box 2. Key environmental metrics

- **Criteria air pollution emissions** (NO_x, SO_x, CO, PM_{10}, $PM_{2.5}$) – These are ambient air quality measures that have known health consequences, including: Particulate matter (PM_{10}, $PM_{2.5}$) of two micron sizes that impact quality and leave behind black carbon, nitrous oxides (NO_x) that contribute to ground-level ozone pollution and acidification, sulfur dioxide (SO_x) contributes to acidification, and carbon monoxide contributes to ozone pollution and is a blood poison.
- **Greenhouse gases** (CO_2, CH_4, N_2O) – Global warming forcing gases created during combustion in ICEs and fossil fuel-fired electric power plants.
- **Reactive organic gases** (ROG)– These components of smog can be measured in exhaust from ICEs and that are evaporated along the well-to-wheels life cycle of liquid fuels.
- **Water use** – The amount of water used is measured in withdrawals and consumption. Withdrawals are total volumes of water taken, whereas consumption is water taken minus water returned. Effluent of water-based wastes released to water bodies can be examined also.
- **Embodied energy** in vehicles & infrastructure – This is the amount of primary energy used to make and produce a product.
- **Eutrophication** – Depletion of oxygen caused by too much fertilizer.
- **Acidification** – Changing soil or water pH through NO_x, SO_x emissions.

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[10] Delucchi, M.A. (2010). "Impacts of Biofuels on Climate Change, Water Use, and Land Use." Annals of the New York Academy of Sciences 1195 (1): 28–45.

[11] Macknick, J., Sattler, S., Averyt, K., Clemmer, S., and Rogers, J. (2012). "The Water Implications of Generating Electricity: Water Use Across the United States Based on Different Electricity Pathways Through 2050." *Environmental Research Letters* 7 (4): 45803–45813.

[12] Fthenakis, V, and Kim, H.C. (2010). Life-Cycle Uses of Water in U.S. Electricity Generation. *Renewable and Sustainable Energy Reviews* 14 (7): 2039–2048.

variable because there are many potential sources. The worst impacts come from electricity supply chains that contain large amounts of coal-fired power, while electricity sourced from renewables has significantly fewer impacts.[14]

Electric vehicles have fewer impacts from fueling, and no direct emissions, but may have increased energy and materials use for production, upstream electric generation, and end-of-life phases. To best understand the tradeoffs requires a full life cycle framework to make comparisons commensurate. An evaluation framework needs to broadly consider both the cradle-to-grave impacts of manufacturing the vehicles and supplying the transportation fuels. Figure 1 shows the life cycle "well-to-wheels" boundary that includes all the stages of production needed to supply fuels and electricity for driving ICEMs versus EMs. The well-to-wheels impacts are measured by distance traveled. "Well-to-pump" studies refer to impacts on a per energy basis and do not consider efficiency of the engine; instead these only measure the impacts of manufacturing the energy delivered to the tank or battery.

2.1 – The life cycle environmental impacts of fuel & electricity

Energy sources used to power transportation vehicles are the major drivers of the overall environmental footprint. GHG and criteria air pollution emissions as well as water use to provide transportation fuels is regularly modeled by Argonne National Labs in a computer program called Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model for various energy and vehicle combinations.[15] Criteria air pollutants accumulate in the air sheds of urban areas and cause the highest concentrated exposures there. SO_x emissions are due to high levels of sulfur in gasoline and diesel fuels, and contribution to the acidification of soil and waters. The source of nitrogen in N_2O and NO_x is the air heated in the combustion process, with N_2O adding to global warming potential and NO_x adds to acidification potential.

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[13] Cai, H., Burnham, A., & Wang, M. (2013). Updated Emission Factors of Air Pollutants From Vehicle Operations in GREET™ using MOVES. *Argonne National Laboratory: Lemont, IL, USA*.

[14] Whitaker, M., Heath, G. A., O'Donoughue, P., & Vorum, M. (2012). Life Cycle Greenhouse Gas Emissions of Coal–fired Electricity Generation. *Journal of Industrial Ecology*, *16*(s1).

[15] Wang, M., Han, J., Dunn, J. B., Cai, H., & Elgowainy, A. (2012). "Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Ethanol from Corn, Sugarcane and Cellulosic Biomass for U.S. Use." *Environmental Research Letters*, *7*(4): 45905–45925.

Figure 1. *Stages of the well-to-wheels life cycle of a gasoline for an internal combustion engine.*

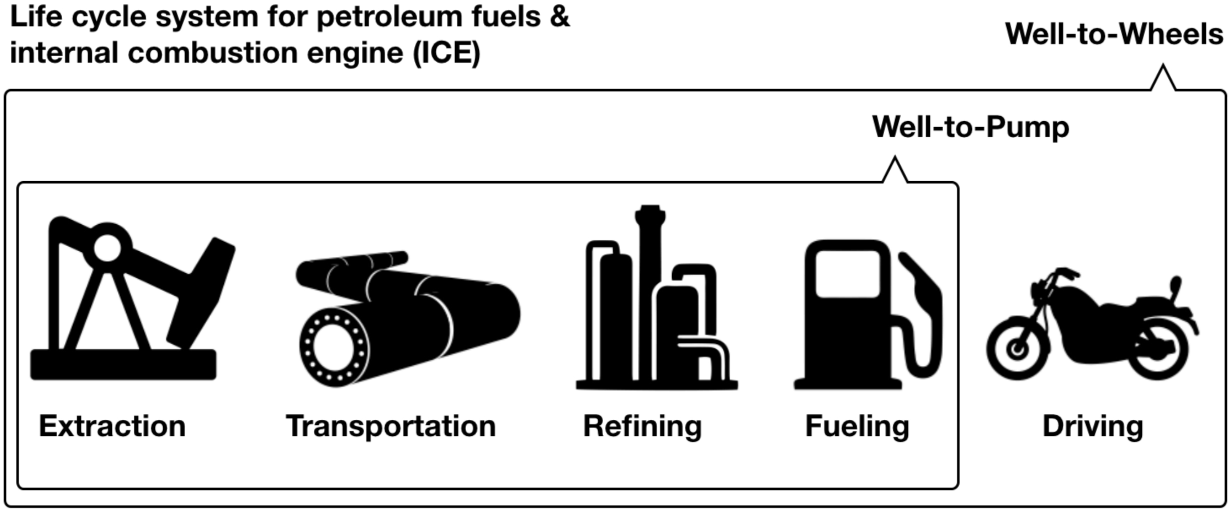
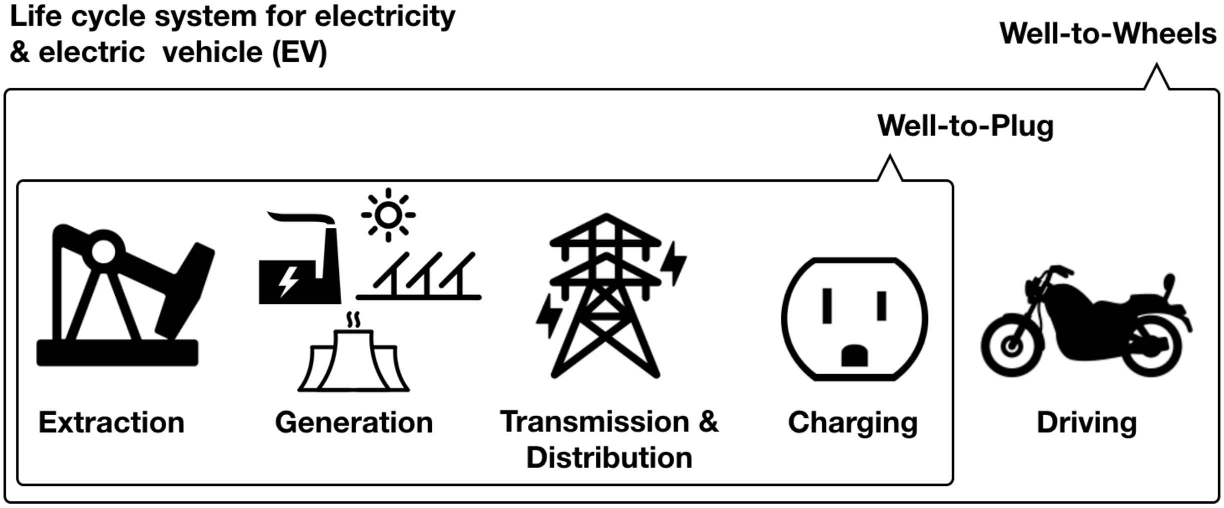


Figure 2. *Stages of the well-to-wheels life cycle of electricity for an electric vehicle.*



In addition to impacts from the fuel cycle for gasoline combustion, there are other environmental considerations from gasoline use including exposures to BTEX (benzene, toluene, ethyl benzene, and xylene).[16] Poly-aromatic hydrocarbons (PAHs) are a class of volatile compound exposure that are linked to public health or

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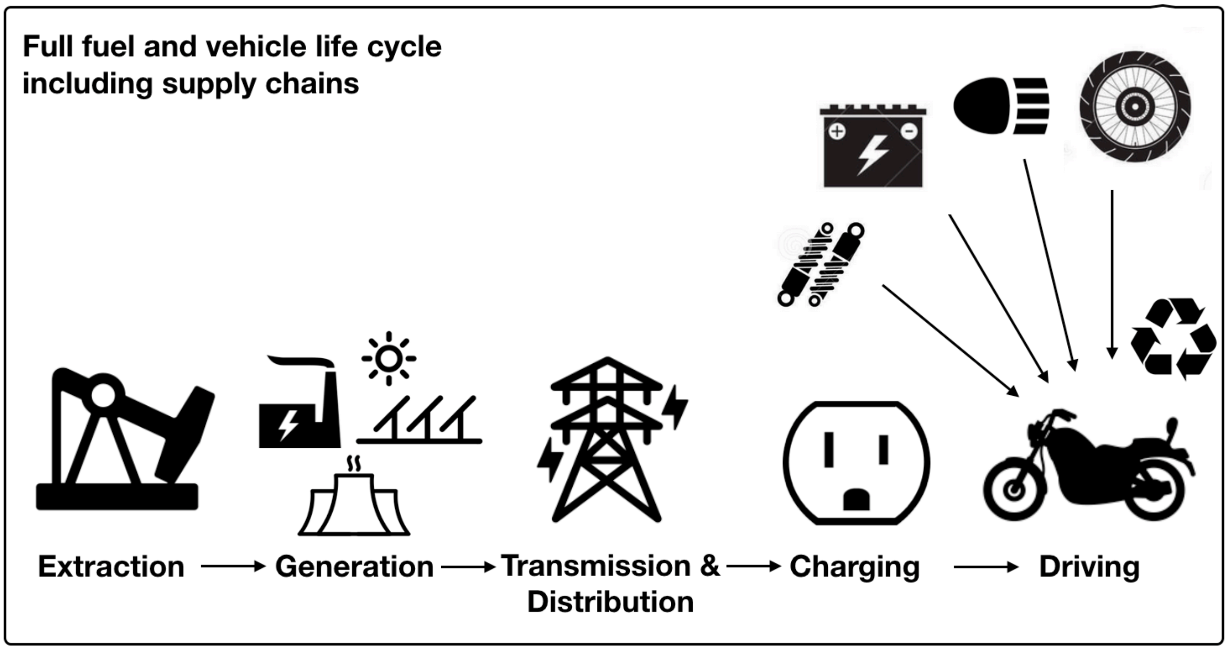
[16] Heibati, B., Pollitt, K. J. G., Karimi, A., Charati, J. Y., Ducatman, A., Shokrzadeh, M., and Mohammadyan, M. (2017). BTEX Exposure Assessment and Quantitative Risk Assessment Among Petroleum Product Distributors. Ecotoxicology and Environmental Safety, 144, 445–449.

occupational health issues.[17] To lessen air quality impacts fuel additives are added like MTBE which allows the gasoline to burn cleaner, but it also has been linked to widespread groundwater contamination.[18]

Figure 3. *The full vehicle life cycle and well-to-wheels life cycle of transportation fuels and energy provides a fuller picture.*



2.2 – The life cycle impacts of the vehicle and use phase

The vehicle life cycle contributes much less to the overall environmental impacts compared to the use phase, which come from electricity or gasoline. Impacts during use are mainly related to combustion, although some vehicle components need to be replaced over its life, such as tires. ICE motorcycles require less energy to make than ZEMs because of the energy needed acquire some materials and to make the battery.[19] Impacts from manufacturing ICE motorcycles versus ZEM, suggest that battery manufacturing adds about to the overall life cycle energy requirements to make the vehicles and to the environmental burden of the vehicle depending on assumptions about battery chemistry, manufacturing capacity and scale, and recycling.[20] These same studies

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[17] Kim, K. H., Jahan, S. A., Kabir, E., & Brown, R. J. (2013). A Review of Airborne Polycyclic Aromatic Hydrocarbons (PAHs) and Their Human Health Effects. Environment International, 60, 71–80.

[18] McHugh, T. E., Rauch, S. R., Paquette, S. M., Connor, J. A., & Daus, A. D. (2014). Life Cycle of Methyl tert-Butyl Ether in California Public Water Supply Wells. Environmental Science & Technology Letters, 2(1), 7-11.

[19] Ellingsen, L. A. W., Hung, C. R., & Strømman, A. H. (2017). Identifying key assumptions and differences in life cycle assessment studies of lithium-ion traction batteries with focus on greenhouse gas emissions. Transportation Research Part D: Transport and Environment, 55, 82–90.

[20] Peters, J. F., Baumann, M., Zimmermann, B., Braun, J., & Weil, M. (2017). The environmental impact of Li-Ion batteries and the role of key parameters – A review. Renewable and Sustainable Energy Reviews, 67(C), 491–506.

point out that the overall emissions from the use phase however dominate the overall footprint, reducing the environmental impact.

One issue to consider when considering the use phase is whether mode-shifts are from automobiles to motorcycles or from non-motorized modes to motorcycles. ZEMs will decrease energy demand for transportation if it replaces trips typically done in an automobile. For some individuals ZEMs could increase energy demand for transportation if it displaces trips made from human-powered bicycles.[21] The displacement factor—the number of automobile trips displaced per ZEM trip made—will depend on the specific regional context.

End-of-life impacts include the disposal and recycling of motorcycle components. The ZEM would most likely have more impacts from this stage because of the electronics and battery components. However, lithium-ion battery impacts are much lower than batteries made of lead, cadmium, or nickel-metal hydride. Early studies suggested the most significant impacts from motorcycles is lead-acid battery disposal.[22] But there is no lead in EMs; lithium-ion batteries chemistries do not depend on toxic heavy metals. Recyclable materials from lithium-ion batteries depend on the particular chemistries used but include copper, cobalt, aluminum, and copper.[23]

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[21] Lin, X., Wells, P., and Sovacool, B.K. (2017). "Benign Mobility? Electric Bicycles, Sustainable Transport Consumption Behavior and Socio-Technical Transitions in Nanjing, China." Transportation Research Part A 103: 223–234.

[22] Cherry, C.R., Weinert, J.X., and Xinmiao, Y. (2009). "Comparative Environmental Impacts of Electric Bikes in China." Transportation Research Part D 14 (5): 281–290.

[23] Vandepaer, L., Cloutier, J., & Amor, B. (2017). "Environmental Impacts of Lithium Metal Polymer and Lithium-ion Stationary Batteries." Renewable and Sustainable Energy Reviews, 78, 46–60.

3 - Comparing environmental impacts of zero emissions motorcycles to internal combustion engine-powered motorcycles

What are the environmental and economic impacts of using ZEMs compared to ICE motorcycles for personal mobility? Our approach provides an overview of prior research and information on the environmental impacts of using electricity as a fuel instead of gasoline, with reference to the environmental impacts of the source of electric power. Environmental performance metrics based on key criteria from prior research and regulatory agencies are synthesized and made commensurate based on the same units. To make more true comparisons, these impacts are best measured on a per mile basis. These were collected from the peer-reviewed research on environmental impacts (air pollutants, greenhouse gases, and water use) and infrastructure consequences (parking, narrowing lanes, managed lanes qualified for motorcycles, charging equipment) of an individual driving via an ZEM compared to travel in ICE-powered light duty vehicles & light duty EVs and on ICE motorcycles. We assume ICE motorcycles are four-cycle/stroke engines with emissions control.

A key driver of variability in the impacts of EVs is the different electricity generation mix of a given region or charging site. Some regions rely heavily of coal for electric charging, while others have higher levels of renewables, large-scale hydro, or nuclear power to make lower GHG electricity. This review includes a range of GHG intensities to represent geographic differences in grid mixes and the benefits of solar charging. Emissions factors were taken from various sources and apply to findings from the research to understand how emissions profiles change from the national level to various states and regions including the USA, California, China and the European Union. The research consensus clearly shows the electricity generation mix used to charge electric vehicles is a major driver of impacts of EVs. There is tremendous variation in the greenhouse gas intensity of the energy sources. In Europe for example, regions, states, or countries that rely on hydroelectric and geothermal like Iceland, or like California have adopted high levels of renewable and having little coal, have very few greenhouse gas emissions.

Since the emissions from EVs occur offsite, the displacement of conventional motorcycles by ZEMs may reduce human exposures to air pollution, except near stationary sources of combustion.[24] Urban air quality presents the highest risk to public health because urban areas have the highest intake fraction of criteria air pollutants, with one study finding that humans are directly exposed to an average 39 grams per ton of emissions in urban areas.[25] The shift to EVs would reduce these numbers by limiting the mobile sources of combustion pollution.

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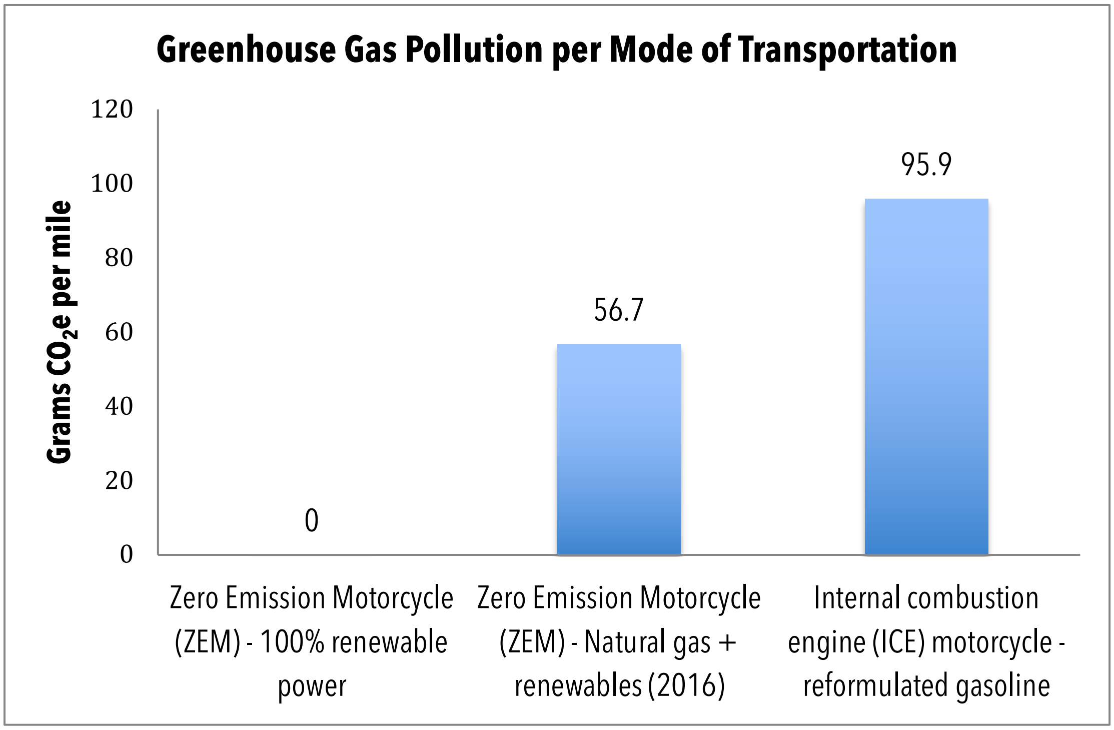
[24] Weiss M., Dekker P., and Moro A. (2015). "On the Electrification of Road Transportation: Review of the Environmental, Economic, and Social Performance of Electric Two-Wheelers." Transportation Research Part D 41: 348–366.

[25] Apte, J. S., Bombrun, E., Marshall, J. D., & Nazaroff, W. W. (2012). Global intraurban intake fractions for primary air pollutants from vehicles and other distributed sources. Environmental Science & Technology, 46(6), 3415-3423.

Figure 5. *Global warming pollution comparing three types of fuel-vehicle combinations*[26]



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[26] Life Cycle Associates. 2010. Life Cycle Assessment comparing Zero Motorcycles. This 2010 study assumed a carbon intensity of electricity from 2009. We took the estimate for "RPS + natural gas" in this scenario and multiplied by the difference in carbon intensity of electricity from 2009 to 2016.

Figure 6. *Tailpipe emissions of ozone-forming nitrogen oxide (NO_x) and hydrocarbon emissions per mile traveled on ZEMs versus ICE motorcycles.*

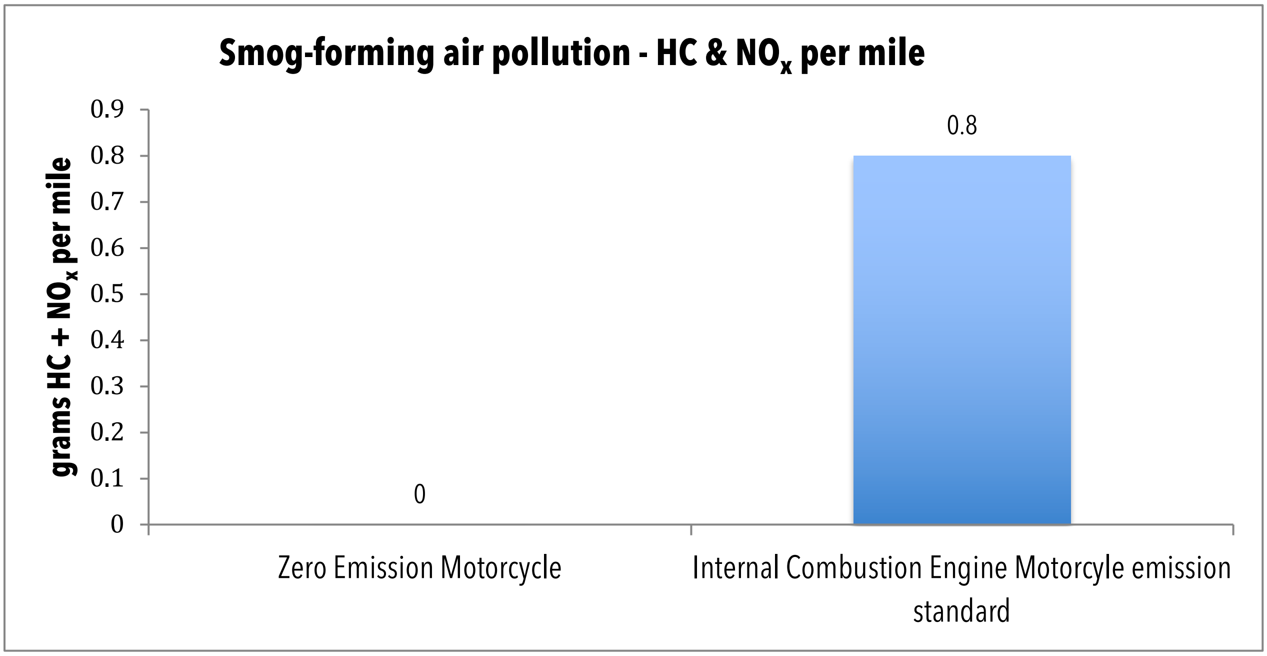

Figure 6 shows the comparative NO_X and hydrocarbon emissions from the two motorcycle types. NO_X and reactive organic gases like hydrocarbons (HC) are criteria air pollutant because they photo-reacts with ultraviolet light to form ground-level ozone, which is a principal component of smog and can cause of severe respiratory distress. Many urban air sheds in the U.S. are frequently out of compliance with ambient air quality standards for ozone set by the EPA or regional air quality boards.

The ZEM shows significant improvements over the ICE motorcycles, and these results will be stronger when grid carbon intensities are lower in the future. Over the life of the ZEM, the air pollution emissions that occur upstream at power plants will go down over time as more renewable energy resources are integrated into the electricity system. Over time, ICE emit more air pollution as disrepair undermines the efficacy and efficiency of combustion.

3 - Consumer economic benefits of ZEM adoption

Simple payback time and returns on investment were compared for ZEMs and ICEMs. The payback time estimates the time it takes for energy efficiency investments to pay off by taking the total cost of the device or vehicle plus the cost of operating fueling and powering it, compared to an alternative gasoline powered-ICEM. Maintenance costs also favor ZEMs, and accelerate these payback times because there are no oil, filters, spark plugs, coolant, valves, which require periodic maintenance and replacement. One estimate of maintenance cost suggests that ZEMs are eight times less expensive to operate with ZEMs at \$0.04 per mile and ICEMs at \$0.32.

Simple payback time is the amount of time that will go by before an efficiency investment is paid for by energy savings; the time that it takes savings to reach initial or first cost:

*Cost (\$) = Purchase cost + [Annual maintenance cost per mile * annual miles)*

ZEM assumptions

Purchase cost ZEM = \$13,500

ICEM assumptions

Purchase cost ICEM = \$10,000

*Net purchase cost ZEM over ICEM = **\$3,500***

Energy use costs

*Energy use EM = 0.11 kWh/mile * 12,000 miles/year = 1,500 kWh/year*

*Energy use ICEM = 0.017 gallons of gasoline /mile * 12,000 miles/year = 200 gallons of gasoline/year*

$\text{10-year energy cost (\$)}_{EM} = \text{10 years} * \text{1,500 kWh/year} * \text{\$0.15/kWh} = \text{\$2,400}$

$\text{10-year energy cost (\$)}_{ICEM} = \text{10 years} * \text{200 gallons of gasoline /year} * \text{\$4/gallon of gasoline} = \text{\$6,000}$

Savings from ZEM

$\text{Savings (\$) over ten years} = \text{Energy cost (\$)}_{EM} - \text{Energy cost (\$)}_{ICEM}$

Savings (\$) over ten years = \$6,000 – \$2,400 = \$3,600

Annual Savings = \$360

$\text{Payback (Years)}_{EM} = \text{Net Cost (\$)} \div \text{Annual Energy Savings (\$)}$

$\text{Payback (Years)}_{EM} = \text{\$3,500} \div \text{\$360} = \textbf{5.95 years simple payback time}$

This assessment of the value proposition for EM shows that the energy savings will pay off the difference in first purchase costs in less than six years. The means the investment in an EM saves both GHG but also money over the operating life of the vehicle. Simple **Return on Investment** (ROI) is an internal rate of return, expressed as a percentage, based on the relationship between annual energy savings and the net installation cost. This can help estimate the full return on investment over some period of time. ROI is only possible where operating costs are reduced such as with energy efficiency or fuel economy.

ROI (%) = [Savings ($) ÷ Cost ($)] x 100

ROI (%) = [Annual Energy Savings ($) ÷ Net Cost ($)] x 100

ROI (%) = ($ 360 ÷ $3,500) x 100 = **9.7% return on investment**

Using modes of transportation such as motorcycles can reduce time spent in traffic. The economic value of this time saved by commuters adds up on a nationwide basis. For example, the most recent Global Traffic Scorecard from the traffic measurement firm INRIX puts the total cost of U.S. traffic congestion at $300 billion annually, including direct and indirect impacts, the biggest portion being the assumed lost wages value of wasted time of vehicle passengers.[27] This economic waste can be higher to the degree that travelers are forced by traffic to be late for the start of important meetings and appointments, but may be increasingly mitigated in the future by automated freeway driving in new cars that makes distracted driving of cars a safer activity. Nevertheless, there is little doubt that many travelers do not like dealing with congestion in automobile travel, and there is anecdotal evidence that some motorcycle commuters in peak periods really like the feeling that comes with beating congestion.[28]

ICEs are loud and directly release air pollutants, particularly when just starting up. In general ICEs make more noise in operation than relatively quiet electric vehicles of all types, including motorcycles.

Motorcycle use can generally provide a traveler with improved urban mobility, especially when HOV lanes are available with motorcycles allowed. Even absent such HOV lanes, any motorcycle, no matter how powered, offers some advantages in speed of movement through urban traffic by taking advantage of the narrow width of these vehicles compared to the width of typical light duty passenger vehicles. Motorcycle and electric bike riders

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[27] INRIX (2017), "Los Angeles Tops INRIX Global Congestion Ranking" http://inrix.com/press-releases/los-angeles-tops-inrix-global-congestion-ranking/ (retrieved November 1, 2017)

[28] SF Area Motorcycle Commuters, https://www.reddit.com/r/bayarea/comments/550z5g/motorcycle_commuters/ ; How Honda bikes beat commuter misery, https://www.youtube.com/watch?v=TaA8ZOTwTmM (both retrieved November 10, 2017)

report that one motivation for adoption of this mode of transportation is ease of getting around in areas with congestion.[29]

In California, travel between cars in the space between them even when lanes full of vehicles are side by side is not prohibited, a practice called "lane splitting." When done cautiously when traffic is slow or at a standstill, the practice can be both safe and a timesaver. A study conducted by researchers at the University of California at Berkeley found "lane-splitting appears to be a relatively safe motorcycle riding strategy if done in traffic moving at 50 MPH or less and if motorcyclists do not exceed the speed of other vehicles by more than 15 MPH."[30] There are some suggestions that this practice may be allowed in more places in the near future.[31]

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[29] Lin, X., Wells, P. and Sovacool, B.K. (2017). "Benign Mobility? Electric Bicycles, Sustainable Transport Consumption Behavior and Socio-Technical Transitions in Nanjing, China." *Transportation Research Part A* 103: 223–234.

[30] Rice, Thomas, Lara Troszak, and Taryn Erhardt (2015). "Motorcycle Lane-splitting and Safety in California." Monograph. Safe Transportation Research & Education Center, University of California Berkeley, http://www.ots.ca.gov/pdf/Publications/Motorcycle-Lane-Splitting-and-Safety-2015.pdf (retrieved November 10, 2017)

[31] American Motorcyclist Association. 2018. Land-splitting. https://www.americanmotorcyclist.com/About-The-AMA/lane-splitting-1

Box 3. Dispelling myths about electric vehicles (EVs)

Misconception #1: EVs never pay back the energy invested because of the battery.
The amount of energy and materials needed to manufacture a battery is small compared to the entire lifetime operating emissions of a conventional vehicle. The battery makes up about 15% of the overall environmental impact of an EV. The battery energy investment pays off with the first few months of an EV displacing an ICE's emissions, depending on the GHG intensity of the electricity used.

Misconception #2: EVs are too costly.
While the sticker price for an electric motorcycle (EM) with a lithium-ion battery may be higher than one with a combustion engine, the operating costs will be lower because electricity is cheaper and more efficiently used in an EM. The best approach is to compare the purchase and operating costs over time. Section 3 shows the payback time on investing in more efficient engines like those in EVs.

Misconception #3: EVs are inefficient when electricity supply chain is considered.
Electric motors are far more efficient at converting fuels to mobility. Electric motors can be 80–99% efficient, whereas combustion engines only convert 25% of fuels to motion. This means electric engines can go farther on the same amount of energy. However, some electric power is generated from combustion sources, and some of these power plants are inefficient, particularly old coal and natural gas plants.

Misconception #4: EVs simply displace emissions elsewhere.
Internal combustion engines (ICEs) are mobile sources of air pollution, whereas electricity is generated at stationary sources. EVs do not generate criteria air pollutants in urban areas, except where combustion related power is generated from oil, gas, or coal. Most stationary sources are better and more predictably regulated, whereas mobile sources can be unknowingly out of compliance without an regular inspection from a SMOG or emissions test. EVs like EMs have no emissions regulation because there are no direct emissions. In most cases, shifting to EVs displaces air pollution emissions away from the potential exposures in urban areas, where most air pollution exposures from transportation occur. Electricity grid are also getting cleaner every year as renewable energy is added, while combustion engines get dirtier over time.

4. Estimating Benefits of Scaling up Zero Emission Motorcycle Adoption

According to the National Highway Traffic Safety Administration (NHTSA), 0.6% of all VMT were by motorcycles in 2016.[32] If all motorcycle VMT were on ZEMs, what would be the overall GHG emissions displaced? What is the GHG savings potential for ZEMs if ridership and VMT by ZEMs expanded further? This section estimates the GHG savings from ZEM adoption. The data used include U.S. Department of Transportation data on street motorcycle registrations, U.S. Census Bureau survey data on journey to work modes, prior research on environmental impacts, and projected growth scenarios for ridership. ZEM adoption scenarios explored include "business-as-usual" based on current ridership trends (0.6%), a modest growth scenario with double current ridership (1.2%), and an ambitious scenario where ZEM is 10% of vehicle miles traveled (VMT). These scenarios help us understand how the broader environmental benefits scale from a shift to ZEMs. Data from prior research and regulatory agencies on environmental impacts per mile traveled were multiplied by the total VMT. We assume that the increment of motorcycle use for commuting above the baseline consists only of new ZEMs. The avoided GHGs are estimated by assuming ZEMs displace emissions from ICE motorcycles.

Business as usual (BAU) ZEM adoption scenario

Our baseline scenario uses U.S. Department of transportation (DOT) data on share of the motorcycle fleet as a portion of total vehicle miles travelled (VMTs). This scenario assumes the motorcycle ridership forecast reflects recent data on the proportion of trips taken on a motorcycle. Using a linear extrapolation of 12 month moving average of VMTs from the US DOT Traffic Volume Trends using data from July 2017, we forecast USA nationwide VMT growth in millions of miles through 2040. Since these data include commercial trucks and buses, we multiplied the total VMT by 83% to account for the size of the light duty passenger vehicle fleet in 2015.

Table 1. *Total Vehicle Miles Traveled by light duty vehicles and motorcycles*

	Million miles	Trillion miles
2016	2,607,698	2.61
2020	2,764,735	2.76
2030	3,048,047	3.05
2040	3,331,359	3.33

High growth ZEM adoption scenarios

For our modest growth scenario growth in VMT shares from motorcycles is assumed to be double that of the BAU scenario. For the aggressive growth scenario there is a tenfold increase. For a maximum benefit scenario,

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[32] National Highway Traffic Safety Administration U.S. "Table 1-35: U.S. Vehicle-Miles (Millions)." U.S. Bureau of Transportation Statistical Summary. Retrieved October 17, 2017. https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_35.html

we scale global motorcycle adoption to 30% based on the study from Belgium that suggested traffic congestion issues are resolved when motorcycles are used for 30% of VMTs.

Figure 7. *Total Vehicle Miles Traveled (VMT) in the USA.*

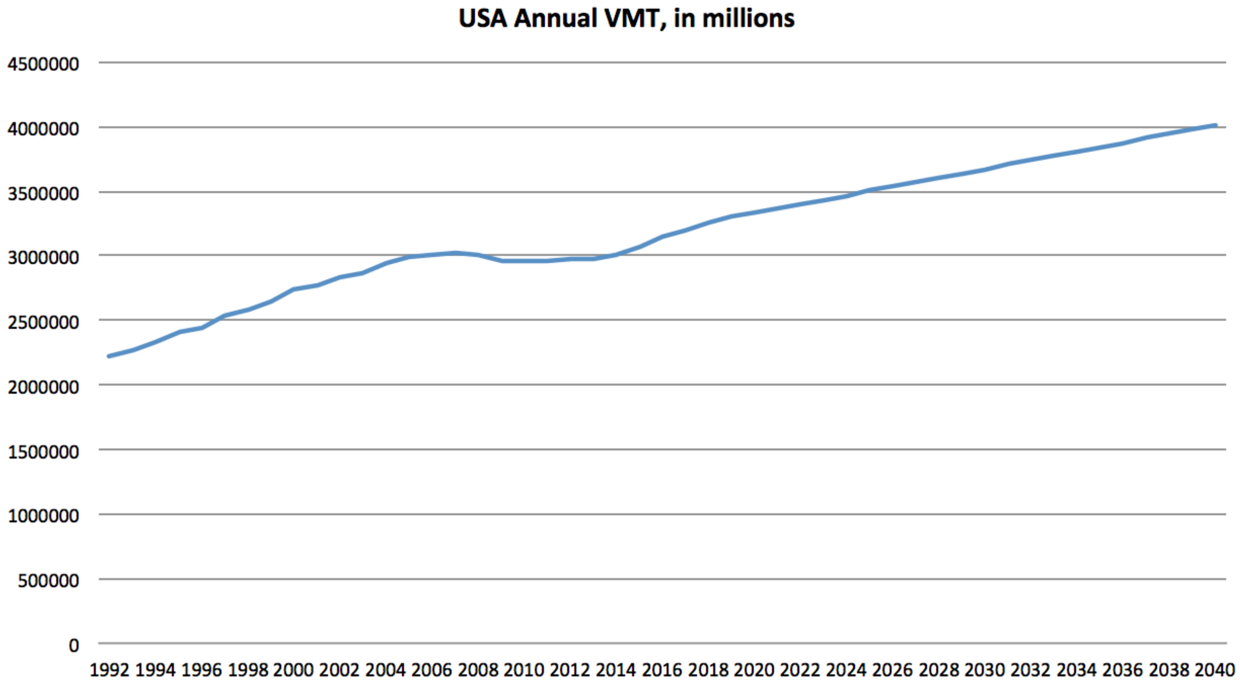
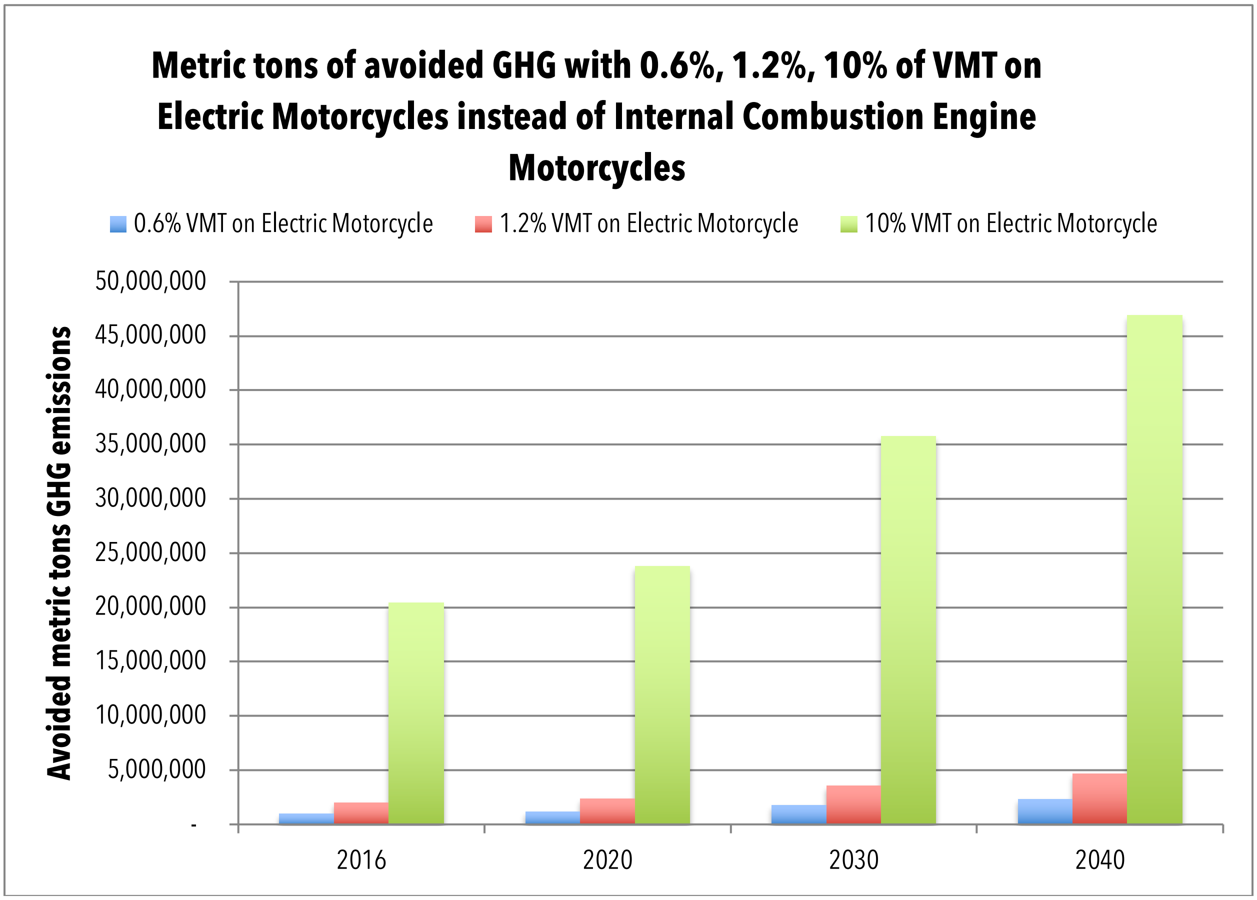
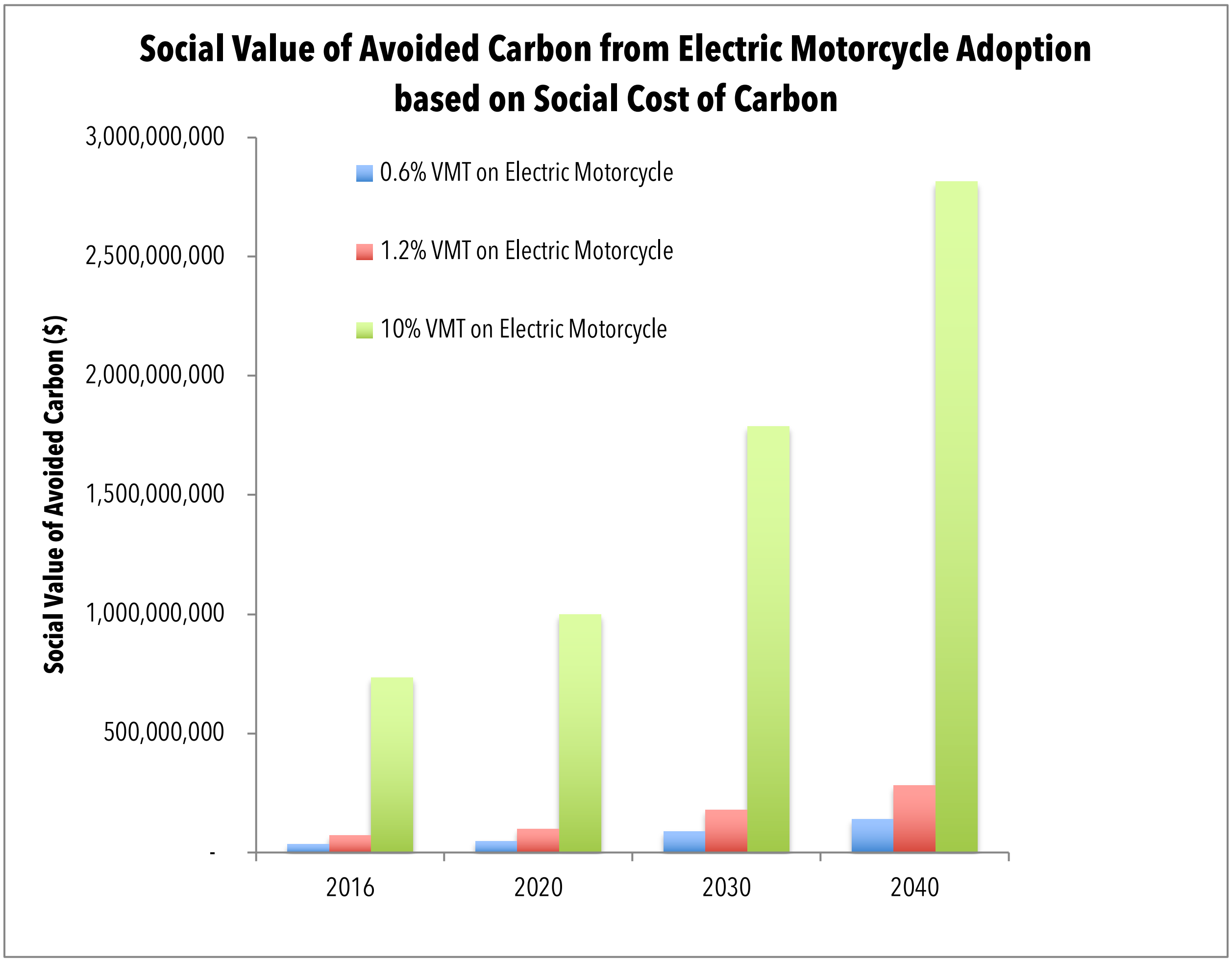


Figure 8. *Avoided GHG emissions (USA) in the BAU (0.6%), growth (1.2%), and high growth (10%) scenarios.*



With an estimate for the avoided GHG emissions, the social cost of carbon value was used to estimate the value of the GHG mitigation. The U.S. Environmental Protection Agency (EPA) set a Social Cost of Carbon to help with estimating the impacts of policies. The discount rate chosen was 3% and the EPA estimates for 2016, 2020, 2030, and 2040 were used to value the avoided GHGs over time.

Figure 9. *Value of avoided GHGs (in USA) based on the Social Cost of Carbon*



Aside from the reduction in emissions, as expansion of motorcycle usage in peak congestion times would offer opportunities to reduce congestion. Motorcyclists can preferentially use slower, less crowded roads, that includes high occupancy vehicle (HOV) lanes. Motorcycles are allowed to use HOV lanes under Federal law. State of California Department of Transportation reports that there are 1,483 lane miles of HOV lanes in operation in the state, with an additional 817 lane miles under development, all in urban areas.[33] Parking during the workday potentially takes less space in specially designated, small spaces in park-and-ride facilities,

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[33] Rouse, Joe (2016) "Managed Lanes 101" presentation, http://www.dot.ca.gov/hq/tpp/offices/owd/horizons_files/ManagedLanes101-PlanningHorizons082416.pdf (retrieved November 12, 2017)

an infrastructure saving. There are as many of 200 million non-residential parking spaces in the U.S.[34] Motorcycles offer the benefit of lower floor space consumption for parking of personal vehicles. Motorcycle parking obviously consumes less floor area than the footprint required for a four-wheel light vehicle.

Motorcycles require less road space and less impactful on road surfaces than four-wheel light duty vehicles. This could result in reduced road and parking infrastructure. Avoided asphalt and pavement can have environmental benefits and also may assist urban climate adaptation goals where the heat island effect can be avoided.[35] One study showed that electric and two wheeled vehicles can lower the need for infrastructure in several transportation scenarios for China.[36]

Not much work has been done analyzing congestion reduction impacts on existing infrastructure of more motorcycle usage in peak periods. However, a careful quantitative computer simulation has been carried out in Belgium.[37] This research examined the impact on freeway traffic congestion that would come from replacing ten percent of car commuters with motorcycle commuters, and it yielded on overall saving in travel time hours across all vehicles of 40 percent. The freeway studied runs between Leuven and Brussels with a free flow speeds between 95 and 115 km per hour. By coincidence this highway was observed by one of the authors of this study in June 2017 on his visit to Europe, and judged to be very similar to a California freeway having two or three lanes in each direction. Motorcycle commuters were presumed in the computer modeling to drive between lanes when traffic slows to a complete stop, and otherwise were given a car equivalency in the taking of space when free flow is occurring. This simulation included the latent demand effect of about two percent more car commuters being attracted to the road as traffic improved. This simulation research also found that motorcycles replacing 25 percent of cars would completely eliminate traffic congestion on the freeways in Belgium.

Given the environmental benefits of electric motorcycles demonstrated in this report, and the reduced amount of lane width they require compared to a four wheel light duty vehicle, we should consider what the benefits would be of facilitating ever greater motorcycle usage in North America. The Belgian study we cited above suggested that road congestion and the associated cost in excessive travel time could in theory be made nil with only a quarter of commuters moving from four-wheels to two-wheels. The economic benefit of eliminating urban road congestion in USA would be very large. For example, the most recent Global Traffic Scorecard from the traffic measurement firm INRIX puts the total cost of U.S. traffic congestion at $300 billion annually, including direct and indirect impacts, the biggest portion being wasted time of vehicle passengers.[38] If a jump

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[34] Chester, M., Horvath, A., and Madanat, S. (2010). "Parking Infrastructure: Energy, Emissions, and Automobile Life-Cycle Environmental Accounting." Environmental Research Letters 5 (3): 034001.

[35] Chester, M., Horvath, A., and Madanat, S. (2010). "Parking Infrastructure: Energy, Emissions, and Automobile Life-Cycle Environmental Accounting." Environmental Research Letters 5 (3): 034001.

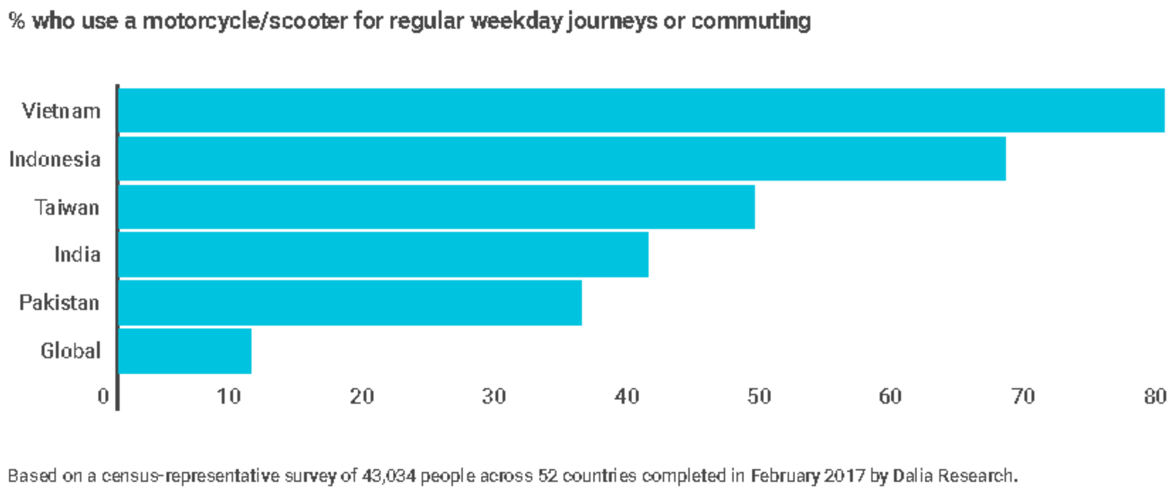
[36] Ou X., Zhang, X., Chang, S. (2010). "Scenario Analysis on Alternative Fuel/Vehicle for China's Future Road Transport Life-Cycle Energy Demand and GHG emissions." Energy Policy 38, 3943–3956.

[37] Yperman, I. (2011). "Commuting by Motorcycle: Impact Analysis." Institute of Transport & Mobility, Leuven, Belgium.

[38] INRIX Global Traffic Scorecard, http://inrix.com/scorecard/

from today's approximately one percent market share in motorcycle commuting of all types to a 25 percent share on zero-emission motorcycles took congestion down to insignificant levels, the greater efficiency of a less congested surface transportation network would result. Occurring over a period of years, growing transportation efficiency would generate an economic surplus that could be invested in a repurposing of existing right of way on four (or more) lane highways and major streets. Twelve-foot wide automobile lanes in each direction could be converted to a pair of motorcycle only lanes of six feet width each.[39] As a practical matter, experience in Asian cities with very high motorcycle usage, the ones in Figure 13, already indicates that for safety reasons the infrastructure of major highways seeing a shift to more motorcycle usage should be converted to incorporate exclusive motorcycle lanes to avoid safety issues that come with mixing large and small vehicles. At the same time, space for parking cars can be converted to multiple spaces for parking motorcycles at a ratio of at least five to one, perhaps as high as ten to one.[40]

Figure 10. Top Motorcycling Countries According to Dalia Research



% who use a motorcycle/scooter for regular weekday journeys or commuting

Based on a census-representative survey of 43,034 people across 52 countries completed in February 2017 by Dalia Research.

Source: https://daliaresearch.com/blog-the-top-5-cycling-motorcycling-countries-in-the-world/

Addressing causes of motorcycle road accidents by improving and expanding safe operator practices will be critical to the public and government acceptance and subsequent success of expanded use of electric motorcycles. Fatalities and injuries to travelers from motorized travel are widely considered an environmental issue in the public policy community. The higher incidence of motorcycle crashes compared to car accidents in today's environment despite years of the motorcycle community in America emphasizing safety suggest that a step increase in motorcycle use like we modeled above has the potential to yield more collisions and spills that in turn would cause an increase in wasted human, physical, and financial resources. That negative potential can

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[39] Lea, Q. and Nurhidayatib, Z.A. (2016). "A Study of Motorcycle Lane Design in Some Asian Countries," Procedia Engineering 142, 292–298.

[40] Barter, P. (2010). "Ten motorcycles per car parking space?" http://www.reinventingparking.org/2010/08/ten-motorcycles-per-car-parking-space.html

hopefully be mitigated with a "target zero" approach to motorcycle accidents like is being pursued in Washington State with the support of the Washington State Traffic Safety Commission, and in other states as well. The methodology of a target zero program is to analyze data and take research-responsive action steps systematically informed by statistics to reach the goal of reducing motorcycle fatalities to zero by 2030.[41]

6. Conclusions

There is a significant shift underway from internal combustion engines to electric vehicles.[42] The potential global benefits of electric zero emission motorcycles are considerable considering the market share of motorcycle travel in many other countries. Asian nations such as Taiwan, Indonesia, India, and Vietnam have rates of motorcycle and scooter use that exceed 40%.[43] China's use is growing despite some policies working against them.[44] Numerous studies point to substantial upsides to increased ZEM usage in terms of public health, mobility, and personal well-being in cities with high levels of air pollutions from transportation and traffic congestion.[45] This study reinforces many of the claims that prior studies of electrification of transportation have already made, namely, that the benefits of electric vehicles displacing vehicles powered by internal combustion engines are significant and will continue to increase as more sources of renewable energy and integrated and more coal-fired generation is retired. Other studies of motorcycle use in general find individual economic and time-saving benefits to increased motorcycle use, irrespective of the engine type because of maneuvering in traffic and ease of parking.

At some point, personal 2-wheel and 3-wheel electric vehicles displacing 4-wheeled vehicles could in theory – with significant road modifications (dedicated motorcycle lanes), safety improvement programs, and consumer embrace of riding on these vehicles -- significantly reduce urban traffic congestion. This study estimates relatively short payback times and a reasonable return on investment from investing in energy efficiency technologies like electric motorcycles. To realize the theoretical possibility by expanding consumer appeal, creative new vehicle designs may have to be realized, for example, incorporation of all-weather enclosures for the operator and at least one passenger, and more automated control and stability for the vehicle.

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[41] "IT'S A FINE LINE: Motorcycle Safety – Target Zero – Washington State" http://itsafineline.com (accessed November 12, 2017)

[42] International Energy Agency. (2017). Global Electric Vehicle Outlook 2017. http://www.iea.org/publications/freepublications/publication/global-ev-outlook-2017.html

[43] Dalia Research. (2017). "Electric Bikes and Bike Sharing Making Headway in China." March 17, 2017. https://daliaresearch.com/electric-bikes-and-bike-sharing-making-headway-in-china/

[44] Fairley P. (2005). China's Cyclists Take Charge: Electric Bicycles are Selling by the Millions Despite Efforts to Ban Them. IEEE Spectrum 42. 54–59.

[45] Jones, T., Harms, L., & Heinen, E. (2016). "Motives, Perceptions and Experiences of Electric Bicycle Owners and Implications for Health, Wellbeing and Mobility." Journal of Transport Geography, 53, 41–49.