2020 Fifteenth International Conference on Ecological Vehicles and Renewable Energies (EVER)

Interdependence of charging infrastructure and battery demand of light electric 3-wheel motor taxis

Benedikt Hanke
German Aerospace Center
Institute of Networked Energy Systems
Carl-von-Ossietzky-Str. 15
26129 Oldenburg, Germany
Email: benedikt.hanke@dlr.de

Mirko Goletz
German Aerospace Center
Institute of Transport Research
Rudower Chaussee 7
12489 Berlin, Germany
Email: mirko.goletz@dlr.de

Christian Wachter
German Aerospace Center
Institute of Vehicle Concepts
Pfaffenwaldring 38-40
70569 Stuttgart, Germany
Email: christian.wachter@dlr.de

Meike Kühnel
German Aerospace Center
Institute of Networked Energy Systems
Carl-von-Ossietzky-Str. 15
26129 Oldenburg, Germany
Email: meike.kuehnel@dlr.de

Daniel Ehebrecht
German Aerospace Center
Institute of Transport Research
Rudower Chaussee 7
12489 Berlin, Germany
Email: daniel.ehebrecht@dlr.de

Frank Rinderknecht
German Aerospace Center
Institute of Vehicle Concepts
Pfaffenwaldring 38-40
70569 Stuttgart, Germany
Email: frank.rinderknecht@dlr.de

Benedikt Nickel
German Aerospace Center
Institute of Networked Energy Systems
Carl-von-Ossietzky-Str. 15
26129 Oldenburg, Germany
Email: benedikt.nickel@dlr.de

Barbara Lenz
German Aerospace Center
Institute of Transport Research
Rudower Chaussee 7
12489 Berlin, Germany
Email: barbara.lenz@dlr.de

Deborah Tolk
German Aerospace Center
Institute of Networked Energy Systems
Carl-von-Ossietzky-Str. 15
26129 Oldenburg, Germany
Email: deborah.tolk@dlr.de

Karsten von Maydell
German Aerospace Center
Institute of Networked Energy Systems
Carl-von-Ossietzky-Str. 15
26129 Oldenburg, Germany
Email: karsten.maydell@dlr.de

Carsten Agert
German Aerospace Center
Institute of Networked Energy Systems
Carl-von-Ossietzky-Str. 15
26129 Oldenburg, Germany
Email: carsten.agert@dlr.de

Abstract—**The paper analyses the role of publicly accessible single phase charging infrastructure with charging currents of 7 A, 10 A and 16 A in the low voltage grid for an economically viable transformation of the informal transport market of three-wheeler motorcycles in Dar es Salaam from fossil propulsion to battery electric drives. An intensive stakeholder process is conducted to analyse the socioeconomic boundary conditions for this transformation. GPS track data of 65 vehicles in four driver groups is collected for 8 days apiece. The data is analysed to study the driving demand of the informal transport market in Dar es Salaam.**

Our results show that the increased weight of lead acid batteries cannot be easily compensated for by installing additional charging opportunities. Coincidence factor analysis reveals, that sharing of opportunity charging infrastructure is possible without reduction of the service level. Li-ion batteries plus publically accessible charging infrastructure shows the potential for the transformation within the next 10-15 years.

Keywords—charging infrastructure, vehicle battery demand, socioeconomic context, three wheeler, informal transport

I. INTRODUCTION

Motorcycle-taxis are an important means of transport in rural areas and increasingly in urban areas in Sub-Sahara Africa (SSA) [1-3]. The popularity of these mobility services results from their ability to fill supply gaps in local transport systems, which result from strong urban growth, ineffective urban and transport planning, and the deterioration of public transport [4-6]. However, besides improving mobility, they also lead to compromised road safety and air pollution [7-9]. In order to stronger regulate these means of transport – and to reduce their negative effects – three-wheeler motorcycle-taxis are increasingly recognized as a legitimate means of transport by local and national governments [3, 8].

In Tanzania traffic laws were amended in 2010 in order to legalize the motorcycle-taxis [10]. Over 830 000 two-wheelers and more than 50 000 three-wheelers were registered in 2014 [11]. In its 2018 report on road safety the WHO reports 1 282 503 two- and three-wheeler motor-cycles in the country, accounting for 59 % of all registered vehicles in the country [13]. A large share of the three-wheeler motor-cycles operate in Dar es Salaam [12]. Over 90 % are operated with a commercial background [14]. They complement the public transport system and are often used as trunk-feeder-services, connecting main roads with adjacent residential areas [15].

Being a shared mode of transport that is used by numerous passengers during a day, there is potential to make them become an integrated part of a sustainable mobility system of the 21st century by abandoning the combustion fuelled engine and going full electric driven by renewable energies. The business case of the vehicle drivers and owners is very cost sensitive, so the transformation of these vehicle fleet into a zero-emission fleet requires economically viable concepts for the vehicles and the charging infrastructure. An understanding of the mechanisms of the current system - including income and costs, distances covered, operating and parking hours – and an assessment of possible impacts and technical requirements of an electrification is therefore a crucial first step.

Fig. 1: three-wheeler motorcycle taxi outside Dar es Salaam

II. METHODOLOGY, DATA OVERVIEW, SOCIAL AND ECONOMIC CONTEXT

The study at hand was conducted as a multi-step process using a mixed-methods approach, including measurement of the vehicle driving profiles, handwritten driver documentation, stakeholder interviews and data analysis, all carried out in Dar es Salaam, Tanzania.

GPS tracking to get the vehicle driving profiles was conducted with 1 second resolution in time using the moving lab[1]. Four different groups of drivers in Dar es Salaam where tracked between Nov. 11th and Dec. 10th 2018. The tracking devices were assigned to one vehicle for 8 days apiece, collecting a weekly driving behaviour profile. The drivers were asked to take notes for clarification of measurement artefacts. During the measurement campaign 65 individual vehicle profiles with over 18 million individual data points were collected (see Figure 2, left). The distance driven during one week is shown in Figure 2, right. Over 400 km per week are driven by 50 % of the tested vehicles and 90 % of all vehicles drive less than 800 km per week. The longest distance recorded during one week by a single vehicle was 1150 km.

The main parking spots of the drivers were identified using a histogram methodology by measurement of the

---

[1] https://movinglab.dlr.de/

number of data points (see Figure 3, right). This data is coherent with the recorded knowledge from the driver interviews conducted during the stakeholder consultation. Six public spots were identified as suitable public or semi-public charging locations to conduct opportunity charging (see Figure 3, left, spots marked in red).

The number of vehicles parked in one of the six potential charging locations is shown in Figure 4. Most of the time, one vehicle is always available at the station with very few exceptions. Most vehicles are available around noon. Vehicle availability is higher during the day than during the night. Depending on the ownership model, vehicles are operated on a 1-shift or 2-shift bases.

The number of vehicles during the week of test and the maximum number of vehicles at any station during that week is shown in Table 1. The coincidence factor is between 60 % and 80 %. If all vehicles need access to a charging point whenever they are at the station, 5 vehicles can share 3-4 charging points. This number might be further reduced by taking the actual charging demand into account, but requires further analysis of the data.

Table 1: Number of vehicles under test and maximum number of vehicles at any given station

week	**# vehicles under test**	**max. # vehicles at station**	**coincidence factor**
1	10	6	60 %
2	14	11	79 %
3	21	14	67 %
4	20	16	80 %

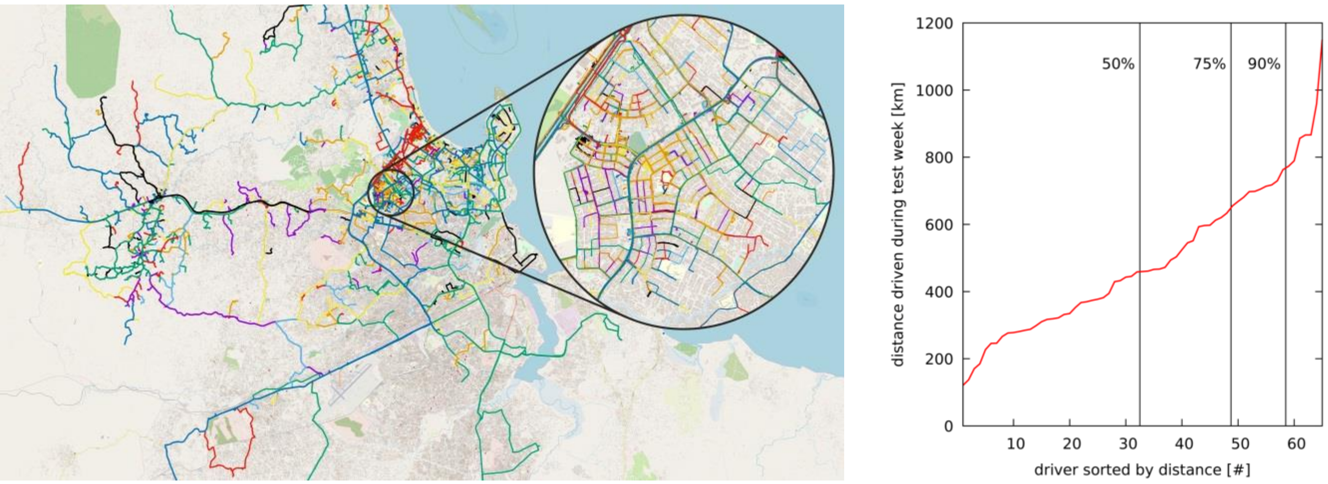

Figure 2: Impression of data collected, map is oriented north (left, with map material from „©OpenStreetMap contributors, CC-BY-SA, www.openstreetmap.org/copyright“) and distance per vehicle driven during one week sorted by distance (right)

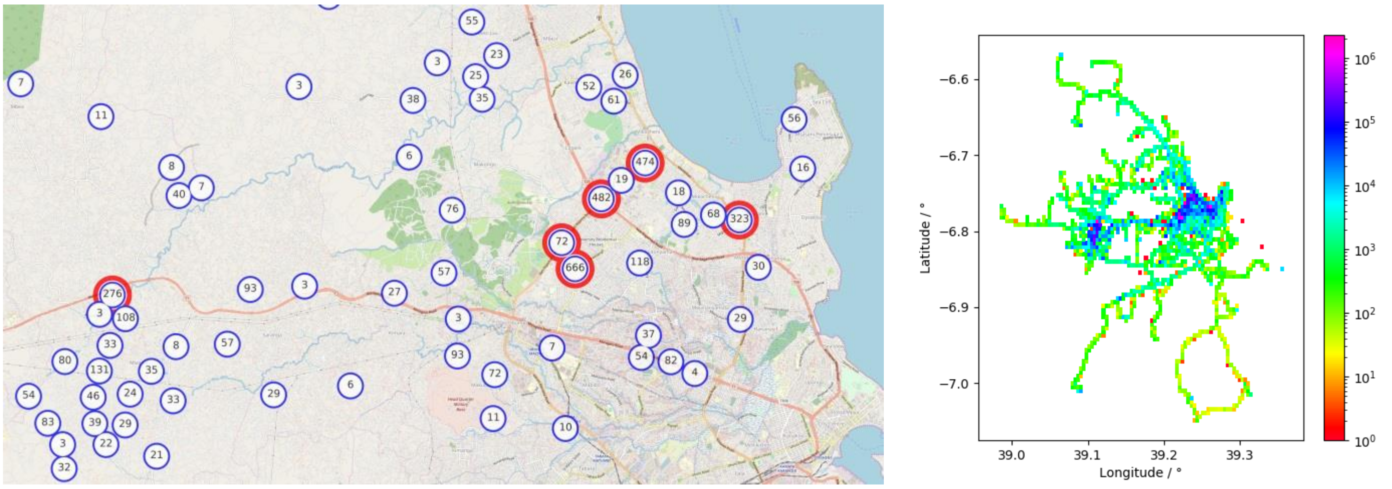

Figure 3: Opportunity charging locations (red) and parking locations with parking times greater 3 hours (blue). The circled numbers represent the number of hours spend within 600m of the location if parking time was longer than 3 hours (left, with map material from „©OpenStreetMap contributors, CC-BY-SA, www.openstreetmap.org/copyright“). Histogram of the measurement campaign representing the number of measurement points used to identify suitable locations for opportunity charging.

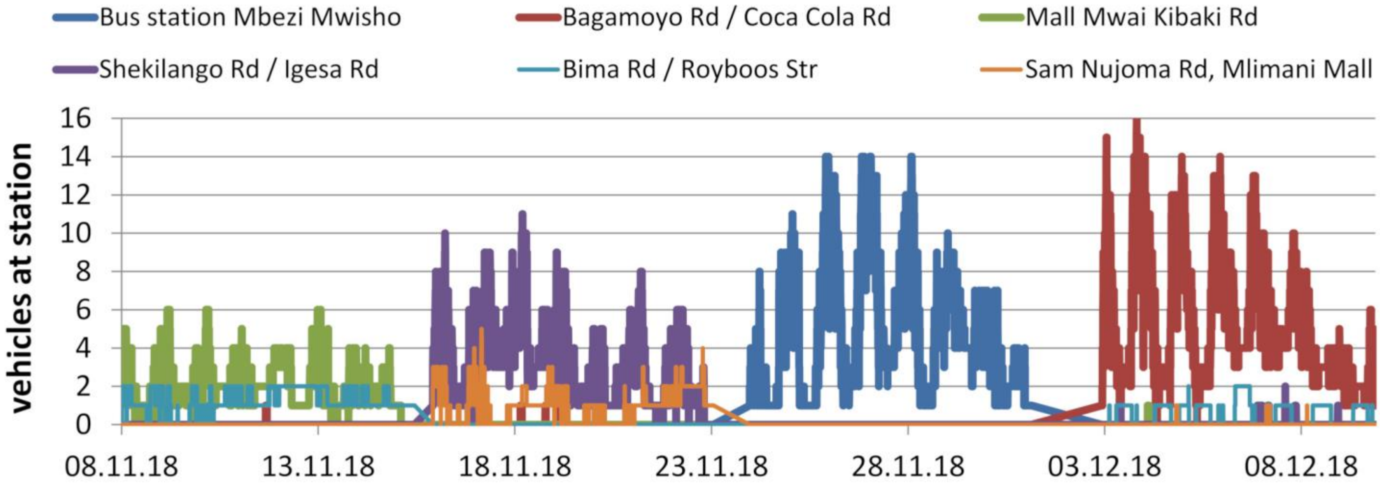

Figure 4: Number of vehicles parked at one of the identified stations (compare Figure 3). Date marks are set at 12:00 UTC.

In terms of charging it was assumed, that every parking event longer than 3 hours is used to charge the vehicle with the given charging power. This assumption recognizes the fact that current fossil fuel driven vehicles can be parked anywhere and refuelled very fast. Introducing a technology change would incentivize drivers to select long term parking spots to recharge the vehicles during breaks. The following filter was applied: If a parking event takes place within 300m of an opportunity charging station and takes longer than 10 minutes, it was used for charging, but 10 minutes are deducted for arriving, connecting and unplugging. During charging a loss of 10 % from grid to battery was considered. A constant current was assumed during the charging process, independent of the state of charge of the battery. This assumption underestimates the time needed to charge the last 20 % effective capacity of the battery, which results in an underestimation of the minimal charging station demand. The authors aim at introducing a more realistic charging model in future analysis of this data.

A stakeholder consultation conducted February 3rd-9th 2019 by the authors in Dar es Salaam included interviews of drivers, driver associations, regulatory bodies and vehicle vendors. One crucial aspect and concern of all stakeholders is the investment cost for the transition towards electrically driven vehicles. Generalizing the investment cost for a vehicle as reported from different parties, the cost is between 2700 US$ and 3500 US$ for a factory new vehicle. The drivers are favouring electricity over gasoline vehicles for the promise of reduced fuel cost at constant investment cost. A concept for the electrification of the three wheeler taxi fleet needs to acknowledge the limited availability of financing opportunities in this market segment.

The economic and social framework does not allow for expensive solutions like DC fast charging, battery swapping or inductive charging, as these solutions increase the upfront investment demand per operated vehicle[2]. Technologically simple and cheap to install recharge opportunities at the central gathering points of the drivers could create additional job opportunities and reduce the battery storage demand for the vehicles, therefore significantly cutting the vehicle price.

Based on the stakeholder consultation, this study analyses the interdependence between the minimum sizing of the vehicle battery and the availability of charging infrastructure at the main parking spots of the drivers for different battery technologies (lead acid, Li-Ion) and AC connection currents (7A / 1610W, 10A / 2300W, 16A / 3680W[3]) to identify the point of minimal cost for the operation of an electric three wheel taxi in Dar es Salaam.

According to a local vendor, the current life time of a three wheeler in Dar es Salaam is 3.5 to 6 years driving 30 000 km per year and 100 km to 200 km per day. Taking a life time distance of 180 000 km as a benchmark, a battery capacity of 100 km would result into 1800 full battery cycles, a capacity of 50 km into 3600 full battery cycles. Currently Li-ion battery technologies reaches 1500-2000 cycles with 3000 cycles expected in 2030 [17]. The vehicle life of battery electric three wheeler with 50 km travel distance could therefore reach 150 000 km in 2030.

An analytical vehicle model was created to deduct the driving demand for different battery technologies and battery sizes. A driving cycle based on the measurement campaign was developed to calculate the average de-

---

[2] This includes the investment for the vehicle and the individual partial cost of he required shared infrastructure to operate it.

[3] AC connection currents where translated into available AC power by assuming a constant 230V at the connection point. This was used as the charging power of the batteries by deducting 10 % losses. Only constant power charging was used with no other complexity applied.

mand per 100 km [16]. An overview of the resulting energy demand per 100 km is presented in Table 2. Due to the increased battery weight, lead acid demand values are more wide spread than Li-ion. The average driving demand values were used for a first assessment of the effectiveness of opportunity charging stations. The authors aim at using the created vehicle model to individually calculate the energy demand per track based on velocity, acceleration and slope.

Ensemble simulations were conducted to identify the range of energy storage demand in the vehicle battery with focus on the identification of the effectiveness of the availability of opportunity charging stations. The simulations neglect, if the demand was calculated based on smaller batteries than required, resulting in a range of required effective battery capacity.

Table 2: Energy demand ranges for modelled vehicles with Li-ion and lead acid type batteries and 150kg and 300kg payload (passengers plus freight).

kWh/100km	**150kg payload**	**300kg payload**
Li-Ion	5.31-5.81	5.94-6.45
Lead Acid	5.66-7.28	6.31-7.95

III. RESULTS AND DISCUSSION

The battery demand of the vehicles to fulfil the mobility needs of the tested individual vehicles with and without opportunity charging is shown in Figure 5, distinguishing between lead acid (top) and Li-ion (bottom) battery technology. The individual lines represent combinatorial scenarios with 7 A, 10 A and 16 A charging station current as well as demand values for 4 kWh-16 kWh technical battery capacity in steps of 2 kWh at 150 kg and 300 kg weight of the passengers and freight. This results in an underestimation of the battery demand for technical battery requirements above 16 kWh (ca. 12 kWh effective battery capacity). The battery capacity demand distributions are fully separable and only overlap for very high capacity demands in the case of lead acid battery technologies. The possibility of opportunity charging results in a more wide spread result of required effective battery capacities.

To reduce the battery capacity demand of electric three-wheel motor-cycles, the availability of opportunity charging stations at central parking points is a viable measure. To serve 75 % of the tested individual cases, the maximum calculated effective vehicle battery storage capacity is reduced from 10.3 kWh to 5.8 kWh in the case of Li-ion and from 14.4 kWh to 7.6 kWh in the case of lead acid. The calculated effective energy demand range to cover 75 % of the measured driving cycles is given in Table 3.

Table 3: Effective battery energy demand range to satisfy 75 % of the measured weekly driving profiles of three wheel taxis.

kWh_{eff}	**Li-ion**	**lead acid**
w/o opportunity	9.20±1.06	11.53±2.89
w/ opportunity	4.95±0.80	6.01±1.59

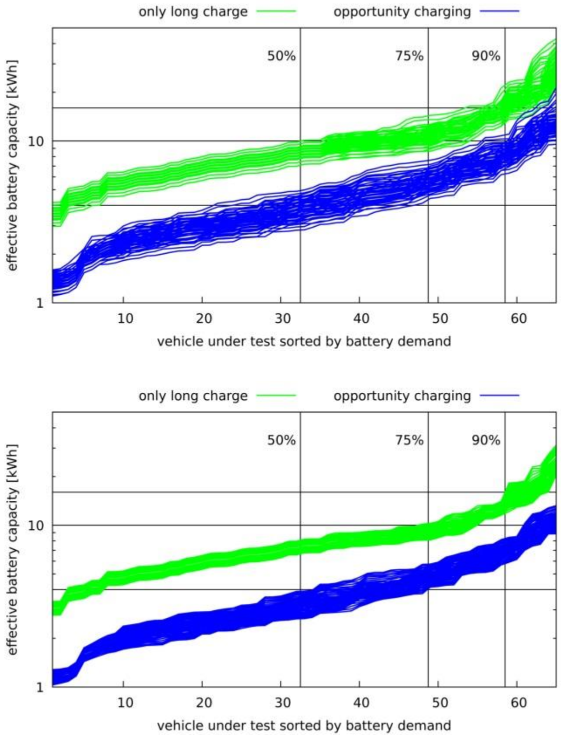

Figure 5: Battery demand to fulfil the mobility demand with and without opportunity charging availability for lead acid (top) and Li-ion (bottom) based battery technologies. Please acknowledge the logarithmic y-axes.

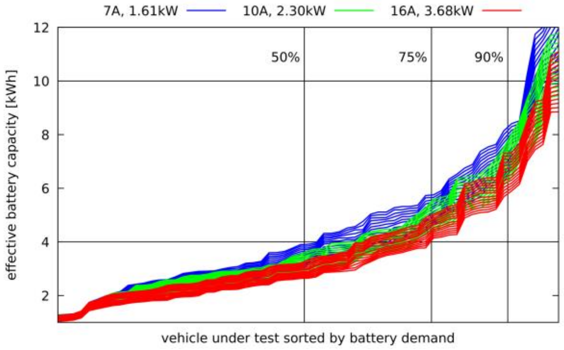

Figure 6: Battery demand to fulfil the mobility demand with opportunity charging availability Li-Ion (bottom) based battery technologies for different charging currents.

The effective battery demand per vehicle under test split into the different charging current scenarios is depicted in Figure 6. As expected larger charging currents result in generally lower effective battery demands. A near doubling of the charging current only results in a reduction of 10 % to 20 % of the effective battery capacity demand.

In order to replace fossil fuel driven vehicles, the battery electric vehicles need to compete in price and benefit on the cost sensitive Tanzanian market. The availability of accessible charging infrastructure in between rides is crucial to the economically viable operation of battery electric motor-cycles. Household typical charging currents can drastically reduce the effective battery demand for the operation of an electric three-wheel motor-cycle taxi in Dar es Salaam.

The measured coincidence factors suggest the possibility for shared infrastructure that requires fairly low investments, opening the opportunity for additional jobs created around these electro mobility activities.

Current studies suggest battery pack prices will become less than half the current price until 2030 at a planned vehicle life time of 150 000 km. Prices between 75 €/kWh [17] and 84 €/kWh [18] seem to be a reasonable estimate. This would put the price of a battery pack for an electric Bajaj to below 1000 US$. Under such developments, battery prices would become less of a hurdle for a technology transformation in the informal transport sector of developing countries.

The authors conclude that smartly dimensioned Li-ion batteries plus publicly accessible charging infrastructure has the potential to support the transformation within the next 10-15 years.

ACKNOWLEDGMENT

The authors acknowledge the involvement, time and patience of all stakeholders during the interviews. The authors thank the German Aerospace Centre (DLR) for the funding of the project activities.

REFERENCES

[1] L. Diaz Olvera, D. Plat, P. Pochet and M.Sahabana, “Motorized Two-Wheelers in Sub-Saharan African Cities: Public and Private Use,” presented at the 12th World Conference on Transport Research, Lisbon, Portugal, July 11-15 2010.

[2] D. Ehebrecht, D. Heinrichs, B. Lenz, “Motorcycle-taxis in sub-Saharan Africa: Current knowledge, implications for the debate on ‘informal’ transport and research needs,” *Journal of Transport Geography*, vol. 69, pp. 242-256, 2018.

[3] P. Starkey, “The Benefits and Challenges of Increasing Motorcycle Use for Rural Access,” presented at the International Conference on Transport and Road Research, Mombasa, Kenya, March 16-18 2016.

[4] J. Evans, J. O'Brien and B. Ch Ng, “Towards a geography of informal transport: Mobility, infra-structure and urban sustainability from the back of a motorbike”, *Transactions of the Institute of British Geographers*, vol. 43, no. 4, pp. 674-688, Dec. 2018, doi: 10.1111/tran.12239.

[5] J. Klopp, “Towards a Political Economy of Transportation Policy and Practice in Nairobi,” *Urban Forum*, vol. 23, no. 1, pp. 1-21, Mar. 2012, doi: 10.1007/s12132-011-9116-y.

[6] A. Kumar, “Understanding the emerging role of motorcycles in African cities. A political economy perspective,” Sub-Saharan Africa Transport Policy Program (SSATP) Discussion Paper 13. Washington, DC: World Bank. p. 9, 2011.

[7] C.M. Adiang, D. Monkam, E. Njeugna and S. Gokhale, “Projecting Impacts of Two-Wheelers on Urban Air Quality of Douala, Cameroon,” *Transportation Research Part D*, vol. 52, pp.49-63, 2017.

[8] L. Diaz Olvera, A. Guézéré, D. Plat and P. Pochet, “Earning a Living, But at What Price? Being a Motorcycle Taxi Driver in a Sub-Saharan African City,” *Journal of Transport Geography*, vol. 55, pp.165-174, Jul. 2016, doi: 10.1016/j.jtrangeo.2015.11.010.

[9] G. Pirie, “Transport Pressures in Urban Africa: Practices, Policies, Perspectives,” in *Africa’s Urban Revolution*, S. Parnell and E. Pieterse, Eds., London, Great Britain, ZED Books, 2014, pp. 133-147.

[10] “The Transport Licensing (Motor Cycles and Tricycles) Regulations,” Republic of Tanzania, 2010.

[11] T. Bishop and P. Amos, ”Opportunities to Improve Road Safety Through ‘Boda-Boda’ Associations in Tanzania,” Final Report. Thame, UK: AFCAP/ASCAP Project Management Unit, Cardno Emerging Market (UK) Ltd., p. 16, 2015.

[12] C.C. Mkalawa and P. Haixiao, “Dar es Salaam City Temporal Growth and its Influence on Transportation,” *Urban, Planning and Transport Research*, vol. 2, no. 1, pp. 423-446, Aug. 2014, doi: 10.1080/21650020.2014.978951.

[13] “Global Status Report on Road Safety,” Geneva, Switzerland, World Health Organization - Management of Noncommunicable Diseases, Disability, Violence and Injury Prevention (NVI), p. 258, 2018, ISBN 978-92-4-156568-4.

[14] Private interview of the authors with members of the “Surface and Marine Transport Regulatory Authority (SUMATRA),” Dar es Salaam, Feb. 2019.

[15] M. Goletz and D. Ehebrecht, “How Can GPS/GNSS Tracking Data Be Used to Im-prove Our Understanding of Informal Transport? A Discussion based on a Feasibility Study from Dar es Salaam,” *Journal of Transport Geography*, (in press, available online), Oct. 2018, doi: 10.1016/j.jtrangeo.2018.08.015

[16] C. Wachter, M. Schüttoff, F. Rinderknecht, B. Hanke, M. Kühnel, M. Goletz, D. Ehebrecht and B. Lenz, “Electric three-wheelers as an alternative to combustion-engined autorickshaws in Dar es Salaam - Generation of a standard drive cycle, Power Train modelling and simulation of the energy demand of light electric vehicles,” EVER 2020, Monaco, May 2020, Topic EV1-d Two- and three-wheel vehicles.

[17] M. Ierides, R. del Valle, D. Fernandez, L. Bax, P. Jacques, F. Stassin, and M. Meeus, “Advanced Materials for Clean and Sustainable Energy and Mobility – EMIRI key R&I priorities,” Energy Materials Industrial Research Initiative (EMIRI) Technology Roadmap, p. 292, Sept. 2019.

[18] “Battery requirements for future automotive applications ,” European Council for Automotive R&D (eucar), p. 4, https://www.eucar.be/battery-requirements-for-future-automotive-applications/, Aug. 2019.