Comparative analysis of city-specific EV applications for passenger transport in Asia and Africa

Subash Dhar[1][0000-0002-5090-4062] , Talat Munshi[1][0000-0001-9609-7246] , George Pangakos[2][0000-0002-3996-5358] , Shritu Shrestha[3][0000-0002-7052-9837] , Michael Bruhn Barfod[2][0000-0002-5666-5453] Marc Hasselwander[4] [0000-0002-0852-5093] , Serra Yosmaoglu[4] [0000-0003-3397-1236], Emilie Martin[3][0000-0003-3460-2299], Moise Bitangaza[5][0009-0004-0921-5507], Bachtijar Ashari[6]

[1] [1]UNEP Copenhagen Climate Centre, Marmovej 53, Copenhagen, Denmark, [2]Technical University of Denmark, 2800 Kongens LyngbyCity, Denmark, [3]Wuppertal Institute for Climate, 42103 Wuppertal, Germany,[4]German Aerospace Center (DLR), Rudower Chaussee, 12489 Berlin, [5]Urban Electric Mobility Initiative (UEMI), Kopenhagener Straße 47 10437 Berlin, Germany, [6]TNO, Anna van Buerenplein 1, 2595 DA Den Haag

Abstract. Mobility demand in developing nations has caused traffic congestion, pollution, and limited accessibility. Urban transport's negative externalities must be reduced. Improvements include sufficient, efficient and quality public transit, supporting active mobility like walking and bicycling, ridesharing and carpooling, and electric and driverless automobiles. Cities should be liveable, ecologically sustainable, and easy to navigate. The EU-funded SOLUTIONSplus project, which promotes sustainable urban mobility through electric mobility, has demonstrated e-three-wheelers in Dar es Salam, Tanzania; e-moto taxis in Kigali, Rwanda; e-mopeds and e-bikes in Hanoi, Vietnam; and remodelled Safa tempos and the newly designed e-3W for passenger services in Kathmandu. The prototypes, developed, produced and/or assembled by local firms, are expected to replace fossil fuel-powered two- and three-wheelers. They reflect local conditions and aims.The project's impact assessment process uses financial cost-benefit analysis (CBA) and multi-criteria decision analysis (MCDA) to examine potential impacts on all sustainability pillars and will be used to build a wider project that considers local stakeholders' values, goals, and viewpoints. The iterative approach makes all new vehicles profitable, with payback periods frequently under two years. Even with decreased returns, current vehicle improvements remain profitable.. In contrast, existing vehicle upgrades are usually profitable, even if they have lower return rates. The upfront cost of electric vehicles is high. Still, the total cost of operations of electric vehicles has shown that they are more profitable in the long run and also have significant social and environmental benefits.

To support e-vehicles, Governments must establish charging infrastructure, create rules that enable manufacturers (technical standards, licensing, etc.), and educate drivers and users to promote e-vehicles as last-mile connections. Last-mile connection alternatives need public transit integration to succeed. This creates a joint business model which allows possibilities of upscaling of the solutions.

Keywords: electric mobility, emerging economies, multi-criteria evaluation.

1 Introduction

In recent years, electric mobility solutions have been promoted to mitigate urban transport's negative externalities. However, the prevailing scientific research addressing this premise has primarily concentrated on isolated impacts from the adoption of electric vehicles (EVs), such as their social [1,2,], environmental[3,4,5] (, climate-related [6,7,8], financial [9,10], or economic impacts[11]. These studies predominantly rely on single-case analyses within the Global North, often using simulated, synthetic, or stated-preference data and primarily focusing on private cars. Consequently, a significant research gap exists, underscoring the need for a holistic approach that incorporates real-world data and encompasses electric public transport and shared-mobility modes, particularly in the context of the Global South.

The SOLUTIONSplus project, funded by the European Union, seeks to facilitate a transformative shift towards sustainable urban mobility by promoting electric mobility. As part of this initiative, demonstration activities have been implemented to enhance public transportation connectivity in Africa and Asia. In Dar es Salam, Tanzania, e-three wheelers have been introduced, while e-moto taxis have been deployed in Kigali, Rwanda. Similarly, in Hanoi, Vietnam, e-mopeds and e-bikes have been utilised, and in Kathmandu, Nepal, Safa tempos (old 3-3W) have been retrofitted, and new e-3W vehicles have been designed for passenger services. All the prototypes have been designed and developed locally in certain instances, manufactured by local enterprises, aiming to substitute fossil fuel-powered two- and three-wheelers. These entities are designed considering for the specific circumstances and objectives of the local context [12]. This article will provide the preliminary findings of the research, accentuation the financial assessment of the examined alternatives and the unique factors of significance to the local populations, and thereby address the stated research gaps for the geography of the global south and also for electric vehicle application in the public transport and micro-mobility options. Hanoi could not be included in the analysis due to the non-availability of data from the demo.

2 Local priorities

The KPI (Key Performance Indicators) weights in the four demo cities appear in Table 1. They resulted from a 2-round Delphi method application involving 10-20 knowledgeable individuals in each city reflecting the corresponding stakeholder priorities. The indicators are organised into six Level-1 and 20 Level-2 KPIs. Due to space limitations, lower-level (3 and 4) indicators are not shown here.

On average, the weights of the six Level-1 indicators appear balanced across the demo cities, ranging from 14.79 (climate) to 19.77 (society) per cent. Environment and climate stand out as the top priorities for Kigali, while societal and wider economic concerns attract the least weight. In Dar es Salaam, on the contrary, society and the wider economy share the top position, followed by environment and climate. Asian cities exhibit higher dispersion. The project's financial performance attracts the highest stakeholder interest in Kathmandu, followed by the applicable institutional framework. Society is the clear winner in Hanoi, followed by the environment far behind. Climate change appears to be the lowest priority in both Asian cities. Although no proper randomisation of the stakeholder sample was attempted, the participation of individuals from all stakeholder groups makes the results indicative of the city perceptions. All of the prototypes are made and, in some cases designed by local companies and are meant to replace two and three-wheelers that run on fossil fuels. They are made with local conditions and goals in mind

Table 1: KPI weights for the demo cities (stakeholders' input)

Level-1	Level-2	Kigali	Dar	Kath.	Hanoi	*Avg.*
Project finances	Financial viability	8.70	8.75	12.25	7.30	*9.25*
	Availability of finance	9.00	7.25	11.19	6.48	*8.48*
	Project finances, total	*17.70*	*16.00*	*23.44*	*13.78*	*17.73*
Institutional framework	Coherence with plans/goals	5.48	5.32	5.86	5.98	*5.66*
	Alignment with legislation	3.91	4.48	5.40	4.61	*4.60*
	Ease of implementation	6.01	4.50	6.39	4.79	*5.42*
	Institutional framework, total	*15.40*	*14.30*	*17.65*	*15.38*	*15.68*
Climate	Effect on GHG emissions	18.40	16.20	13.19	11.35	*14.79*
Environment	Effect on air pollutants	7.56	4.97	6.37	7.08	*6.50*
	Effect on noise	5.69	4.73	4.26	4.02	*4.67*
	Effect on resource use	5.25	7.20	4.84	5.10	*5.60*
	Environment, total	*18.50*	*16.90*	*15.46*	*16.20*	*16.77*
Society	Effect on accessibility	1.92	2.86	2.04	4.47	*2.82*
	Effect on affordability	2.16	2.01	2.16	3.11	*2.36*
	Effect on travel time	2.04	2.57	1.36	4.73	*2.68*
	Effect on road safety	1.87	2.20	1.60	4.11	*2.45*
	Effect on charging safety	1.50	1.85	1.79	3.06	*2.05*
	Effect on security	1.56	2.01	1.23	3.07	*1.97*
	Effect on well-being	1.94	2.32	1.68	2.71	*2.16*
	Effect on service quality	2.21	2.48	1.94	6.50	*3.28*
	Society, total	*15.20*	*18.30*	*13.81*	*31.76*	*19.77*
Wider economy	Effect on budget	5.02	5.68	6.09	4.56	*5.34*
	Effect on external trade	5.17	5.83	5.64	3.03	*4.92*
	Effect on employment	4.61	6.79	4.71	3.94	*5.01*
	Wider economy, total	*14.80*	*18.30*	*16.44*	*11.53*	*15.27*
	Grand total	*100.00*	*100.00*	*100.00*	*100.00*	*100.00*

3 Financial analysis

The financial performance of the project vehicles is assessed either through the Net Present Value (NPV), Internal Rate of Return (IRR), and payback period for revenue-earning operations or the Cost Effectiveness Ratio (CER) otherwise. In the context of this paper, it was decided to restrict the analysis to IRR, as this is the most suitable indicator for comparison purposes among projects of similar scale. Furthermore, and in order to exclude tax-related effects, the discussion is based on before-tax returns. The calculations assume that investment associated with the acquisition of the demo vehicle exclusively through own funds and its operation according to an operational profile typical for the existing fossil fuel vehicle type examined in the corresponding demo city. Among the three three-wheeler (3W) demos, the 'bajaj' in Dar es Salaam exhibits an IRR of 22.5%. Being a three-seater, it is the smallest of the project 3Ws, also reflected in its purchase price of $ 6,344 on 31 Dec. 2022). Equipped with a li-ion battery of 7.0 kWh, it can execute 10 round trips daily (over a total distance of 130 km) if fully charged overnight and with additional partial recharging during the day The newly designed 3W in Kathmandu is larger than Dar's bajaj, as it has a capacity of 6 passengers. With a purchase price of € 8,110 (equivalent to NPR 1,150,000 on 31 Dec 2022), the vehicle exhibits an IRR of 30.6%. On a similar deployment of 10 round trips and total distance of 100 km/day, its 10kWh LiFePo^{4} battery needs to be charged only once overnight, offering sufficient flexibility during daytime.

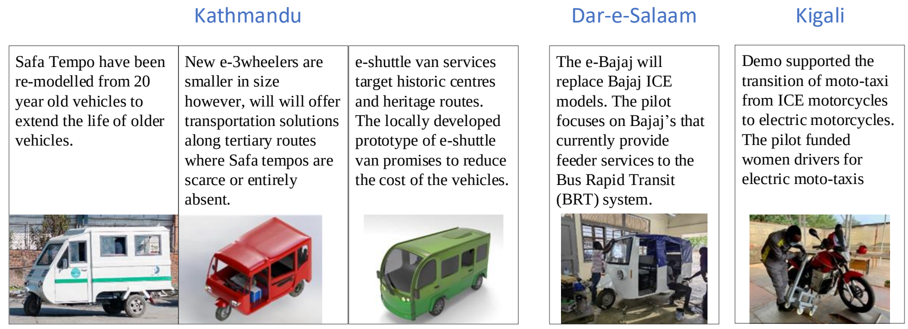

Fig 1: Demonstration e-vehicles under Solution Plus project

The remodeled 'safa tempo' in Kathmandu is the largest of the project 3Ws. . The project vehicle is a remodeled safa tempo, where its old lead-acid battery is replaced with a li-ion 23 kWh set, while the cabin is refurbished to seat 11 passengers more comfortably. At a price of € 13,760 (approximately NPR 1.950.000 as of 31 Dec. 2022), an investor can purchase one of these vehicles together with a license valid until 2029. Its battery, with an expected life of about 6 years, is sufficient to run 117 km/day (9 trips of 13 km each) with overnight charging only. Under these conditions, an investor can expect a healthy IRR of 57.8%. Seen from a safa tempo operator's viewpoint, however, the picture is different. Until the expiration of its license, an existing safa tempo is expected to make a pre-tax profit of NPR 1.280.000. This is earnings foregone for the operator who decides to remodel their vehicle. After accounting for this additional cost, the IRR of a safa tempo remodeling drops to 40.2%, which is still quite profitable.

With a purchase price of € 2,480 (equivalent to $ 2,644 on 31 Dec. 2022), the Kigali e-moto taxi offers an IRR of 17.5%. This figure is based on a total of 157 km/day, which can be supported by its 3 kWh li-ion battery only if swapped 2.23 times per day on average. Unlike the bajaj 3 wheelers the battery will be swapped, providing convenient conditions for the driver . Although the IRR is not impressive, it is still better with the ICE equivalent moto that exhibits an IRR of only 12.2%. The Kathmandu shuttle van is the only vehicle with a negative IRR. The expected number of 100 passengers per day (tourists visiting the World Heritage sites of the city) is not sufficient to support the commercial operation of a vehicle worth € 17.800 (NPR 2.525.000 as of 31 Dec. 2022). If, however, the Bhaktapur municipality decides to offer this service anyway, with 31 NPR/passenger, the newly designed vehicle exhibits a much better CER than the existing electric open van deployed in a similar service that costs 86 NPR/passenger.

4 Environmental and societal attributes

UNEP E-Mob calculator is used to analyse the impact of SOL+ interventions on GHG emissions and air pollution. The GHG emissions are calculated well-to-wheels (including CO2 emissions in electricity production); however, NOX and PM2.5 are based on a tank-to-wheel basis. In Kigali and Dar-e-salaam, as the e-motos (Kigali) and e-Bajaj (Dar-e-salaam) replace the old ICE vehicles, therefore, these result in significant GHG emission reduction of 73% and 12%, respectively, from the base case technology in the base year. In terms of NOx and PM2.5 emissions, the reductions are 100% from the base case since EVs have no tailpipe emissions. However, the absolute NOx and PM2.5 reductions decline with time since there is improvement in the emission standards for ICE vehicles as well e.g., NOX emission reduction in a year from 24 eMotos in Kigali declined from 113.6 kg in 2023 to only 68.9 kg in 2033. In Kathmandu, no major environmental impact is expected from the re-modelled 3-wheeler, as it replaces an older electric vehicle (Safa Tempo). However, for the newly designed 3-wheeler and the shuttle van, both of which will have a capacity of 6 passengers, the equivalent existing ICE vehicle is a microbus run on diesel. The yearly CO_2 emissions of this microbus and for the same mileage are estimated at 15.2 tons and the corresponding NO_x and $PM_{2.5}$ emissions are 70.2 and 24.1 kg/year.

In both Kigali and Dar-e-salaam interviewed, stakeholders felt that the risk of charging hazard was considerably low. No impact on road safety was foreseen by the experts interviewed for the re-modelled 3-wheeler (safa tempo) in Kathmandu, the e-moto in Kigali and e-Bajaj in Dar-e-salaam. The drivers identified minor improvements in terms of noise and the passengers ' suitability for adverse weather conditions. The passengers reported significant improvements in terms of comfort, perceived safety, and personal security in Katmandu and Dar-e-salaam, In Kigali, no major changes were observed. Overall, the perception of electric vehicles is positive by drivers. Some see a problem in the ease of charging and with the brakes. However, a major downside is the availability and affordability of spare parts. In relation to institutional issues, the experience varies across demos. In Nepal, the lack of technical standards for electric vehicles and the frequent rotation of public servants hinder the promotion of e-mobility in the country. Further barriers are faced by small-scale investors willing to invest in public transport despite the formal abolishment of the syndicate system a few years ago. In Rwanda, there are several positives that facilitate the implementation of the project, including the Government of Rwanda's policy and large fiscal and non-fiscal incentives and the NAMA support project to accelerate the deployment of electric motorcycles.

The project has also led to the creation of supporting institution structures, e.g., the E-mobility Technical Committee gathering public and private stakeholders involved in e-mobility. In Dar-e-salaam, the barriers include the lack of an e-mobility policy, need for collaboration among different stakeholders, the lack of involvement of political players (e.g., National Environment Management Council), and conflicting individual political ambitions.

5 Preconditions and limitations

The pilots under the SOLUTIONSplus project are all paratransit electric vehicles (EVs), an essential transport solution in developing and emerging countries, where a large section of the population depends on these modes of transport for their daily travel. Therefore, most countries are testing out electric vehicles as paratransit mobility options, and the local priorities are also set around getting the project viable and having appropriate institutional frameworks to ensure scaled up. Exceptions are wider economic impact in Dar-e-salaam. As most of these initiatives will be run by private operators, it is important that they are financially viable, and most SOLUTIONSplus pilot operations have shown that these are good options financially. The only option with a negative IRR was the Katmandu shuttle van, where the expected passengers were not enough to make the option viable. If this option was used at a high public transport location, the option could be more viable. Moving to electric vehicles from ICE vehicles is expected to deliver significant GHG mitigation and benefits in abating air pollution. Electric vehicles also have very little noise so there is also lower noise pollution when these modes become an upscaled solution in cities. At the point of article writing, we don't have the data for the retrofitted Dar es Salaam ICE bajajs, and the e-bikeshare in Kigali, both very delayed due to the Covid crisis and delays from supply chains for some components from Asia, and that we might find different results for these two components

Increasing the uptake of electric paratransit vehicles requires a multifaceted approach that involves various stakeholders, including government agencies, paratransit service providers, vehicle manufacturers, and advocacy groups, But what is observed from the pilots under SOLUTIONSplus projects are signs which are very positive, indicating that if countries are able to create an enabling policy and institutional environment, it should be possible to scale up these modes of transport, that play an important role in aiding personal mobility in developing countries.

6 Conclusions

The EU-funded SOLUTIONSplus project’s objective is to promote sustainable mobility through electric mobility, done via pilot projects of prototypes produced and developed by local firms. The project's impact assessment process uses financial cost-benefit analysis (CBA) and multi-criteria decision analysis (MCDA) to examine potential impacts on all sustainability pillars. The purpose here is also to build a wider project that considers local stakeholders' values, goals, and viewpoints. The project as was envisaged provides early findings, focusing on the financial evaluation of the choices and local community priorities. Apparently, the iterative approach makes all new vehicles profitable, with payback periods frequently under two years. Even with decreased returns in some cases, current vehicle improvements remain profitable. Electric vehicles cost a lot upfront but are more lucrative in the long term and offer considerable social and environmental advantages, according to their total cost of operations.Most countries are in the process of creating an enabling environment where electric mobility initiatives like the ones proposed here can incubate. It is imperative that these processes continue leading to a proper policy and institutional environment and establishing charging infrastructure, creating rules that enable manufacturers (technical standards, licensing, etc.) and guarantee the deployment of safe and robust vehicles, and educating drivers and users to promote e-vehicles as last-mile connections.

References

1. Kontou, E., Yin, Y., Lin, Z., 2015. Socially optimal electric driving range of plug-in hybrid electric vehicles. Transportation Research Part D: Transport and Environment 39,
2. Tamor, M.A., Milačić, M., 2015. Electric vehicles in multi-vehicle households. Transportation Research Part C: Emerging Technologies 56, 52–60. doi:10.1016/j.trc.2015.02.023
3. Albrechtowicz, P., 2023. Electric vehicle impact on the environment in terms of the electric energy source — Case study. Energy Reports 9, 3813–3821. doi:10.1016/j.egyr.2023.02.088
4. Basso, R., Kulcsár, B., Egardt, B., Lindroth, P., Sanchez-Diaz, I., 2019. Energy consumption estimation integrated into the Electric Vehicle Routing Problem. Transportation Research Part D: Transport and Environment 69, 141–167. doi:10.1016/j.trd.2019.01.006
5. Jochem, P., Babrowski, S., Fichtner, W., 2015. Assessing CO2 emissions of electric vehicles in Germany in 2030. Transportation Research Part A: Policy and Practice 78, 68–83. doi:10.1016/j.tra.2015.05.007
6. Liberto, C., Valenti, G., Orchi, S., Lelli, M., Nigro, M., Ferrara, M., 2018. The impact of electric mobility scenarios in large urban areas: The Rome case study. IEEE Transactions on Intelligent Transportation Systems 19, 3540–3549. doi:10.1109/TITS.2018.2832004
7. Jochem, P., Doll, C., Fichtner, W., 2016. External costs of electric vehicles. Transportation Research Part D: Transport and Environment 42, 60–76. doi:10.1016/j.trd.2015.09.022
8. Wu, Y.C., Kontou, E., 2022. Designing electric vehicle incentives to meet emission reduction targets. Transportation Research Part D: Transport and Environment 107. doi:10.1016/j.trd.2022.103320
9. Kang, S.C., Lee, H., 2019. Economic appraisal of implementing electric vehicle taxis in Seoul. Research in Transportation Economics 73, 45–52. doi:10.1016/j.retrec.2018.11.007
10. Morrison, G., Stevens, J., Joseck, F., 2018. Relative economic competitiveness of light-duty battery electric and fuel cell electric vehicles. Transportation Research Part C: Emerging Technologies 87,
11. Meisel, S., Merfeld, T., 2018. Economic incentives for the adoption of electric vehicles: A classification and review of e-vehicle services. Transportation Research Part D: Transport and Environment 65, 264–287. doi:10.1016/j.trd.2018.08.014
12. Panagakos, G., Goletz, M., Hasselwander, M., Mejia, A., Aittoniemi, E., Barfod, M. B., Dhar, S., Munoz Barriga, M. R., Munshi, T., Painuly, J. P., Shrestha, S., Silla, A., Teko, E., Torrao, G., Werland, S., & Dematera-Contreras, K. (2023). E-mobility solutions for urban transportation: User needs across four continents. Transportation Research Procedia, 72, 2558-2565. doi: 10.1016/j.trpro.2023.11.772