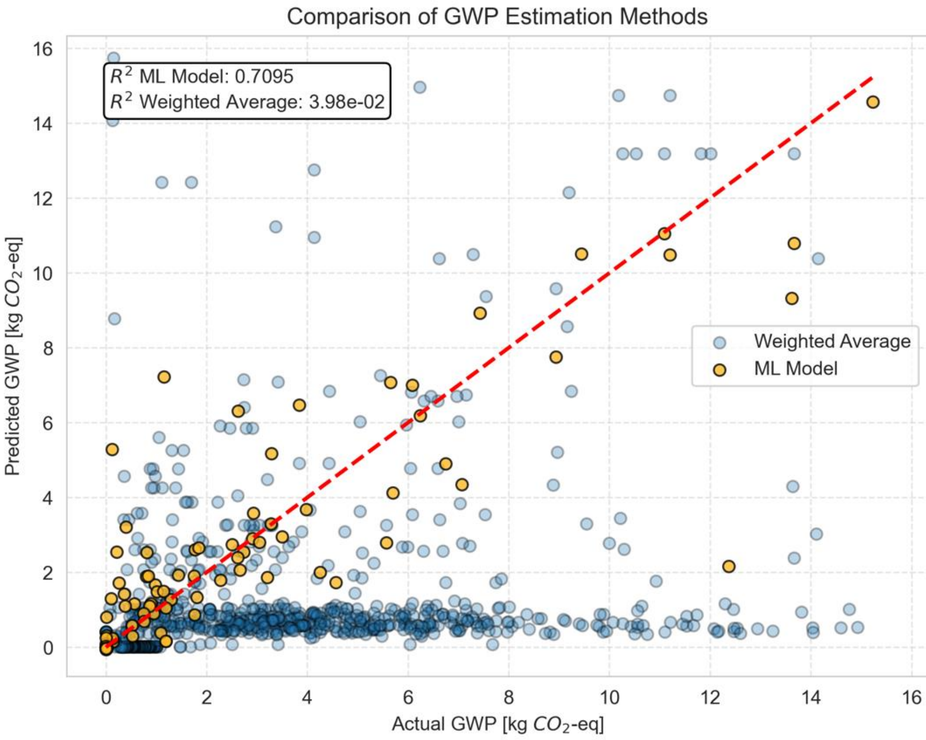
Environmental Impact Assessment and Predictive Materials Estimation of Munich's Shared Electric Scooter Fleet within the Life Cycle Assessment Framework

Master's Thesis of Santiago Buitrón Soto

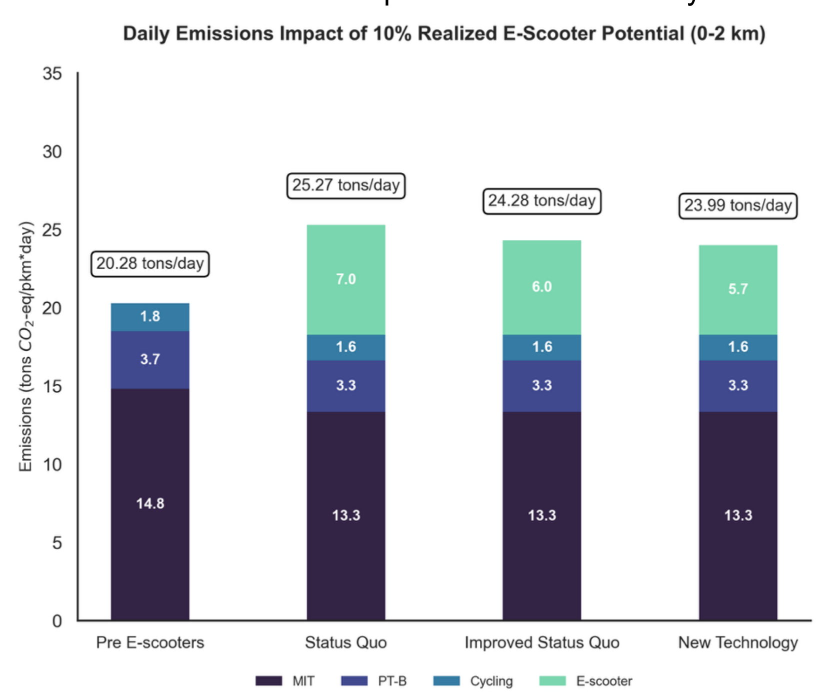
Mentoring:
Fabian Fehn, M.Sc.
Mario Ilic, M.Sc.

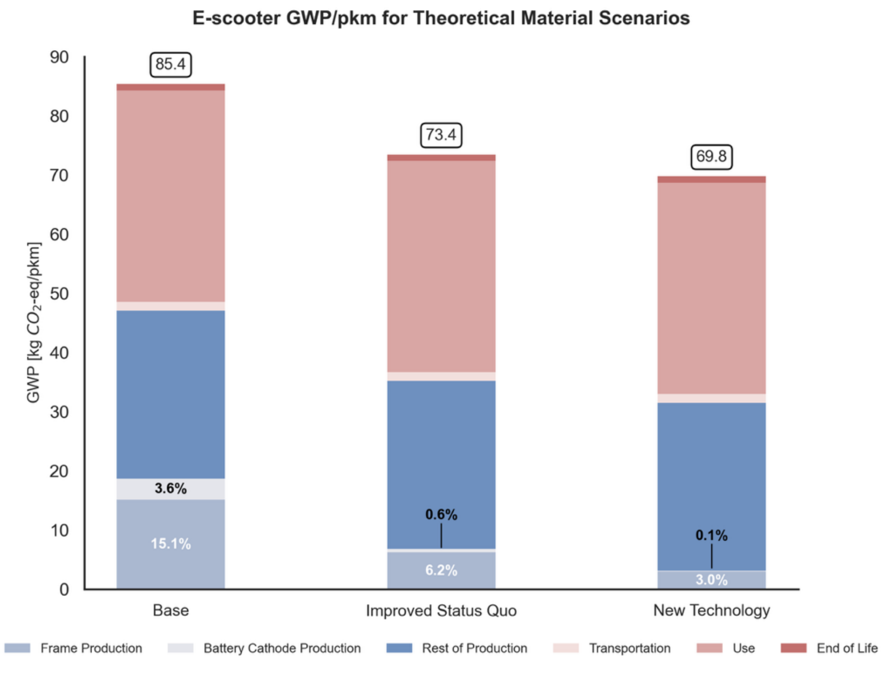
External Mentoring:
Dr. Sebastián Caicedo-Dávila (ExoMatter GmbH)



Munich's shared electric scooter fleet has rapidly grown since 2019, offering new micro-mobility options but raising concerns about its environmental impacts on a microscopic and macroscopic scale. The larger modal shift and integration impacts of e-scooters have yet to be analyzed since robust mobility reports such as the Mobilität in Deutschland have not released reports since this mode's introduction in the late 2010s. Life Cycle Assessment (LCA) studies show that the aluminum frame and lithium battery cathode account for nearly 20% of all life cycle emissions, showing a need to find more sustainable material alternatives. However, conducting LCAs for every possible material alternative is impractical and nearly impossible considering the billions of possible materials within the field of materials research and development (R&D). Thus, estimation methods are considered such as machine learning (ML) models to instantaneously provide a global warming potential (GWP) prediction. This thesis explores the feasibility of employing ML to estimate the GWP for theoretical inorganic materials, and how these materials can be applied to Munich's ES fleet. Further, the present and future integration effects of ES on Munich's transport emissions are analyzed.

This study combined LCA and ML techniques to predict the GWP impact from ES materials. First, the ML model was created through an iterative process, considering several model families, techniques, and descriptor types. Then, Munich's transport emissions were estimated before and after ES introduction by using substitution potential (SP) methods derived from literature and Mobilität in Deutschland's 2017 reports. A hotspot analysis on ES emissions helped determine the two major contributing materials, which became the focus of the theoretical material search and screening within the ExoMatter R&D platform. Next, the ML model was used to predict the GWP of these material candidates and an LCA was re-calculated with these new materials in mind, allowing for a microscopic comparison between the old ES composition and theoretical scenarios. Coupling the SPs with the new LCA results, a macroscopic view of the integration effects throughout Munich were obtained to highlight the effects of ES on the present situation, while also creating long-term forecasts to analyze the potential future impacts.





The ML model predicted the GWP of inorganic materials with an R^2 of 0.71, providing a viable alternative to full LCAs for early-stage material screening. Replacing high-emitting materials for theoretical and feasible materials found in the ExoMatter platform led to an 18% decrease in GWP emissions per person-kilometer travelled. The introduction of ES increased GWP emissions by nearly 5 tons CO_2-eq daily due to the frequent substitution rates of low-carbon mode trips such as walking (32%) and cycling (21%). However, under realistic scenarios, improved materials could help mitigate up to 1.3 tons CO_2-eq daily. Despite this, ES still led to a net emission increase, and over a 10-year forecast, could add over 90,000 tons CO_2-eq to Munich's transport sector. This study effectively demonstrates ML's potential as a predictive tool within the LCA framework and its possible applications in materials R&D. The results also suggest broader adoption of ML could significantly enhance sustainability in urban mobility systems. This thesis also calls for policy considerations to ensure actual carbon savings from ES and positive integration with sustainable modes of transport.