Catalyst Grant Final Project Report

Project title: Modeling Current and Future Emission Impacts of Electrifying Motorcycle Taxis (*Boda Bodas*) in Kampala, Uganda, in Partnership with Zembo

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Summary
Rapidly urbanizing cities across low and middle-income countries (LMICs) suffer from poor air quality, which contributes to morbidity and mortality. In these cities, transportation fleets are major emitters of local air pollutants and often include hundreds of thousands of fossil-fueled motorcycles. Many companies have started deploying electric motorcycles to improve air quality and health outcomes, but no studies have quantified emissions benefits of electric motorcycles. This proposal addresses this gap for a rapidly diffusing technology that could yield large, diverse benefits in an urbanizing area (Sub-Saharan Africa) home to over 1 billion people.

Our partner, Zembo, has deployed over 40 electric motorcycles and associated charging stations in Kampala, Uganda. Working with Zembo, this proposal quantified how electrifying motorcycle taxis affects emissions of local and global air pollutants in Kampala. With data and feedback from Zembo, we built an integrated modeling framework that quantifies emissions given interactions between motorcycles, travel, charging infrastructure, and the electric grid.

We found that electrifying gas-powered motorcycle taxis would reduce carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (NO_x), and hydrocarbon emissions by 38%, 90%, 58%, and 97%, respectively, but would increase sulfur oxide (SO_x), particulate matter 10 µm or less (PM_{10}), and particulate matter 2.5 µm or less ($PM_{2.5}$) emissions by 870%, 109%, and 97%, respectively. CO, NO_x, hydrocarbons, SO_x, PM_{10} and $PM_{2.5}$ are all local air pollutants that drive morbidity and mortality. PM and SO_x emission increases stem from generation at bagasse (sugarcane biomass) and heavy fuel oil electricity generators, which are far from load centers. Overall, we found clear and potential sustainability benefits of electrifying motorcycle taxis in Kampala.

Our work resulted in a peer-reviewed publication currently under review. We have also disseminated some of our results through an accompanying MS project in the School for Environment and Sustainability, and will engage in further dissemination leveraging local contacts once published. Zembo has also found our work valuable in understanding their value and in driving future actions.

Project background and approach

Cities across Africa suffer from poor air quality [1, 2], which contributes to morbidity and mortality [3, 4]. In Kampala, Uganda, air pollution levels frequently exceed levels deemed safe for humans by the World Health Organization [5, 6]. Improving air quality through reduced emissions of air pollutants would significantly improve health outcomes [3, 7, 8].

Transportation is a major emitter of local air pollutants, and transportation fleets include hundreds of thousands of motorcycles in Kampala and other cities in Africa, Southeast Asia, and South America [10, 11]. If replacing diesel and gas with electric motorcycles reduces pollutant emissions and improves air quality, then electrifying the motorcycle fleet could yield significant health benefits. The extent of environmental benefits of electric motorcycles depends on how those motorcycles are charged, as associated emissions come from electricity generation.

Our partner Zembo [9] has deployed over 100 electric motorcycles in Kampala and has significant near-term expansion plans. Electric motorcycles are also rapidly growing in other sub-Saharan

African cities [12–14], with Rwanda even considering banning gasoline motorcycles [15]. Understanding the air quality and health benefits of electric motorcycles is crucial for policymakers, companies deploying motorcycles, and companies' financers.

Research on electric motorcycles lags deployment, as no studies quantify emissions benefits of electric motorcycles in Africa or elsewhere. In a PhD thesis, Farquharson [16] provides a first-order estimate of emissions and health benefits of switching from gasoline to electric motorcycles in Kigali, Rwanda. This work lacks a long-range perspective by focusing on the present and lacks an integrated framework that captures interactions between transport and electric power. Other work estimates emission benefits of bicycles (not motorcycles) in China [17, 18].

Our research filled this knowledge gap for a rapidly diffusing technology that could yield large, diverse benefits in a rapidly urbanizing area home to over 1 billion people. **Working with Zembo, we quantified how electrifying motorcycle taxis affects emissions of local and global air pollutants in Kampala, Uganda.** To do so, we built an integrated modeling framework that captures interactions between travel, charging infrastructure, electric grid operations, and emissions.

Our partner was Zembo, an electric motorcycle company founded in 2017 by Étienne Saint-Sernin and Daniel Dreher. Zembo has over 100 electric motorcycles and several charging stations with distributed solar in operation in Kampala. Zembo partners with SafeBoda, a popular ride-hailing app that emphasizes driver safety, and sells most of its motorcycles to SafeBoda drivers through conventional lease-to-own arrangements. The company generates revenues from these leases, battery charging and swapping for their drivers, and used battery sales in second-life markets. Zembo participated in our research through reviews, data, and stakeholder connections. Zembo's interest stems from wanting to analyze their impact on emissions to guide their operations and expansion and secure funding through green bonds.

Findings

Our work's findings are detailed in our peer-reviewed publication currently in review. In that publication, we provide synthetic summary data for Zembo's boda boda trips, enabling follow-on research. We also quantify emissions impacts of electric versus conventional boda bodas across numerous sensitivities. Below, we highlight our main findings.

Given charging demand of 1.40 MWh/year/motorcycle taxi (or boda boda), we optimize power system operations with and without motorcycle charging demand to estimate the electricity source for charging. We find charging demand is met by large hydropower plants (LHPP), bagasse and heavy fuel oil (HFO) generators, with each generator type meeting charging demand in a particular quarter in all scenarios except 10,000 motorcycle taxis. LHPP generators serve motorcycle taxi demand in Q1 and Q3, bagasse generators serve it in Q2, and HFO generators serve it in Q4. This seasonal allocation is due to the quarterly budgets and is discussed in Section 3.2.1. With the charging demand fairly evenly distributed throughout the year, LHPP, bagasse, and HFO serve 0.75 MWh, 0.37 MWh, and 0.38 MWh respectively. As the load is served by primarily a single generator type in each season, the ratio of energy provided by these fuel types remains fairly constant as we increase the number of motorcycle taxis to 1,000.

Due to electricity generation changes, each motorcycle taxi's annual charging emissions total 972 kg CO2, 6.2 kg CO, 1.3 kg NOx, 2.9 kg SOx, 1.0 kg PM10, 0.8 kg PM2.5, and 0.3 kg HC. Annual charging emissions per motorcycle taxi vary little (by +/- 6.6 kg CO2, +/- 0.1 kg all others) between the 80, 250 and 1,000 motorcycle taxi scenarios (Figure 1). Gas-powered motorcycle taxis annually emit 1,560 kg CO2, 61 kg CO, 3.1 kg NOx, 0.3 kg SOx, 0.5 kg PM10, 0.4 kg PM2.5, and 11.2 kg HC with little variation (by +/- 1 kg CO and +/- 5 kg CO2). Thus, we estimate switching from gasoline to electric motorcycle taxis would reduce emissions of CO2 by 38%, CO by 90%, NOx by 58%, and HC by 97%, but would increase emissions of SOx by 870%, PM10 by 109%, and PM¬2.5 by 97%. On an annual basis, for every motorcycle taxi converted to electric, emissions would be reduced by 588 kg

CO2, 55 kg CO, 1.8 kg NOx, and 10.9 kg HC but would be increased by 2.6 kg SOx, 0.5 kg PM10, and 0.4 kg PM2.5.

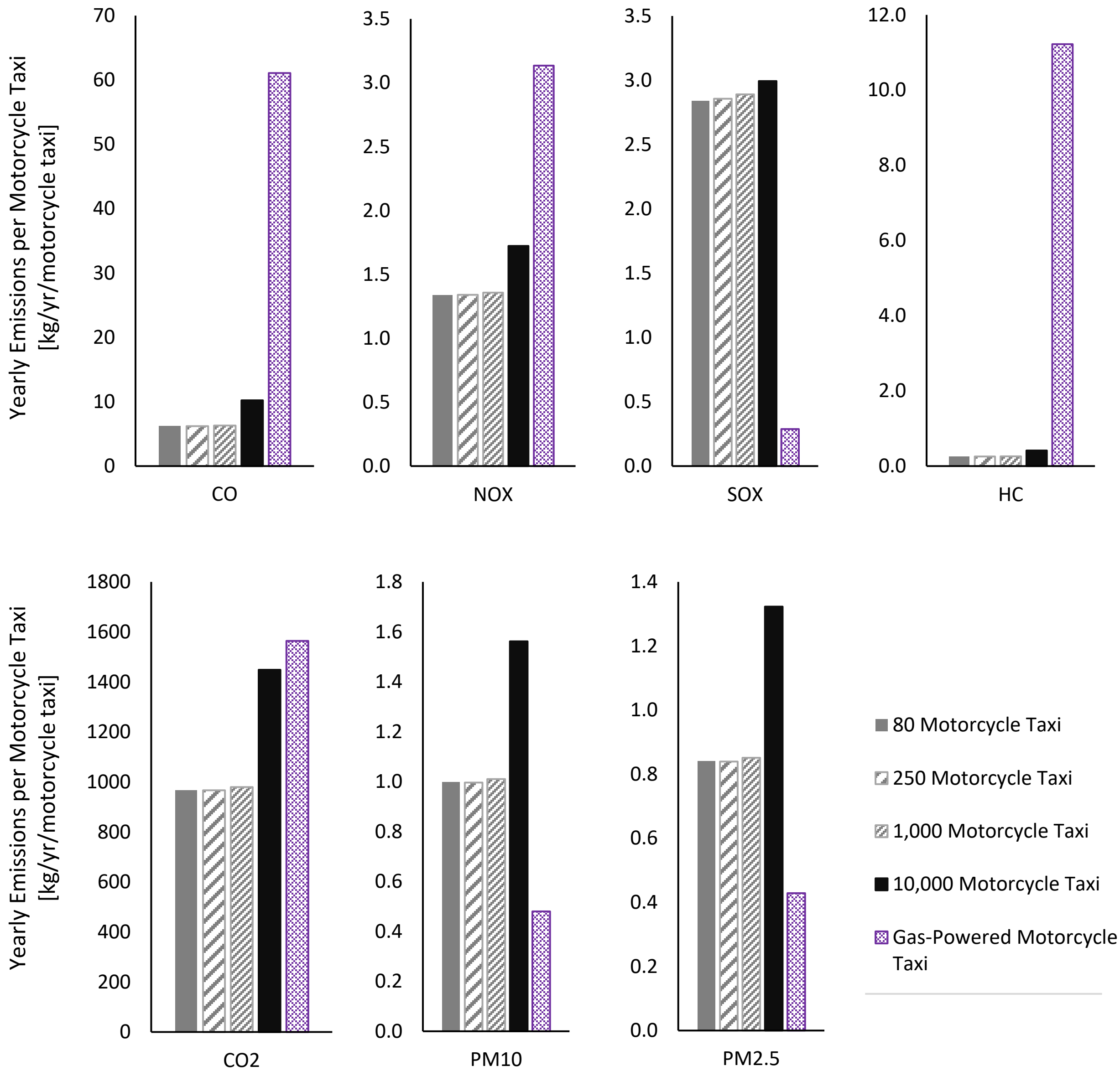

Figure 1: Annual emissions (in kg) per motorcycle taxi across scenarios. Note differing y-axis scales between pollutants.

Outputs

Our project yielded a publication currently under review. In that publication, we estimated emission benefits of Zembo's current operations and of a widespread shift to electric motorcycles across Kampala. As demonstrated in our findings above, we quantified emissions impacts of Zembo's current fleet and of larger penetrations. These outputs, once published, will be usable by all NGOs, governments, and private companies participating in the boda boda market. Our publication also quantified emission benefits of changes to current operations for Zembo, namely from installing distributed solar at charging stations. This output is valuable to guide Zembo's near-term actions.

Our study also yielded an integrated, flexible, open source modeling framework that Zembo, government agencies (e.g., the Ministry of Works and Transport), and others can use to estimate the emission implications of their actions. With location-specific data, our framework could be applied to estimate benefits of new transport technologies in the many other rapidly urbanizing cities in LMICs, such as Nairobi and Kigali. This framework will be made publicly available on github when our publication is published.

Outcomes

Our research, publication, insights, and frameworks will contribute to positive changes in Kampala and possibly other cities in LMICs. Our work provided Zembo actionable information regarding their operations and near-term expansion – namely, expanding their electric boda boda will continue to yield environmental benefits, and rooftop solar deployment can yield further environmental benefits. These benefits, in turn, will likely reduce morbidity and mortality from local air pollution.

In demonstrating these benefits, our work supports further expansion of electric boda bodas from the perspective of environmental impacts. This might improve Zembo's access to funding, although this has not occurred yet. We also, once published, will disseminate our report to government and NGO contacts in Uganda, which can help inform policies related to electric boda bodas and support other ongoing projects in the region, e.g. by Airqo.

Our modeling framework and initial results from this project will serve as pilot data in other funding opportunities. This outcome has not yet been realized – PI Craig plans to conduct follow-on proposal writing within the next year.

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