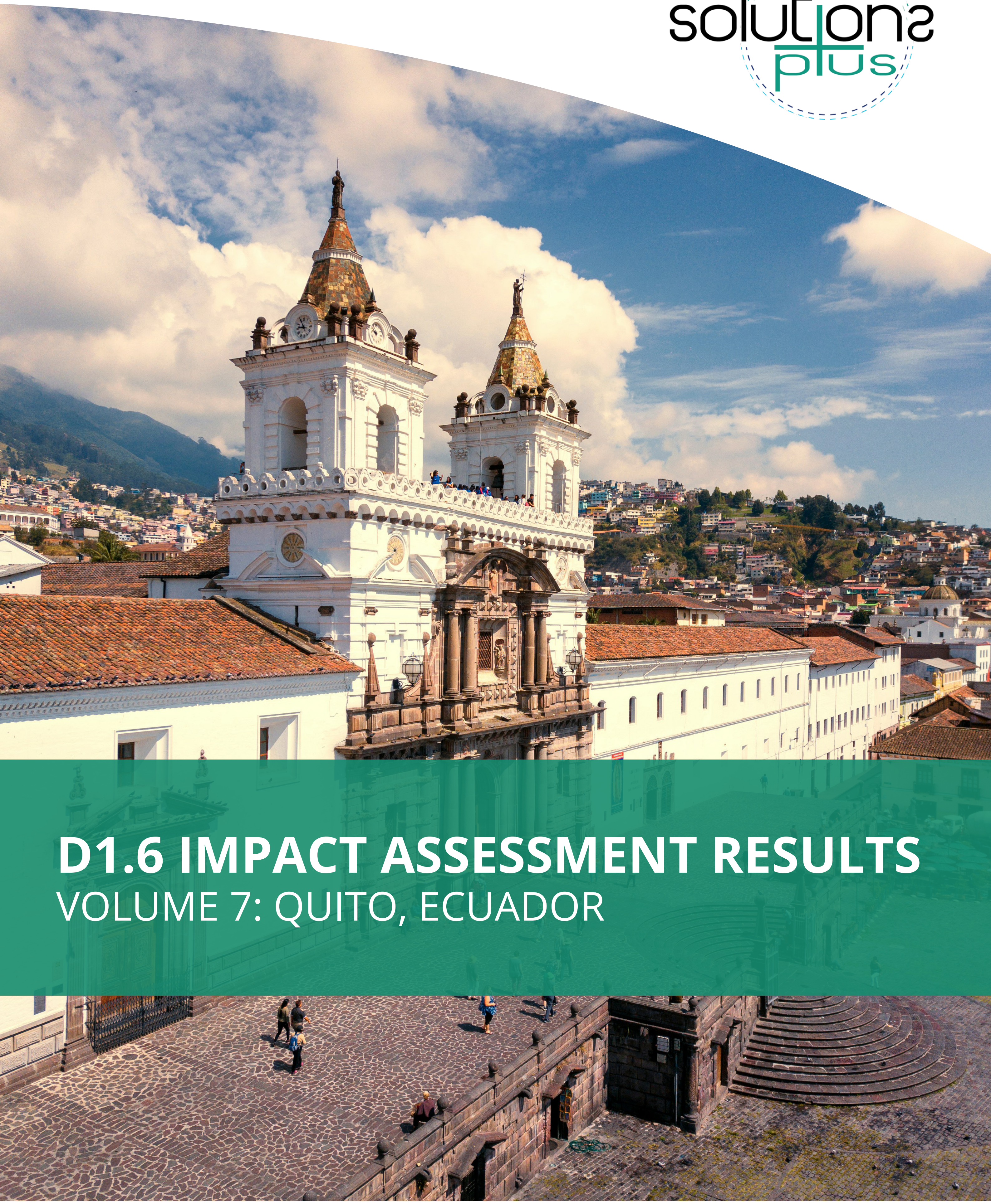

D1.6 IMPACT ASSESSMENT RESULTS

VOLUME 7: QUITO, ECUADOR

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AUTHORS

Eetu Wallius, Elina Aittoniemi, Carlos Lamuela Orta, Grace Lopez, Maria Rosa Muñoz, Lorena Saavedra, Merja Penttinen, Anne Silla, Guilhermina Torrão, Anu Tuominen

AUTHORS

Subash Dhar (UNEP CCC)

LAYOUT

Yasin Imran Rony, WI

PICTURES

All the pictures are provided by the SOL+ partners

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EXECUTIVE SUMMARY

This report The Metropolitan District of Quito (DMQ) is the capital and largest city of Ecuador. It has approximately 2.7 million inhabitants (INEC, 2020) and is in the Pichincha province in the north of the country. The SOLUTIONSplus actions in Quito focussed on Historic Center (HCQ) that comprises an urban area of 376 hectares, with approximately 40,000 inhabitants. Due to its location in the centre, the HCQ is an obligatory crossing point for all the commuters from the southern area of the city that go to the Central Business District (CBD) and is also a mobility hub.

However, Quito, and particularly the HCQ, face various problems regarding freight and passenger transport. Some of the main problems regarding freight transportation in the HCQ area relate to infrastructure that is characterized by narrow streets, high population density as well as restrictions to motorized traffic. The current restrictions do not allow the entry of regular medium and large freight vehicles to pedestrianized areas during daytime, increasing the costs for shop owners. As some streets in the Historic Centre have been converted into pedestrian corridors, this resulted in difficulty in the distribution of goods in the area. Together, these characteristics hinder the economic activities of the HCQ. Regarding personal mobility, the main problems in Quito relate to congestion, dispersed transport services, low perceived quality and comfort of public transport, and a lack of capacity of current services. These problems contribute to the use of private vehicles instead of using public transport. To tackle these problems, the SOLUTIONSplus actions in Quito comprised two components: piloting of e-cargo bikes and piloting of a mobility-as-a-service (MaaS) application for public transport.

The first component involved piloting seven e-cargo bikes to serve delivery logistics, restaurant logistics and recycling in the HCQ area. Three different locally manufactured e-cargo bike models were used between November 2022 and January 2023. For delivery logistics, the implemented long-john e-cargo bike after tax net present value was 8021 USD, internal rate of return 97.97% and payback period 0.97 years, based on the data obtained collected during the pilot implementation. For restaurant logistics and recycling, which are not revenue generating activities, cost-effectiveness ratios were calculated. For restaurant logistics, the cost-effectiveness ratio of the implemented e-cargo bike was 1.47 USD per m^3 and for recycling, 7.47 USD per m^3. Regarding CO2 emission reduction stemming from replacing the previous transport solutions with SOLUTIONSplus vehicles, 247.4 kg per vehicle would be saved annually in logistics deliveries (replacing motorcycles), 173.3 kg per vehicle annually in restaurant logistics (replacing private car), while no reductions would be realized in recycling (replacing manual pushcarts). Overall, the quality and usability of the implemented e-cargo bikes were perceived favourably by the pilot participants, implying that they might be a good fit for the rather challenging circumstances faced in the HCQ area.

The second component involved piloting of a MaaS-application that allowed users to plan multimodal trips, access information regarding timetables, public transport routes, schedules, stations and stops as well as purchase tickets for public transport. The pilot took place during one month between November-December 2022, during which 45 students used the developed application prototype. Several usability issues hindered application usage and realizing its potential in terms of impacts. However, given such issues would be resolved in the future, MaaS-approaches could have a positive impact in terms of public transport accessibility and different reaching destinations, thus contributing to shift away from private cars towards sustainable modes of mobility.

CONTENTS

1 BACKGROUND AND CONTEXT

The Metropolitan District of Quito (DMQ) is the capital and largest city of Ecuador. It has approximately 2.7 million inhabitants (INEC, 2020) and is located in the Pichincha province in the north of the country. Quito is located in the northern highlands of Ecuador in the Guayllabamba river basin. The consolidated urban area is settled on a long plateau lying on the east flanks of the Pichincha volcano, even though the political-administrative border of the Metropolitan District of Quito (DMQ). The urbanized area is the result of three growth phases: until the 1950s it grew in a radial form; from the 1950s until the 1990s it grew longitudinally in north-south direction; and since the 1990s Quito has experienced urban sprawl to the east side of the territory (Carrión, 1987)

The administrative division of the Metropolitan District includes 33 rural and 32 urban parishes. Quito is situated at an elevation of 2,850 meters above sea level, the second highest official capital city in the world, and the closest to the equator. The Historic Centre of Quito (HCQ) is one of the largest, least-altered, and well preserved place which was the first World Cultural Heritage Sites declared by UNESCO, in 1978.

The HCQ comprises an urban area of 376 hectares, with approximately 40,000 inhabitants. Due to its location in the centre, the HCQ is an obligatory crossing point for all the commuters from the southern area of the city that go to the Central Business District (CBD) and it is also a mobility hub.

Quito is the second city in Latin America to have implemented a Bus Rapid Transit (BRT) system, which has been expanded over time, increasing the served area and number of passengers. At present, the system is composed of 5 BRT lines, which cover 136 km with exclusive lanes that cross the city in a north-south direction, completing 1 million trips on a regular working day (Havela, 2019). During the last years, 80 biarticulate (18 m) diesel buses were bought and they replaced some of the oldest buses (Bravo, 2017).

Despite its continuous expansion, the system has already reached capacity and 40% of its fleet will soon reach the end of its useful life. As part of international negotiations, Quito committed to replacing the BRT fleet with e-buses by 2025 to achieve the goal of zero emissions by 2030. In such context, a draft ordinance for 'Gradual Decarbonization of Transportation and Promotion of Clean Transportation in the Metropolitan District of Quito' is under discussion. One of the main points of the proposed ordinance is the progressive renewal of the bus fleets of all BRT lines starting with 10% of the fleet. All public transport operators should present fleet renewal plans. With the aim of creating a zero-emissions HCQ by 2020, the public transport fleet that circulates through the HCQ will be the priority for renewal.

1.1 GEOGRAPHY AND THE SOCIAL/URBAN CONTEXT

Topography and Weather

The Metropolitan District of Quito (DMQ) presents a wide altitude gradient due to its geographical location marked by the Andes Mountains. The variation of average heights in relation to sea level can vary between 500 and up to 4,870 meters above sea level, the highest point of the Sincholagua hill. Specifically, the city of Quito is located on a plateau between the Western and the Eastern Ranges of the northern Andes of Ecuador. This plateau extends over 2,850 meters above sea level and is surrounded by volcanoes and mountainous reliefs that delimit an elongated urban area, adapted to the relief of 42 km in length compared to the width of 15 km, with an expansive development of urban areas in the valleys of Tumbaco and Los Chillos (DMQ, 2020)

The topographic characteristics of the DMQ allow the generation of various climatic floors, ranging from a temperate climate in its valleys, humid areas in the external foothills of the mountain range to a high mountain climate in areas that exceed 3,000 meters above sea level. According to the climate observed between 1981 and 2005, Quito reaches an average annual temperature throughout its territory of 15°C. The temperature increases gradually from the Western Range to the north western District.

Precipitation levels vary depending on local geographic patterns (relief, vegetation, humidity, etc.). In this framework, the DMQ presents three different zones: 1) the inter-Andean dry zone (554 mm/year), 2) the inter-Andean zone (960 mm / year), and 3) the inter-Andean rainy zone (1,400 mm / year). However, in a general context, the average of total annual precipitation shows an increase in precipitation towards the northwest of the District, with an annual average of 2,369 mm, while the lowest values are recorded south of the DMQ with an annual average 1,133 mm (DMQ, 2020).

Urbanization and Population

As mentioned before, the urbanization process has gone over three phases, showing a sprawling behaviour in the last decades. Nonetheless, the percentage of urban land remains low in comparison with the whole Metropolitan District surface. The assigned uses and occupation of the land of the District are mainly natural (natural heritage, sustainable production, non-renewable natural resources), occupying more than 87% of the total area, followed by the area defined as urban residential with 6.8% and the residential agricultural area with 2.7% (DMQ, 2020).

The expansive urbanization process derives from a population increase that showed an average annual growth rate of 3.5% between the 1950s and 1970s and has lowered to 2.2% average annual growth between 2001 and 2010 (DMQ, 2020). Yet, the overall population growth does not translate into an evenly distributed variation throughout the city. The peripheral areas at the north and south borders and in the eastern valleys show growth rates over 3.4% while the central areas experience negative population growth of up to 2.3% (Muñoz, 2013)

The age structure by gender with changes between census years (1990, 2001 and 2010) is portrayed in Figure 1. It shows a population that enjoys a demographic bonus, due to the increase of the percentage in working age people 73.6% in 2001 to 75.0% in 2010. However, the pyramid base has shrunk between census periods, showing a reduction in the percentage of the population under 10 years old (DMQ, 2020)). In terms of gender, by 2010, the distribution depicts 48.7% of men and 51.3% of women (figure on page 08).

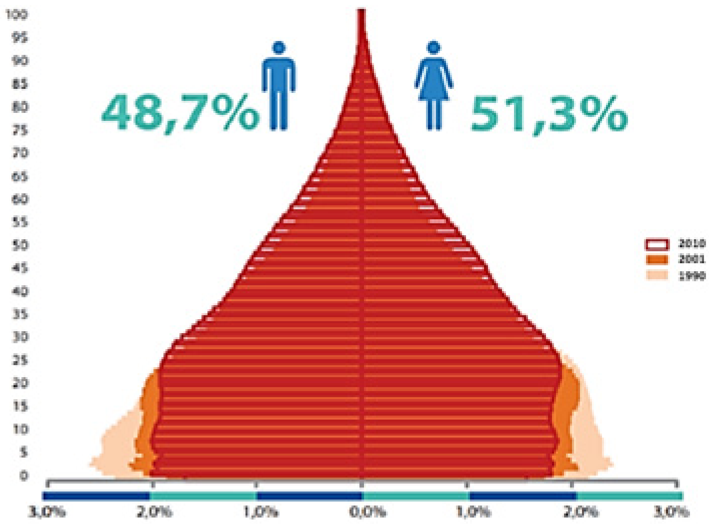


Figure 1. Age structure by gender, variation among census years (Source: Climate Action Plan of the Metropolitan District of Quito, 2020).

Social and Economic Development

The overall social and economical development conditions for Quito are better than in the rest of the country (DMQ, 2020). In terms of employment, the distribution of jobs is highly concentrated in the centre of the city (54% of total jobs) while the working population is distributed throughout the city and highly concentrated in certain peripheral parishes. This explains the daily commute patterns of a monocentric city (Muñoz, 2013).

With an estimated GDP of USD 24 billion for 2020, the Metropolitan District of Quito contributes by 24.5% to the national GDP, making it the first economic development area of the country. Considering the direct economic specialization indicator, the three most relevant activities of the city's economy are 1) professional activities and real estate (20%), 2) manufacturing (18%), and 3) public administration (16%). On the other hand, transport, information and communications account for 7% of Quito's direct economic specialisation. (Saavedra & Villacres-Endara, 2021)

Emissions

The Greenhouse Gas Inventory (GHGI) of Quito for 2015, identifies emission levels in metric tons of carbon dioxide equivalent for each sector and subsector prioritized by the city (DMQ, 2020). The most relevant sectors contributing to CO2 emissions are: transport (40%), stationary (26%), agricultural and land use (24%) and waste (10%) (DMQ, 2020). These results resemble the national GHGI, where transport is the sector with the highest energy consumption with 46% of the total amount of oil consumed annually, from which 31% corresponds to diesel oil and 27% to gasoline. The National GHG Inventory of 2012 showed that the energy sector was responsible for 46.3% of GHG emissions from which transport accounted for 45.2%, with a total of 37,6 million tCO2eq. By 2015, land transport consumed 87% of the energy of the subsector, from which heavy freight was responsible for 44% (MTOP, GIZ Ecuador & b4future, 2018).

1.2 URBAN TRANSPORT

The city's public transport system is divided between the Metrobus-Q subsystem that includes the two corridors operated publicly and one operated privately and the conventional subsystem with private operators receiving authorization to operate on particular routes. Figure 2 details the classification and numbers of units and routes available in each category.

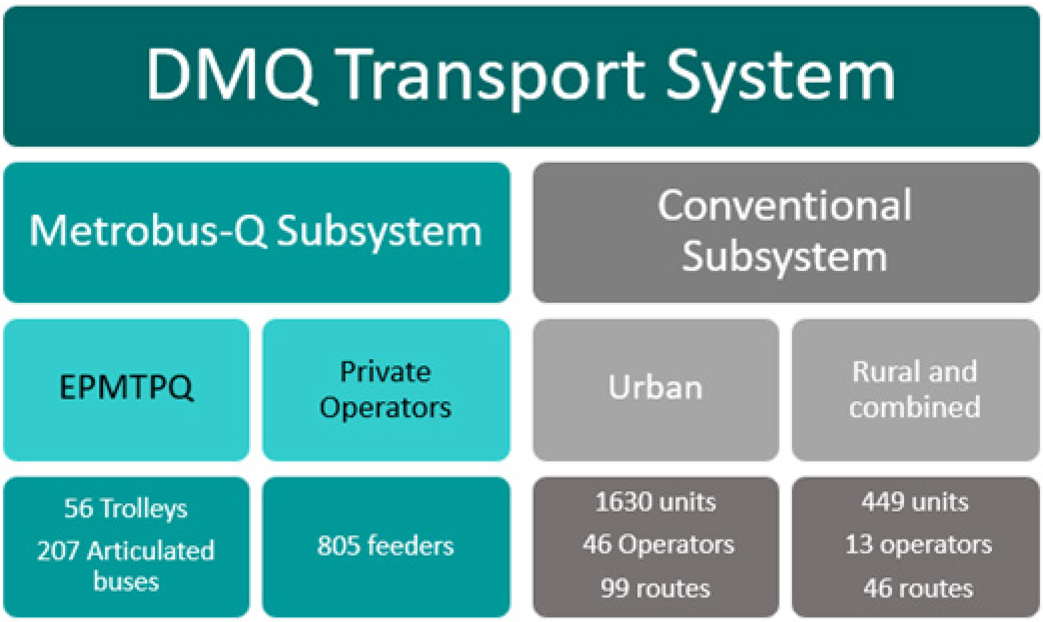


Figure 2. Classification of the DMQ Transport System (Source: Mobility Secretariat and Estudio de actualización del Modelo de Demanda del DMQ. TRN Taryet, julio de 2018).

From the supply side, Table 1. details the infrastructure available in the urban area of the city.

Table 1. Infrastructure supply in Quito, 2015 (Source: Urban Mobility Observatory-CAF, 2015).

INFRASTRUCTURE	UNITS
Roads (km)	4,170
Traffic light intersections	600
Roads with priority to collective transport (km) - sideway	34.5
Roads with priority to collective transport (km) - centre of the road	34.1
Priority of collective transport/ road extension (%)	1.7
Cycling lanes (km)	54
Cycling paths (km)	119
Priority of cyclists/road extension (%)	4.1

The public transport system in Quito has already reached capacity and has not been able to provide safe and comfortable travels to its passengers, generating a shift towards private cars in the past years. Thus, the first subway line is under development and started operation in 2023.. The line crosses the city from north to south, serving a similar route to the one done by the BRTs. Moreover, Quito is committed to renewing the bus fleet with electric buses until 2025 to achieve the goal of zero emissions by 2030 (El Comercio, 2017).

1.3 IDENTIFICATION OF MAIN PROBLEMS

1.3.1 Passenger transport services

According to the Mobility Secretariat (Ordenanza-017, 2020) the main problems in the public transport service of the DMQ are:

• **High degree of redundancy of routes on roads leading to low quality of service:** It refers to the superposition of unnecessary routes along with the largest percentage of routes, generating various negative effects such as i) individual competition between the different providers of the transport service and between the operators of the same or other companies, since there is no global integrated common cash operation, generating the so-called "run-ins" (competition for exceeding between transport units to capture more passengers) or "held" (arrests deliberate to also attract more passengers), ii) weakened road safety as a product of the above, iii) operational deficiencies evidenced in low productivity, and iv) environmental effects due to the pollution generated by the emissions that, above all, are evidenced especially where there is a greater agglomeration of units in the same road section.

• **Congestion due to saturation of the roads and road insecurity in the main road network:** This is a consequence of the problems described in the preceding point, where the magnitude (number and volume) of public transport units (buses) is very significant.

• **No network of complementary public transport services:** transport services, instead of forming a complementary system make up a transport network of individual routes throughout the Subsystem Conventional Urban and partially between the corridors of the Subsystem Metrobús-Q.

• **Elementary business organization of the operators:** Although the provision of public transport services is exercised by delegation of the authorities corresponding to the organizations legally formed according to the provisions in national and local regulations (cooperatives, companies or companies), which implies a corporate provision, in practice the service is done individually, since the income that corresponds to each operator comes directly from the collection of fees to users in each transport unit.

• **Failure to comply with schedules and frequencies:** Around 50% of the routes of the conventional services do not comply with the schedules or frequencies established in the enabling titles. One of the causes is that the operation of the buses is performed by a single driver who works up to 16 continuous hours, which is extremely strenuous, against labour norms. Consequently, operational indicators are not met.

• **The minimum comfort indicator is not met:** 80% of the public transport offer has an average occupancy rate of eight passengers per square meter in the peak hours, exceeding the maximum allowable limit of six passengers per square meter internationally recommended. This condition is dissuasive to the use of public transport services and encourages the use of the private vehicle to those who have it and the acquisition of those who do not have it yet, a situation opposite to the policies sustainable mobility of the DMQ.

- **Deficit of capacity in the supply of Passenger Transport (PT) Services:** The deficiency is notorious in most of the services of the integrated corridors, in terms of their capacity, where users must wait for up to three or four articulated units to be able to enter and move comfortably. Although, on one hand, they comply with a good speed of movement when traveling in segregated lanes, its capacity leaves much to be desired, even in the so-called valley hours. In the same way this problem is evident in most of the conventional services subsystems. This deficit derives from the use of informal transport services. On the other hand, it can also be observed that there is a group of conventional transport routes that have low occupancy, making evident the oversupply there.

- **Increasing supply of informal transport:** Given the lack of coverage and the deficient PT service, informal transport services have emerged and increased continuously, coexisting in parallel with regular services. One of the main causes for the deficit is the current regulatory framework for public transport, which has not allowed to establish regular procedures to increase the supply against a justified demand. These informal services are carried out with units outside the current regulations, even charging fees above the authorized, especially to cover trips to peripheral sectors.

Therefore, the current system is neither competitive nor attractive compared to the private vehicles, which, despite a complex economic situation of the population, continues increasing its automobile fleet to the detriment of public transport. Consequently, working towards an integrated transportation system where each component contributes to the integrity of urban mobility is unavoidable, both from the social point of view, as well as the economic and environmental one.

Regarding current traffic-related issues in the HCQ area, 76,038 private vehicles, 1,233 buses, 65 conventional bus lines and 16 feeder lines circulate daily. This situation has led to high levels of vehicle congestion, reducing traffic speed to 3 km/h at peak hours, when the average in the city is 25 km/h. The most important travel modes in the Historic Centre are public transport (72%) and walking (19%). Due to the topography of the territory, there are areas of difficult pedestrian access, as there are slopes exceeding 30% (IMP, 2018). Also, walking is challenging since pedestrians must share the road with heavy congestion and deal with a poor safety situation. In addition, pedestrian routes are not well connected. This situation led to the pedestrianization of further streets in the core of the HCQ and the decision of turning the area into a Low Emission Zone (LEZ), which is a major goal for the city of Quito.

Regarding air pollution in Quito, the general analysis of air quality during 2020 (SecAmb, 2020) shows showed that on 26% of the days of the year, the air quality is kept was in good condition, 71% remain acceptable, while 3% of the days (37), the air quality was reported as in a state of caution. The significant increase in days with desirable air quality and the decrease in days with caution is due to mobility restrictions caused by the pandemic due to the proliferation of the SARS-Cov-2 virus, which forced a decrease in vehicle traffic from March 2020 until the end of the year. This limitation of traffic caused the concentrations of pollutants PM2.5 and NO2 to reach their lowest values during March and April (the lowest in the last 15 years) and restored according to the release of restrictions and the end of the state of emergency. The pollutant values have not reached those measured during the first months of the year 2020, before the pandemic.

1.3.2 Freight transport services

As some streets in the Historic Centre have been converted into pedestrian corridors, this resulted in difficulty in the distribution of goods in the area. The supply activities are complex due to the population density, the existing infrastructure in the territory and the width of the streets (ICQ, 2017), which impairs the enjoyment of the public space of pedestrians (AEUB, 2015). Despite the provisions of ordinance No. 147, which regulates logistics in the Historic Centre, night loading and unloading schedules are not compatible with the business dynamics of the territory, and the infrastructure to support the load or unload goods temporarily accordingly to the needs of commercial establishments in the HCQ is deficient (IMP, 2018). A survey involving the residents showed that 58% of respondents identified congestion problems as the main barrier for provisioning for their businesses, a circumstance aggravated by the fact that 93% get supplies at least once a week, and 28% in fact receive merchandise daily (SecMov, 2018). Besides local shops and businesses, there is uncertainty about the official loading time. The current restrictions do not allow the entry of regular medium and large freight vehicles to pedestrianized areas during daytime, increasing the costs for shop owners.

1.4 RELEVANT STAKEHOLDERS AND USER NEEDS

1.4.1 Relevant stakeholders

The stakeholders relevant to the pilot implementations are described in table 2.

Table 2. Relevant stakeholders identified for the Quito implementation

STAKEHOLDER GROUP	ORGANISATION
NATIONAL / REGIONAL / LOCAL AUTHORITIES	Mobility Secretariat – The Municipal Department for policy, guidelines, and regulation on urban mobility.
	Environment Secretariat – The Municipal Department for policy, guidelines and regulation on environmental issues including climate change.
	Territory Habitat and Housing Secretariat (STHV) – The Municipal Department in charge of regulation on land use, and promotion of urban habitat improvement and housing.
NATIONAL / REGIONAL / LOCAL AUTHORITIES	Urban Planning Metropolitan Institute (IMPU) – It is a municipal institute in charge of studies related to urban design, territory, mobility, environment, and socio-economic issues.
	Central District Administration (CDA) – Municipality is divided into districts for administrative purposes and attention to the public.
	C40 – Adviser of C40 to the Municipality for implementation of Climate Action Plan signed by Quito.
PUBLIC TRANSPORT COMPANY	Metropolitan Public Transportation Company (EPMPTQ)- Public company in charge of operating two public transport corridors: trolebús and ecovía.

PASSENGER / INDIVIDUAL TRAVELLER / CONSUMER	Historic Centred Buró (HCB) – NGO that represents business owners (specially restaurants and touristic services) in the HCQ.
ORIGINAL EQUIPMENT MANUFACTURERS (OEMS)	SIDERTECH- Startup specialized in motor parts and with previous experience on e-scooter.
SERVICE PROVIDERS (DELIVERY SERVICES)	Bixi Mensajería Tulcán y Bixi Cargo Ecuador- Bike Courier service start-up
ELECTRICITY AND CHARGING INFRASTRUCTURE COMPANIES	ABB Ecuador – Local branch of the electric generation and industrial automatization multinational.
ACADEMIA/ RESEARCH	(CATENA-USFQ) Institute for Innovation in Logistics and Productivity of the University San Francisco de Quito
	International University of Ecuador (UIDE) Private University that offers the auto mechanics career.

1.4.2 User needs

The user needs assessment (UNA) conducted via online survey and interviews allowed the identification of main motivations for the demonstrations, as well as to collect feedback on e-mobility solutions implementation, and insights on obstacles and barriers related to the SOLUTIONSplus demonstrations. The main findings of this analysis are summarized next. More details about Quito's user needs assessment can be found in the city report (SOLUTIONSplus Consortium, 2021).

The most important aim for Quito city is to analyse costs related to the implementation of e-vehicles and to increase the share of e-vehicles in the transport of goods. Additionally, the reduction of emissions, such as CO2 and also NOx, CO, PM, VOC emissions, and decreasing exposure of citizens to air pollution is very important.

The most important use for the e-mobility solutions for the last and first mile delivery was the transport of goods, followed by the transport of people. For this use case, the most important target user groups are all citizens and disabilities and senior citizens. This shows a vision towards inclusive mobility, which is also aligned to the United Nations (UN) Goal 11 which is about making cities and human settlements inclusive, safe, resilient and sustainable (UN, 2021).

Despite expected benefits, stakeholders are also aware of barriers related to the implementation of SOLUTIONSplus demo prototypes in Quito. The most relevant challenges for the successful implementation of e-vehicles were identified as lack of money and/or financial resources, and lack of enabling policies, and investments needed. For the regulatory barriers, the absence of a specific homologation process for subcategory L electric vehicles (e.g. motorcycles, tricycles and quadricycles) can potentially generate delays in the registration process and circulation permits or discourage local design and assembly of EVs due to the potential risk of not complying with homologation norms, and therefore not being able to commercialize the vehicles thereafter. Other relevant issues are the lack of safety and safe interaction between the different transport modes as well as speed regulation for different types of vehicles which could affect their use in public space.

Regarding business models, e-mobility solutions are considered a valuable opportunity to formalize current informal services and provide better transport services for users. The new e-mobility solutions can favour customers and merchandisers by creating better transportation opportunities. Some believe that freight trip services might change if there is a distribution centre, while others consider that commercial establishments will have to adapt to good provision planning needed for the logistics operational model for the HCQ, which therefore will change their supply chains. Based on the stakeholders' opinion, the main service operator for the e-vehicles should be a private service operator. E-mobility solutions can contribute to job creation, and even promote a shift towards more specialized jobs, new business models, and the emergence of an industry of alternative mobility. Potentially, enabling an opportunity for transport providers to renew their fleet or innovate in their service to continue operation in the same HCQ.

Regarding the implications for planning and urban development, stakeholders emphasised the need for design customised to the characteristics of the Historic Centre of Quito and to ensure quality and good performance given the topography of that area. Technical specifications must meet users' needs and promote democratization of public space. However, this needs to be integrated into Quito's urban planning vision, as provided e-mobility solutions will change the accessibility to different places. The testing phase may be the most critical one as safety and security issues may arise once the EVs start circulating. Therefore, it requires not only detailed planning of demo prototype pilots but also an evaluation of the accessibility of vehicles to certain zones inside the Historic Centre to harmonize pedestrian zones with bicycle zones with the right signs before the implementation of these e-mobility solutions. Besides, charging time is crucial and needs to be considered as part of route planning. There was no common view on the ease of e-mobility solution's implementation. Some considered distance as the biggest limitation for e-mobility solutions, thus transition towards e-mobility would imply urban planning with a focus on enhancing proximity to the desired destinations (e.g. offices, shops) and therefore improving urban accessibility. On the other hand, enough space and parking lots for charging (e-buses, e-vehicles) need to be carefully planned. Some reflected that e-mobility hubs might act as urban amenities. Others considered that route planning will not face a major change, but that new infrastructure will be needed. In contrast, some stakeholders argued that transport planning will be more complex and require more specialized professionals. In addition, new investments will be required, especially charging infrastructure for bigger e-vehicles.

Stakeholders have also reported concerns with the e-solutions implementation. One is to identify key locations where to distribute the EVs to ensure appropriate use and efficiency of service. Other, the non-existent culture of using e-mobility solutions. Currently, users see EVs as leisure vehicles, which discourages the potential as a reliable transport mode. A potential basis for this skepticism could be the lack of information on EVs. Despite all these concerns, stakeholders believe that potential negatives impacts can be mitigated if adequate planning is developed.

2 KEY PERFORMANCE INDICATORS (KPIS)

2.1 PRIORITIZATION OF KPIS ADDRESSING THE SPECIFIC CITY NEEDS

The KPI priorities of the stakeholders are formally determined through the weights assigned to the selected KPIs. The weighting of KPIs in Quito took place in conjunction with the stakeholder interviews organized under the user needs assessment analysis as presented previously. The KPI aggregation procedure (based on Chapter 2 in D1.2) considers all the nine interviewed stakeholders, representing seven stakeholder groups.

Figures 3 and 4 exhibit the mean values of the weights received from the 11 stakeholders for all Level 1, 2 and 3 KPIs with relative (in black) and cumulative (in red) numeric digits. Relative weights indicate stakeholder priorities within a family and sum to 1, whereas the cumulative weights at each level are determined by applying the relative weights of that level to the cumulative weight of the parent attribute. The attributed weights calculation model was set to a maximum value of 100 for the sum of all cumulative weights at each level to minimise potential errors. The cumulative weights of level 1 KPIs are identical to the corresponding relative ones but expressed at a different scale.

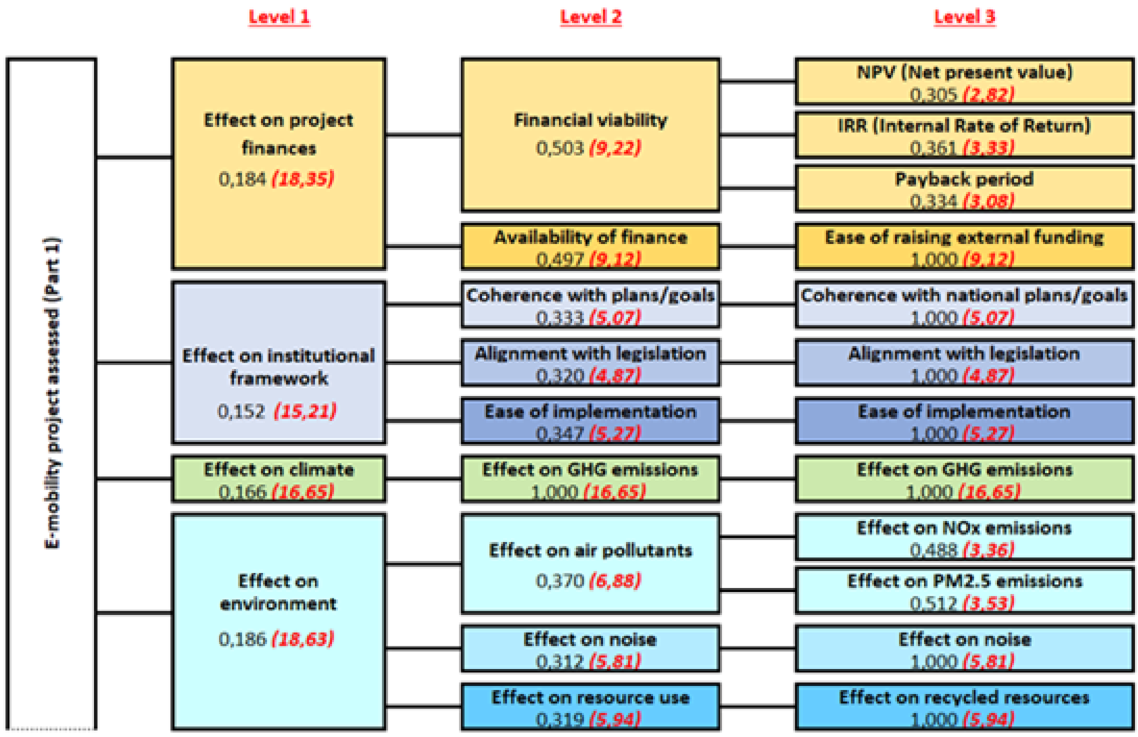


Figure 3. KPI weights indicated by the Quito stakeholders for effects on project finances, institutional, climate and environment.

The demonstration's effect on the environment is identified as the most relevant evaluation aspect by Quito stakeholders with a cumulative weight of 18.65, followed by project finances with a cumulative weight of 18.35, as exhibited in Figure 3 for level 1 KPIs. Nevertheless, these groups show a very small difference in weight (0.30), thus suggesting that both are very much in the interest of Quito's stakeholders. It is interesting to notice that for the other impact areas, the attributed weights are differentiated in decreasing order: society (17.32), climate (16.65), institutional framework (15.21). On the other hand, the wider economy was ranked with the lowest priority (13.84).

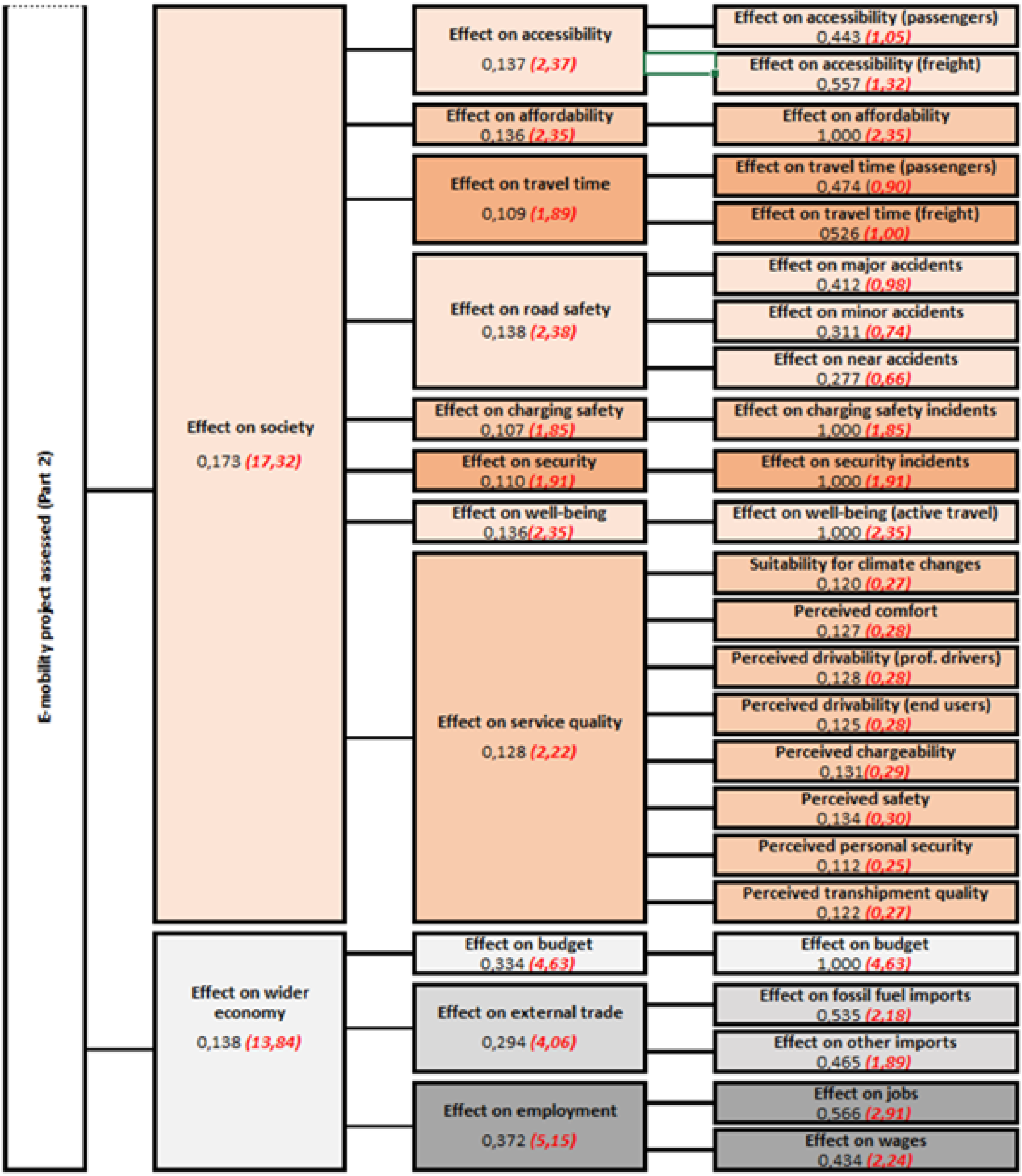


Figure 4. KPI weights indicated by the Quito stakeholders for effects on society and wider economy.

For level 2 KPIs, the effect on GHG emissions shows the highest score (16.65). Other observations related to level 2 KPIs are summarised next.

- For project Þnances, Þnancial viability (9.22) gets a higher weight than Þnancial availability (9.12), but with a marginal difference in the cumulative weights. The former is also the highest priority across all level 2 KPIs.
- For the environment, the effect of air pollutants is the priority (6.88). This KPI is the third most important KPI across all level 2 KPIs.
- For society, the highest priority is for KPI on road safety (2.38), followed by accessibility (2.37), affordability (2.35) and well-being (2.35).
- For the wider economy, the most important KPI is employment (5.15), whereas the external trade (4.06) got the lowest value.

For level 3 KPIs, stakeholders prioritise ease of raising external funding (9.12), followed by recycled resources (5.94) and noise (5.81). For society, it is interesting to notice that all level 3 KPIs based on user perception (e.g. perceived comfort, perceived safety, perceived changeability) scored very low (<1), and the lowest priority was given to KPI on perceived personal security (0.25). For the wider economy, higher importance was given to budget (4.63) over wages (2.24).

3 BASELINE VALUES

3.1. BASELINE PROJECTIONS BASED ON REFERENCE SOURCES

This section presents the socio-economic demographics as well as the environment, transport and mobility related indicators which are of interest for Ecuador's SOLUTIONSplus project baseline targeting the 2025−2030 time period. Although the baseline focuses on the years 2025–2030, data is also presented for the year 2019. Table 3 presents some of the socio-economic demographics, environmental and transport related indicators considering the reference year and forthcoming baseline period. Where data is not available at Quito city level, national figures for Ecuador are used.

Table 3. Demographics and transport indicators for Ecuador for the baseline period.

INDICATOR	Data aggregation level	YEAR			SOURCE / REFERENCE
		REFERENCE	BASELINE		
		2019	2025	2030	
SOCIO-ECONOMICS AND DEMOGRAPHICS					
Population (thousands)	National	17,374	18,741	19,819	(UN Population Division, 2019)
GDP, current prices (Purchasing power parity; billions of international dollars)	National	205,989	230,437	NA	(IMF, 2020a)
Unemployment (%)	National	3.8%	4.1%	NA	(IMF, 2020b)

INDICATOR	Data aggregation level	YEAR			SOURCE / REFERENCE
		REFERENCE	BASELINE		
		2019	2025	2030	
ENVIRONMENTAL					
GHG from transport (tCO2eq/yr)	National	NA	NA	3,800,000	(DMQ, 2020)
GHG (tCO2eq/yr)	Quito	1,585,809	1,950,727	2,329,86	(Pintor, 2017)
TRANSPORT – MODAL SHARE					
Trips by car (%)	Quito	21.1%	20.0%*	29.4%	(Pintor, 2017)
Trips by buses (%)	Quito	57.7%	50.1%*	35.8%	(Pintor, 2017)
Trips by bicycle (%)	Quito	0.3%	0.3%*	0.4%	(Pintor, 2017)
Walking (%)	Quito	16.4%	17.5%*	19.6%	(Pintor, 2017)
Vehicle/1,000 habitants	Quito	241	314	368	(Pintor, 2017)
TRANSPORT – E-VEHICLES FLEET PENETRATION					
E-cars (number vs %)	National	NA / 0.0%	5,500 / 0.4%	65,000 / 4.0%	(DMQ, 2020)
E-buses (number vs %)	National	NA / 0.0%	1,500 / 4.0%	11,000 / 28.0%	(DMQ, 2020)
E-cars (number vs %)	National	0.0%	2.0%	8.0%	(DMQ, 2020)
TRANSPORT– ROAD SAFETY					
Number of road accidents	Quito-provincial	4,977	-	-	(DMQ (National Institute of Statistics and Census, 2021), 2020)
Number accidents involving vehicles only (single vehicle or 2 vehicle collision)	Quito-provincial	2,250	-	-	
Number injured people	Quito-provincial	3,128	-	-	
Number fatalities	Quito-provincial	357	-	-	
Number accidents involving pedestrians or cyclist	Quito-provincial	357	-	-	

Number of accidents involving property damage only	Quito-provincial	1,535	-	-	(National Institute of Statistics and Census, 2021)
Number of near accidents/ dangerous situations	Quito-provincial	NA	-	-	
Number of road accidents	Quito	3,015**	-	-	
Number injured people	Quito	1,551**	-	-	
Number fatalities	Quito	212**	-	-	

NA: Not available (NA); *: Data is presented for 2022 as for 2025 was NA; LDV: Light Duty Vehicles (LDV); **: Data is presented for 2002 as 2019 was NA.

The SOLUTIONSplus demo will first be implemented in the HCQ, which has approximately 40,000 inhabitants. The HCQ is the most visited area of Quito which accommodates 2.7 million inhabitants (INEC, 2020), representing 15% of Ecuador's population (UN Population Division, 2019).

For population growth, it is estimated that by 2025, Ecuador's population will increase by 7.87% compared to the reference year (2019). It is also interesting to notice that by the end of the baseline time frame, 2030, the population increase based on the reference year will be twice the increase estimated by the start of the baseline period, 7.87% and 14.07%, for 2025 and 2030 respectively. By 2030, Ecuador's population will reach 19.8 million, thus reinforcing the need for more sustainable and energy-efficient modes of transport able to provide a smart solution for increased user needs.

For GDP per capita (current prices, USD dollars per capita), in 2018, Quito's inhabitants showed an income of USD 24 billion despite 12.8% of Quito's metropolitan population living in poverty (DMQ, 2020). However, at the national level and based on International Monetary Fund (IMF) data the income is much lower. The IMF projections for the upcoming years show that Ecuador's GDP per capita could decrease by 2.7% (IMF, 2020a).

For unemployment rate predictions for the next five years expressed as a percentage of the total labor force, IMF's projections for Ecuador show a decrease from 3.8% in 2019 to 4.1% in 2025 (IMF, 2020b).

Regarding the environment, GHG emissions are expected to continue to grow due to the growing transport sector and the increased number of vehicles. Figure 5 shows the GHG estimations until 2030 for Quito by vehicle category.

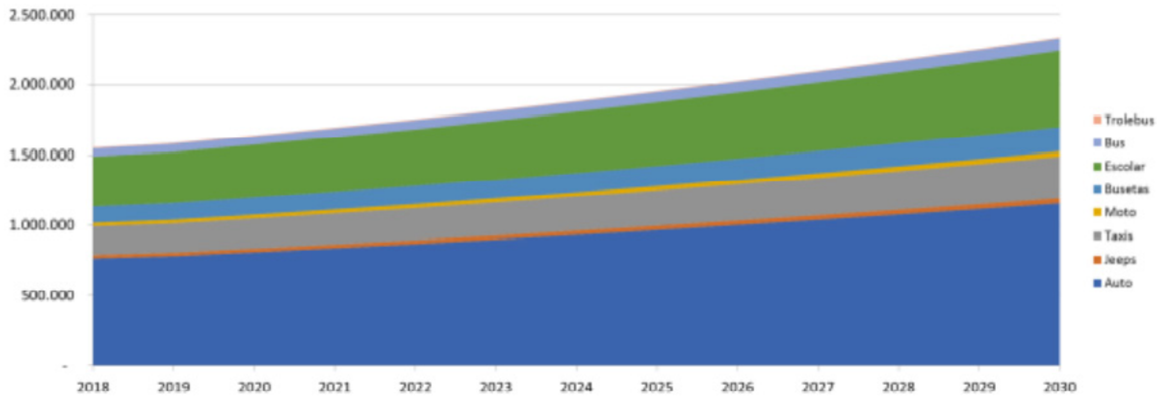


Figure 5. Quito's GHG emissions estimations until 2030 by vehicle type [tCO2eq/yr] (Pintor, 2017).

For the baseline period, 2025 to 2030, the main contributors to GHG emissions are passenger cars ("Auto"), school buses ("Escolar") and buses in general ("Busetas" and "Bus"), followed by taxis, as shown in Figure 5. By 2025 GHG emissions from transport are estimated to reach 1,900,000 [tCO2eq/yr] and this value will be even higher by 2030, with an estimation of 2,300,000 [tCO2eq/yr] (Pintor, 2017).

Regarding estimated travel mode patterns in Quito, information was available from 2019 to 2022 and then for 2030 but without reference to 2025. Modal share estimates revealed an increase for almost all modes from 2019 to 2030, with exceptions for public transport (by bus) (Pintor, 2017). Daily trips using a private vehicle (passenger car or motorcycle) account for 25.2% in 2019 and 35.3% in 2030 as shown in Figure 6. Daily trips using passenger cars are estimated to represent 21.05% in 2019 and 29.4% of all daily trips in Quito in 2030. On the other hand, daily bicycle trips are estimated to increase slightly from 0.3% in 2019 to 0.4% in 2030. Last, walking is estimated to increase from 17.3% in 2021 to 19.6% in 2030. In addition, Figure 6 shows an overview of daily trip trends and prospects until 2030 by travel mode: public transport ("Publico", either by metro or by bus), private ("Privado", e.g. passenger cars), bicycle ("Bicicleta") and walking ("Peatonal").

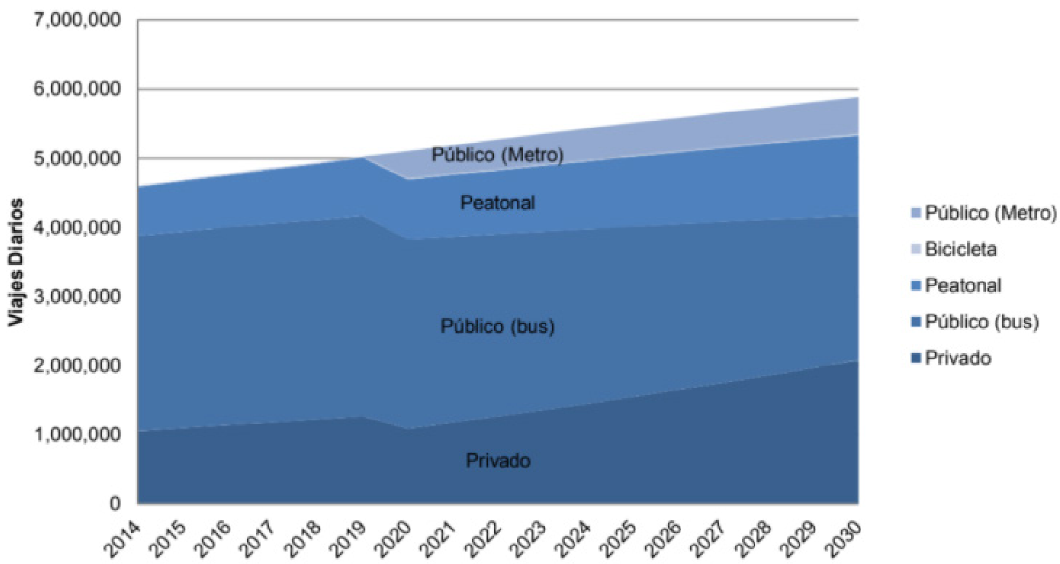


Figure 6. Quito's modal share (as a number of daily trips) (Pintor, 2017).

Considering the baseline period, from 2025 to 2030, the modal share is expected to increase for private vehicle use and walking. As already mentioned, for public transport by bus, it seems there will be a decrease in the daily trips by 2030. For the Quito demonstration project baseline period, it is also projected that vehicle motorization rates will grow from 256 vehicles per 1,000 habitants in 2025 to 368 vehicles per 1,000 habitants in 2030.

It is important to consider that the projections for the Quito SOLUTIONSplus project baseline covering the time period between 2025 to 2030 are based on available estimates. In addition, since 2020 the COVID-19 pandemic situation has impacted the lives of people worldwide and it is unknown how this will affect the projections, such as GDP per capita growth and employment rate, potentially also affecting the implementation of e-mobility solutions.

4 COMPONENT 1 – E-CARGO BIKE IMPLEMENTATION

4.1. COMPONENT DESCRIPTION

The demonstration implementation aligned with the Quito municipality plan for creating a zero-emission zone in the Quito Historic Centre (HCQ). The implementation took place between November 7th 2022 and January 6th 2023. The impact assessment of e-cargo bicycles focused on the implementation in the HCQ.

During the two-month implementation, ten e-cargo bikes consisting of three different models were implemented (i.e., Long John bicycle, rear-loading e-tricycle, front-loading e-tricycle – Figure 6). ECargoBikeUIO and Sidertech were selected to receive seed funding from SOLUTIONSplus to manufacture ten e-cargo bikes and four e-quadricycles, respectively, in the context of the Local Innovators Call launched by UN-Habitat in 2021. In August 2022, the Environmental Fund of the Municipality of Quito launched a competitive call for the local design and assembly of four e-mini vans, two for passenger and two for freight transport. The selected SME under this process was Grupo Miral.

Figure 7. E-cargo bike models.

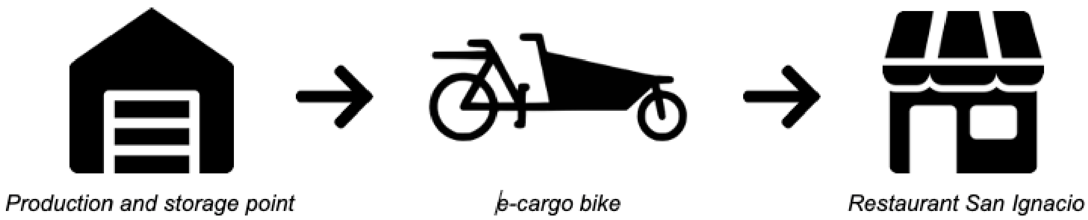
The manufactured e-cargo bikes were provided to local last mile delivery services and incorporated onto existing operational models, as presented in Figure 7.

SCHEME 1

Operators: Bike messengers and Frutería Merceditas.
Use case: Food distribution from local markets and shops to restaurants and hotels

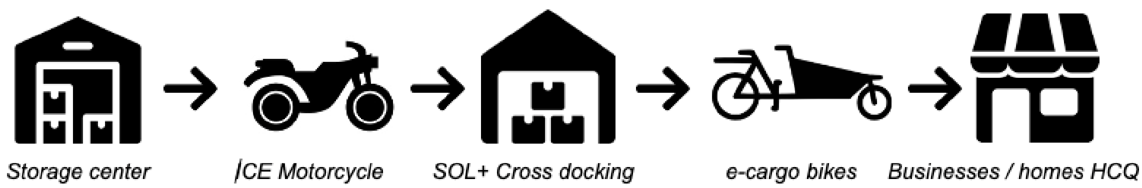
SCHEME 2

Operators: San Ignacio Restaurant
Use case: Restaurant with its own storage point in the HCQ



SCHEME 3

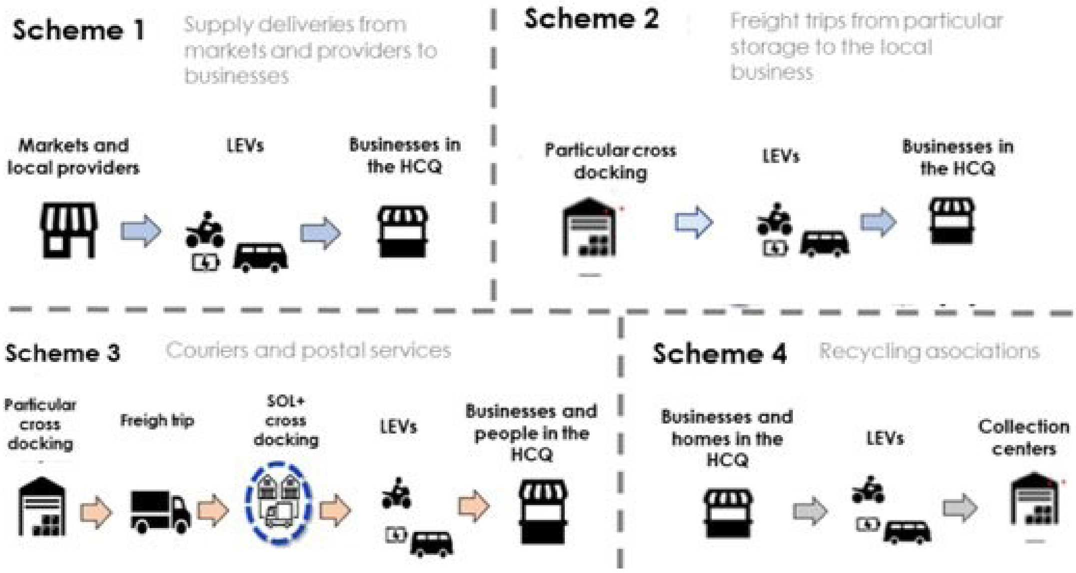
Operators: Urbano Express and Grupo Entregas
Use case: Courier and postal services



SCHEME 4

Operators: Recycling Associations Recicladores Unidos and Buena Esperanza de Pichincha
Use case: Collection of recycling materials

Figure 8. Operating Schemes.



Altogether, seven logistics operators took part in the pilot, divided onto the different operating schemes as follows:

1. Supply deliveries from markets and providers to businesses
    - A total of 2 pilot participants, 5 drivers
2. Freight deliveries from storage to local businesses
    - A total of 1 pilot participants, 1 driver
3. Couriers and postal services
    - A total of 2 pilot participants, 2 drivers
4. Recycling deliveries from homes and businesses to the collection centres
    - A total of 2 participants, 2 drivers

Overall, 16 tons of cargo were delivered during the pilot (313.7 kg/day on average). The deliveries conducted during the pilot were monitored using GPS tracking as well as user diaries.

Figure 8 shows the number of operational days by vehicle based on both GPS and diary data, ranging between 1 and 30.

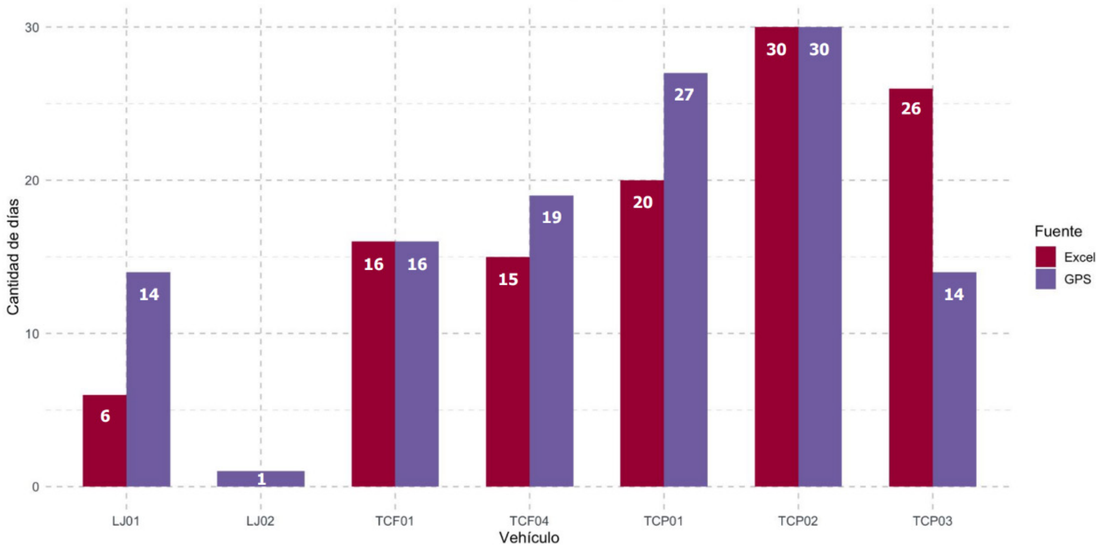


Figure 9. Number of operational days per vehicle.

The overall distance covered during the pilot was 2547.1 km, 1056.7 of which within the HCQ area. Figure 9 details the total distances covered by each vehicle and Figure 10 the total distances by vehicle within the HCQ.

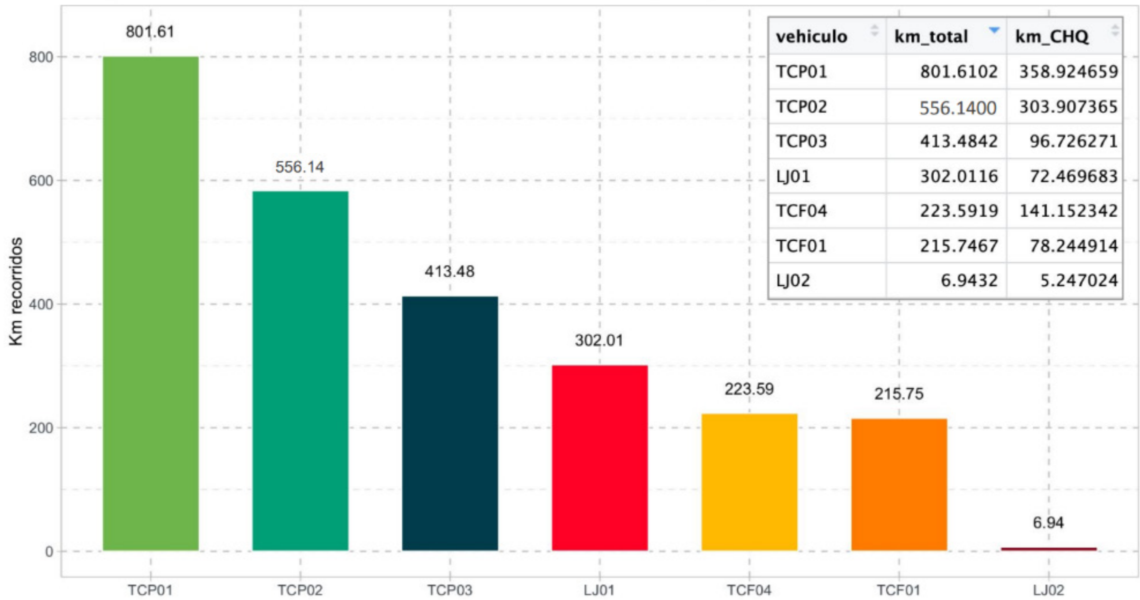


Figure 10. Total distances covered by vehicle.

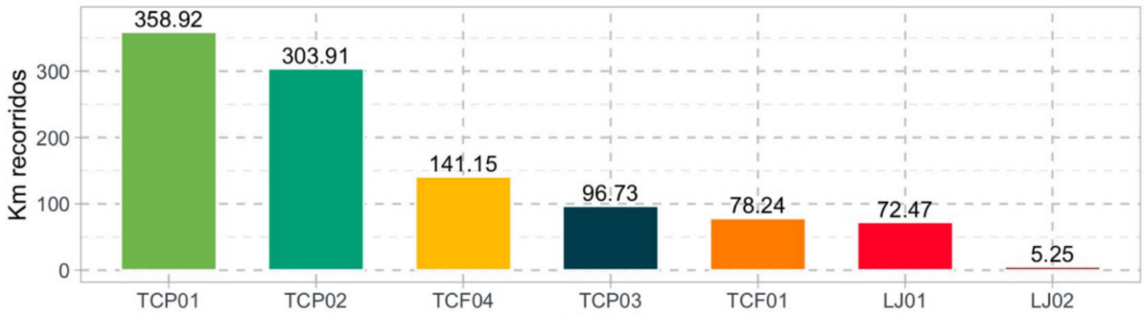


Figure 11. Total distances covered by vehicle within the HCQ.

4.2. IMPACT ASSESSMENT

4.2.1. Financial viability

4.2.1.1. Logistics services

The financial viability of SOLUTIONSplus implementation for logistics was assessed using three KPIs: Net Present Value (NPV), Internal Rate of Return (IRR), and payback period.

Sol + Vehicle (Long John e-cargo bike)

Table 4. outlines the operational profile, costs and revenues of a long john e-cargo bike used in logistics services.

Capital costs. The purchase price of a long john e-cargo bike was 2800 USD, expected useful life 5 years, and the price of a new battery 500 USD.

Operational profile: Based on the pilot implementation, the average number or round trips was 8, each being on average 0.625 km in length. Considering the number of operational days per year (264), the yearly mileage per vehicle is 1320 km, with 2112 delivery round trips.

Total operating costs: Considering a basic salary of 1.3 USD per delivery, the monthly salary of a rider is on average 208 USD. With electricity consumption of 0.03 kWh/km, and a tariff of 0.09 USD/kWh, the yearly electricity costs are 3,56 USD. Additional costs consist of maintenance fees of 220 USD/year (tires 60 USD, brake shoes 40 USD, dent paint 40 USD, wiring 80 USD). This leads to yearly total operating costs of 2900 USD.

Yearly revenues: Considering an income of 3.15 USD per trip, the yearly revenues per vehicle are 6653 USD.

Table 4. Operational profile, costs, and revenues of long john e-cargo bike.

CATEGORY	PARAMETER	VALUE	UNITS
General Info	Year built	2022	
	Year of purchase	N/A	
	Passenger capacity	N/A	
Propulsion	Battery type	Lithium Ion	
	Battery size	624	Wh
	Number of batteries	1	
Operational Profile	Length of round trip	0,625	km
	Round trips/day	8	trips/day
	Total distance/day	5	km/day
	Operating days/year	264	days/year
	Delivery trips/day	8	trips/day
	Chargings/day	1	
Yearly Operating Cost	Total operating cost	2 932	/year
	* Licencing/renewal	180	/year
	* Personnel cost	2 496	/year
	- Monthly salary	208,0	/month
	Basic salary per delivery	1,3	USD
	- Social security	0	/month
	- Yearly bonus	0	/year
	* Electricity cost	3,56	/year
	- Electricity consumption	0,030	kWh/km
	- Electricity tariff	0,09	/kWh
	* Maintenance cost	220	/year
	- Tires	60	/year
	- Brake shoes	40	/year
	- Dent paint	40	/year
	- Wiring	80	/year
Yearly Revenues	Total revenues	6 653	/year
	Average income per trip	3,15	USD
Income Tax	Total revenues	6 653	/year

Considering the costs and income outlined above, the pre-tax NPV of an e-cargo bike is 11363 USD, pre-tax IRR 130,44%, and pre-tax payback period 0.75 years (table 5).

With the income tax rate of 25%, and depreciation rate of 10%, the after-tax NPV is 8021 USD, after-tax IRR 97,97%, and after-tax payback period 0.97 years (table 6).

Table 5. Financial KPIs for the long john e-cargo bike before tax

Grupo Entregas - Cargo Service - Investor's Perspective - Calculations (Before Tax)						
Discount Rate	10%					
	Y0	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**
Year	2022	2023	2024	2025	2026	2027
Investment	-2 800					
Residual Value						500
Annual Revenues		6 653	6 653	6 653	6 653	6 653
Annual Operating & Maintenance Costs		-2 900	-2 900	-3 400	-2 900	-2 900
Net pre-tax cash flow	-2 800	3 753	3 753	3 253	3 753	4 253
Cumulative pre-tax cash flow	-2 800	953	4 706	7 960	11 713	15 966
Year	0	1	2	3	4	5
Pre-tax NPV	11 363					
Pre-tax IRR	130,44%					
Pre-tax payback (Years)	0,75					

Table 6 Financial KPIs for the long john e-cargo bike after tax

Grupo Entregas - Cargo Service - Investor's Perspective - 25% Income Tax Rate						
Discount Rate	10%					
	Y0	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**
Year	2022	2023	2024	2025	2026	2027
Depreciation	-280	-252	-226,8	-204,12	-183,708	-165,3372
Book Value	2 520	2 268	2 041	1 837	1 653	1 488
Taxable Income	- 2 800	3 501	3 526	3 049	3 570	4 088
Tax	0	875,309	881,609	762,279	892,382	1021,9747
Net Post Tax	- 2 800	2 878	2 878	2 491	2 861	3 231
Cumulative Post-tax	- 2 800	78	2 950	5 441	8 301	11 533
Year	0	1	2	3	4	5

after tax NPV	8 021					
after tax IRR	97,97 %					
after tax payback (Years)	0,97					

Previous solution

In the case of logistics operations, the deliveries were conducted using motorcycles. However, the company did not own the vehicles, but they were privately owned by the couriers. Therefore, the financial indicators cannot be calculated for the previous solutions. Nevertheless, the operational profile of the previous vehicle is presented in table 7 below based on the information obtained from the logistics company. As can be seen, the number of deliveries using motorcycles were significantly greater than when using the SOLUTIONSplus vehicles, leading to a greater income as a result.

Table 7. Operational profile, costs, and revenues of a previous solution (ICE motorcycle).

CATEGORY	PARAMETER	VALUE	UNITS
Operational Profile	Total distance/day	30	km/day
	Operating days/year	264	days/year
	Delivery trips/day	43	trips/day
Yearly Operating Cost	Total operating cost	14 515	USD/year
	* Licencing/renewal	180	USD/year
	* Personnel cost	13 416	USD/year
	- Basic monthly salary	1 118,0	USD/month
	* Fuel cost	499	USD/year
	- Fuel consumption	0,090	liters/km
	- Fuel price	0,7	/liter
	* Maintenance cost	420	USD/year
Yearly Revenues	Total operating cost	35 759	USD/year
	Average income per trip	3,15	USD

4.2.1.2. Restaurant logistics

The operational profile, costs and cost-effectiveness ratio are presented in table 8.

Capital costs: The purchase price of a rear-loading e-cargo bike used in restaurant logistics was 3200 USD.

Operational profile: Based on the pilot implementation, the average mileage per day is 2 km, and the number of yearly operational days 300, leading to a yearly mileage of 600 km.

Yearly operating costs: The personnel costs of picking up groceries at the market using an e-cargo bike can be estimated 200 USD/year, electricity costs 1 USD/year (considering consumption of 0.03 kwh/km, and price of 0.09 USD/kWh), and maintenance and other costs 300 USD/year, leading to total operating costs of 501 USD/year.

Annualized costs: The annualized costs for 10-year lifespan are 1040 USD (539 capital, 501 operational).

Cost effectiveness ratio: Considering the yearly volume of cargo of 711m³, the cost effectiveness ratio of an e-cargo bike is 1.47 USD/m^3.

Table 8. Operational profile, costs, and revenues of rear-loading e-cargo bike used in restaurant logistics

CATEGORY	PARAMETER	VALUE	UNITS
General Info	Year built	2023	
	Payload	150	kg
	Volume	2,370	m³
Propulsion	Battery type	Lithium Ion	
	Battery size	0,624	kWh
	Number of batteries	1	
Capital Cost	Purchase price	3 200	USD
	* Manufacturing	1 250	USD
	* Drive train	1 700	USD
	* Battery	250	USD
	Expected useful life	10	years
	* Vehicle body	10	years
	* Battery	4	years
	Residual value	150	USD
	* Body	150	USD
	Discount rate	10 %	
Operational Profile	Average distance/day	2	km/day
	Operating days/year	300	days/year
Yearly Operating Cost	Total operating cost	508	USD/year
	* Personnel cost	200	USD/year
	* Electricity cost	8	USD/year
	- Energy consumption	0,03	kwh/km
	- Electricity tariff	0,09	USD/kwh
	* Maintenance cost	250	USD/year
	- Tires	90	USD/year
	- Brake shoes	40	USD/year
	- Dent paint	40	USD/year
	- Wiring	80	USD/year
	* Other	50	USD/year
Annualized Cost	Capital	539	USD/year
	Operational	508	USD/year
	Total	1 047	USD/year
Annual Cargo Collected	Volume of cargo	711	m³/year
Annual Cargo Collected		**1,47**	USD/m³

4.2.1.3. Recycling

The operational profile, costs and cost-effectiveness ratio are presented in table 9.

Capital costs: The purchase price of a rear-loading e-cargo bike is 3200 USD.

Operational profile: Based on the pilot implementation, the average mileage per day is 9 km, and the number of yearly operational days 353, leading to a yearly mileage of 3177 km.

Yearly operating costs: The yearly personnel costs can be estimated to 2,824 USD, electricity costs 9 USD/year (considering consumption of 0.03 kWh/km, and price of 0.09 USD/kWh), and maintenance, parking and other costs 3,102 USD/year, leading to total operating costs of 5,935 USD/year.

Annualized costs: The annualized costs for 10-year lifespan are 6,474 USD (539 capital, 5,935 operational).

Cost effectiveness ratio: Considering the yearly volume of cargo of 837 m3, the cost effectiveness ratio of an e-cargo bike is 7.74 USD/m3.

Table 9. Operational profile, costs, and revenues of rear-loading e-cargo bike used in recycling

CATEGORY	PARAMETER	VALUE	UNITS
General Info	Year built	2023	
	Waste payload	150	kg
	Waste volume	2,370	m³
Propulsion	Battery type	Lithium Ion	
	Battery size	0,624	kWh
	Number of batteries	1	
Capital Cost	Purchase price	3 200	USD
	* Manufacturing	1 250	USD
	* Drive train	1 700	USD
	* Battery	250	USD
	Expected useful life	10	years
	* Vehicle body	10	years
	* Battery	4	years
	Residual value	150	
	* Body	150	
	* Battery		USD
	Discount rate	10 %	
Operational Profile	Average distance/day	9	km/day
	Operating days/year	353	days/year
Yearly Operating Cost	Total operating cost	5 935	USD/year
	* Personnel cost	2 824	USD/year
	* Electricity cost	9	USD/year
	- Energy consumption	0,030	kwh/km
	- Electricity tariff	0,09	USD/kwh
	* Maintenance cost	222	USD/year
	- Tires	90	USD/year

Yearly Operating Cost	- Brake shoes	40	USD/year
	- Dent paint	12	USD/year
	- Wiring	80	USD/year
	* Parking cost	1 500	USD/year
	* Other	1 380	USD/year
Annualized Cost	Capital	539	USD/year
	Operational	5 935	USD/year
	Total	6 474	USD/year
Annual waste collected	Volume of waste	837	m³/year
Cost effectiveness ratio (CER)		**7,74**	USD/m³

4.2.2. Availability of financial resources

The potential funding instruments for the project were mapped by the local project team in Quito (Table 10).

Several potential international instruments for supporting the project were identified, along with commercial banks that provide credit for the transportation sector. Moreover, due to the project being a part of the Quito municipality plan of creating a Zero Emissions Historic Centre, city funds have been allocated for supporting the project. Due to these notions, the indicator is assigned a **STAR value of 5** for all three components.

Table 10. Potential funding instruments for the project

	SOURCE OF FUNDING	ELIGIBILITY CRITERIA
Instruments related United Nations Framework Convention on Climate Change	Climate Change Technology and Network	Supports applications that: • contribute to increasing resilience or emission reduction • align with national plans • strengthens national capacities • implement processes that allow monitoring and evaluation of the provided support
Instruments related United Nations Framework Convention on Climate Change	Green Climate Fund	Key areas of impact: • Access to low emission energy and power • Low emission transport • Energy efficient buildings, cities, and industries • Sustainable land use and forest management • Improved livelihoods for the most vulnerable people communities and regions • Increased health and well-being and food and water security • Resilient infrastructure and built environment against the threats of climate change • Resilient ecosystems

Instruments related United Nations Framework Convention on Climate Change	Global Environmental Facility	Provides support for: • Projects that are country-driven and consistent with national priorities that support sustainable development • Primarily available for government-supported projects • The incremental costs of measures to achieve global environmental benefits • Projects that involve public in the design and implementation
	Climate Investment Funds	• Transformational change • Involvement and benefits for local actors • Impacts on climate change and justice • Mobilization of the private sector
Bilateral Funds	French Development Agency (AFD)	
	Japanese International Cooperation Agency (JICA)	Applications are evaluated in terms of: • Relevance • Sustainability • Efficiency • Impacts
	German Agency for Development Cooperation (GIZ)	
	German Development Bank (KfW)	Bases its support on the Agreements signed between the governments of the partner countries and the Federal Government of Germany. In most projects, a feasibility study is required that includes an analysis of all the key aspects of the project.
	International Climate Protection Initiative (IKI)	The government of the partner country must express its explicit interest in the project. Projects must be implemented in cooperation with national, local and regional partners to ensure their regional anchorage.
	Euroclima+	The program prioritizes criteria such as: transformative and/or catalytic effects • Potential for innovation • Balancing ambition and vulnerability Replicability and scalability • Bankability • Support gender equity, women's empowerment and human rights
	Nordic Development Fund (NDF)	Relevance, feasibility, innovativeness

Bilateral Funds	Austrian Development Bank	Development criteria Economic criteria Environmental and social sustainability criteria
	Canadian Climate Fund for the Americas (C2F)	Projects must demonstrate climate benefits
Commercial Banks	Procubanco	
	Oscus	Provides commercial credit for the transport sector
	Banco Procredit	Provides commercial credit for the transport sector
	CFN	Provides commercial credit for the transport sector
	Cooperativa Jardin Azuayo	Provides commercial credit for the transport sector
	BanEcuador	Provides commercial credit for the transport sector
	Banco Pacífico	Provides commercial credit for the transport sector
	Banco Pichincha	Provides commercial credit for the transport sector

4.2.3. Institutional and political indicators

4.2.3.1. Coherence with national plans and development goals

Alignment with transport policies: At the national level, the project aligns with the Organic law of Land Transport which incentivises the use and acquisition of e-mobility and zero-emission mobility technologies, the National Electric Mobility Strategy, and the National Urban Mobility Policy (NUMP) that supports clean mobility, efficient and safe urban transport and efficient and sustainable freight distribution and logistics. At the city level, the project aligns with the Sustainable Mobility Plan for the Metropolitan District of Quito, which aims to mitigate the climate impacts of the mobility sector, improve connectivity and accessibility, and make the economy in the are more dynamic through an effective mobility system. The project also aligns with the Historic Center Parcial Development plan that prioritizes e-mobility.

Alignment with energy policies: On a national level, the project aligns with the Law on Energy Efficiency that obligates the prioritization of electric public transport, freight, and logistics in planning, and poses limits to the emissions of new vehicles. Moreover, the project aligns with Ecuador Climate Change National Strategy. On the city level, the project aligns with Quitos Climate Action Plan, and the plan for Low Emission Zone HCQ.

Alignment with environmental policies: The project aligns with the national technical regulation Control of Pollution Emissions of Road Movable Sources.

Alignment with overarching national policies: The project aligns with the Ecuador

'Agenda Habitat Sostenible 2036' plan for sustainable development.

The scaled-up project therefore aligns with the identified transport, energy, environmental and overarching policies, giving the indicator a **STAR value of 5.**

4.2.3.2. Alignment with supra-national/national/city legislation & regulations

The identified regulations relevant to the project are compiled in Table 11 below. As can be seen, one instance of uncertainty with project compliance has been identified regarding the management of used acid batteries (i.e., Ministerial Agreement No. MAATE-2021-034, Extended Producer Responsability (REP) in the Management of Used Lead Acid Batteries Regulation), giving the indicator a **STAR value of 4.**

Table 11. Relevant regulations identified for the project

STANDARD NUMBER	PARAMETER	VALUE	UNITS
	Organic Law of Land Transportation, Traffic and Road Safety - Art (s). 205	Homologation requirement for both importers of vehicles, spare parts, equipment, parts and pieces; and assemblers	Project Complies
NTE INEN 2656:2012	Vehicle classification standard	This standard applies to all vehicles designed for land circulation (motor vehicles and cargo units)	Project Complies
RTE INEN 034	Minimum safety elements in motor vehicles	This Ecuadorian technical regulation applies to all vehicles that will enter the park Ecuadorian automotive, whether imported, assembled or manufactured in the country.	Project Complies
RTE INEN 136 (1R)	Technical Requirements for Motorcycles	This technical regulation applies to all motorcycles and tricycles that are imported or assembled and commercialized in Ecuador.	Project Complies
NTE INEN 2558	Braking System	Product requirement	Project Complies
RTE INEN 011	Tires (including emergency tires,if any)		
NTE INEN 2556	Mirrors		
NTE INEN 2559	Suspension system		
NTE INEN 2557	Direction system		
NTE INEN 2560	Lighting		
RTE INEN 048	Three-wheeled motor vehicle for passenger transport and freight transport	This Ecuadorian technical regulation applies to all three-wheeled vehicles for passenger and freight transport, whether imported, assembled or manufactured and commercialized in the country.	Project Complies

RTE INEN 017	Control of Pollution Emissions of Road Movable Sources	This Ecuadorian Technical Regulation applies to both imported and motorized vehicles locally manufactured.	Project Complies
PRTE INEN 162	Charging accessories for electric vehicles	Draft regulation that establishes the technical and safety characteristics that connectors, chargers, wiring and batteries must meet for charging electric vehicles.	Project Complies
Ministerial Agreement No. MAATE-2021-034	Extended Producer Responsability (REP) in the Management of Used Lead Acid Batteries Regulation	Art. 1d. Prepare and present the Comprehensive Management Plan (PGI) for used lead acid batteries, in accordance with the provisions of these instructions, before the Environmental National Authority, for your approval.	Uncertain

4.2.3.3. Ease of implementation in terms of administrative barriers

Required administrative interventions: The Sustainable Mobility Ordinance requires the approval from political instances, the Low emission Historic Center has not been officially created through Ordinance or Decree. Municipal entities need to approve the use of municipal space for crossdocking, and the use of charging infrastructure. The draft micromobility ordinance should be finalised and approved in the City Council, regulating the circulation conditions of all vehicles under the LEV umbrella as recommended by SOLUTIONSplus. The significant barriers in terms of homologation and imports related to the local manufacturing of LEV identified in the SOLUTIONSplus pilot need to be reduced to enable the scale-up.

The political and institutional bodies needed for supporting the implementation include the City council, Mobility Secretariat, District Administration, Municipal Enterprise of Public Works (EPMMOP), Environmental Secretariat, Environmental Fund, Metropolitan Institute of Urban Planning (IMPU), Municipal PTO (EPMTPQ).

It is unclear whether **the existing national/city political and institutional bodies are (likely to be) supportive of the necessary actions required for the project implementation.**

Overall, the political bodies are in place, while the project requires some administrative interventions, and it is difficult to assess whether institutional bodies are likely to support the project actions, giving the indicator a **STAR value of 2.**

4.2.4. Climate related indicators

4.2.4.1. Impact on GHG emissions

Logistics services: Based on the pilot implementation, an average mileage of 5 km a day can be assumed for the logistics services. Considering 264 yearly operating days, the yearly mileage per vehicle adds up to 1,320 km.

The main vehicle used for deliveries prior to the implementation were small motorcycles. Based on the information obtained from the logistics company, consumed on average 0.09 litres of gasoline per kilometre travelled in the Quito Historic Center. Therefore, considering the estimated yearly mileage per vehicle, the annual fuel consumption per vehicle adds up to 118.8 litres.

Considering the emission factor of 2.31 kg CO2 per liter, the estimated amount of CO2 emissions per vehicle yearly adds to 274.4 kg. Thus, under the assumption that electricity is produced using renewable, emission free, resources, switching from motorbikes to e-bikes can be expected to save 274.4 kg per year of CO2 per vehicle.

Restaurant logistics: Based on the pilot implementation, an average mileage of 2 km can be assumed for the restaurant logistics. Considering 300 yearly operating days, the yearly mileage adds up to 600 km.

The main vehicle used for deliveries prior to the implementation was a passenger car that, based on the information obtained from the logistics company, consumed on average 0.125 liters of gasoline per kilometer travelled in the Quito Historic Center. Therefore, considering the estimated yearly mileage per vehicle, the annual fuel consumption per vehicle adds up to 75 liters.

Considering the emission factor of 2.31 kg CO2 per liter, the estimated amount of CO2 emissions per vehicle yearly adds to 173.25 kg. Thus, under the assumption that electricity is produced using renewable, emission free, resources, switching from a passenger car to an e-bike when conducting restaurant logistics can be expected to save 173.25 kg per year of CO2.

Recycling: The recycling was previously conducted using manual pushcarts, and therefore, under the assumption that electricity is produced using renewable, emission free, resources, switching to SOLUTIONSplus vehicles does not have an impact on CO2 emissions.

4.2.5. Environmental indicators

4.2.5.1. Impact on air pollutants

Logistics services. Air pollutants emitted by ICE motorbikes comprise NOx and particular matter (PM) from fuel combustion. As no local information is available of the local air pollutant emissions, comparable data is used. According to EMEP/EAA, the NOx emissions from 4-stroke - Mop - Euro 3 are 0.17 g/km and PM2.5 emissions 0.004 g/km. Therefore, considering the yearly mileage of 1320 km, the amount of abated local air pollutants is 0.224 kg NOx and 0.0053 kg PM2.5.

Restaurant logistics. As no local information is available of the local air pollutant emissions, comparable data is used. For instance, using emissions from a Euro 3 class medium diesel car as a reference (i.e., PM2.5 0.0391 g/km and NOx 0.773 g/km), and considering the yearly mileage of 600km, the annual reduction in local air pollutant emissions would add up to 0.464 kg NOx and 0.023 kg PM2.5.

Recycling. The previous solutions used in recycling were manual pushcarts, and therefore the pilot had no impact on local air pollutant emissions.

4.2.5.2. Impact on noise

Based on the pilot, the uptake of e-vehicles contributes to the reduction of noise levels within the HCQ. The impact on noise indicator is based on the subjective evaluation of riders that took part in the demonstration project (n=7). During the demonstration, the participants were asked to evaluate whether they perceived that the noise of SOLUTIONSplus e-vehicles is better than that of the previously used vehicles on a 5-point Likert scale (completely disagree-completely agree). The average value was 4.57.

4.2.5.3. Effect on recycled resources

A major consideration for the project is the end-of-life of lithium-ion batteries that current e-vehicles typically use. In many parts of the world, practices for recycling and disposing these batteries are immature, which poses impacts on the environment as well as human health. In Quito, there is currently a lack of procedures and regulations for battery second-life use and recycling, which might cause environmental and health issues if not implemented.

The typical chemical compositions of different types of lithium-ion batteries are presented in table 12 below (Sobianowska-Turek et al., 2021). It is noteworthy that lithium-ion batteries include toxic and environmentally harmful materials such as cobalt, nickel and manganese that can harm ecosystems as well as contaminate water supplies if disposed at landfills.

Table 12. Lithium-ion battery materials (Sobianowska-Turek et al., 2021)

MATERIAL	LITHIUM AND COBALT OXIDE LICOO2 (% OF WEIGHT)	A CATHODE MADE OF IRON PHOSPHATE LIFEPO4 (% OF WEIGHT)	MANGANESE OXIDE LIMN2O4 (% OF WEIGHT)	LITHIUM-MANGANESE-COBALT OXIDE LINIMNCOO2 W(% OF WEIGHT)
Aluminium	5.2	6.5	21.7	22.72
Cobalt	17.3	-	-	8.45
Copper	7.3	8.20	13.5	16.60
Iron/steel	16.5	43.2	0.1	8.79
Lithium	2	1.2	1.4	1.28
Manganese	-	-	10.70	5.86
Nickel	1.2	-	-	14.84
Binder	2.4	0.90	3.70	1.39
Electrolyte	14.00	14.90	11.8	11.66
Plastic	4.8	4.4	4.5	3.29

The typical mass of a lithium-ion battery is 15–30% of the e-vehicle total mass (Winslow et al., 2018). A typical life of a lithium-ion battery has approximately 500–1000 recharging cycles, or approximately 5–8 years of use (Haram et al., 2021), yet if charged daily, it could be somewhat shorter in the case of the implemented e-cargo bikes.

The e-cargo bikes implemented during the pilot used 48V 13 Ah lithium-ion batteries, which weigh approximately 4 kg. Assuming a battery lifetime of 5 years, this means that 0.8 kg of waste would be generated per adopted e-bike per year, including approximately 0.14 kg of cobalt, 0.016kg lithium, and 0.01 kg of nickel, which are environmentally harmful substances and dangerous to human health.

4.2.6. Social indicators

4.2.6.1. Impact on accessibility

Based on the pilot demonstration, the uptake of e-cargo bikes contributes to the accessibility of pick-up and delivery locations. The accessibility indicator is based on the subjective evaluation of riders, operators and customers that took part in the demonstration project (n=39). During the demonstration, the participants were asked to evaluate whether the use of SOLUTIONSplus e-vehicles decreased the distance from parking to establishment on a 5-point Likert scale (completely disagree-completely agree). The average value was 3.95.

4.2.6.2. Impact on delivery time

Logistics services. Based on the information obtained from the logistics company, on average 43 delivery trips were conducted daily prior to the pilot implementation, and 8 delivery trips after the implementation, leading to a reduction of 80 % in delivery efficiency. This means that the operating scheme for e-cargo bikes needs to be adjusted to facilitate more efficient deliveries that take advantage of the benefits of using e-cargo bikes such as their ability to reach destinations within the HCQ that are difficult for ICE vehicles to reach due to e.g., restrictions and infrastructure.

Restaurant logistics: No differences in delivery times were observed for restaurant logistics before and after the implementation.

Recycling: Based on the survey responses of recyclers, the average time per day it took to collect the recycled materials was 4 hours prior to the implementation, and 1.19 hours after the implementation, leading to a reduction of approximately 70 %.

4.2.6.3. Impact on road safety

The impact on road safety was assessed using two KPIs – road accidents involving vulnerable road users and overall amount of road accidents.

4.2.6.3.1. Road accidents involving vulnerable road users

Based on the pilot demonstration survey as well interviews of local experts, the uptake of e-cargo bicycles contributes to the safety of vulnerable road users within the HCQ. The 13 riders and logistics operators were asked whether SOLUTIONSplus would increase the safety of vulnerable road users (5-point Likert scale completely disagree – completely agree). The average value of the responses was 4.08.

4.2.6.3.2. Road accidents

The 13 riders and logistics operators were asked whether the SOLUTIONSplus vehicle is safer than the vehicle used previously (5-point Likert scale completely disagree – completely agree). The average value of the responses was 3.29.

4.2.6.4. Quality

Quality dimensions were assessed based on a user survey conducted during the pilot implementation together for all three components. The results are presented in Table 13 below and further detailed in Figure 11. As can be seen, the evaluations were mainly favourable in terms of suitability for adverse weather conditions, riding comfort, ease of charging and ease of riding and continuity of the journey chains, while the evaluation regarding safety and security were neutral.

Table 13. Quality assessment of the implemented vehicles

KPI	ITEM	SCALE	RESPONDENTS	RESULT (MEDIAN)
Perceived safety	'Compared with the previous solution the safety of the SOLUTIONSplus vehicle is better' (riders)	5-point Likert scale (...)	Riders (n=7)	3.29 (SD=1.7)
Suitability for changing weather conditions	Compared with the previous solution.... The suitability for adverse weather conditions of the SOLUTIONSplus vehicle is better.	5-point Likert scale (completely disagree – completely agree)	Riders (n=7)	4 (SD=1)
Comfort	The comfort in travel of the SOLUTIONSplus vehicle is better	5-point Likert scale (completely disagree – completely agree)	Riders (n=7)	4.29 (SD=1.25)
Ease of driving	The ease of driving of the SOLUTIONSplus vehicle is better	5-point Likert scale (completely disagree – completely agree)	Riders (n=7)	3.86 (SD=1.68)
Ease of charging	The ease of charging/refu-eling of the SOLUTIONSplus vehicle is better	5-point Likert scale (completely disagree – completely agree)	Riders (n=7)	3.86 (SD=1.21)
Perceived security	The personal security (in terms of unlawful behaviors) of the SOLUTIONSplus vehicle is better	5-point Likert scale (completely disagree – completely agree)	Riders (n=7)	3.43 (SD=1.51)

Perceived security	The personal security (in terms of unlawful behaviors) of the SOLUTIONSplus vehicle is better	5-point Likert scale (completely disagree – completely agree)	Riders (n=7)	3.43 (SD=1.51)
Perceived continuity of the journey chains	The continuity of journey chains, including switching from one travel mode to another of the SOLUTIONSplus vehicle is better	5-point Likert scale (completely disagree – completely agree)	Riders (n=7)	4.14 (SD=1.21)

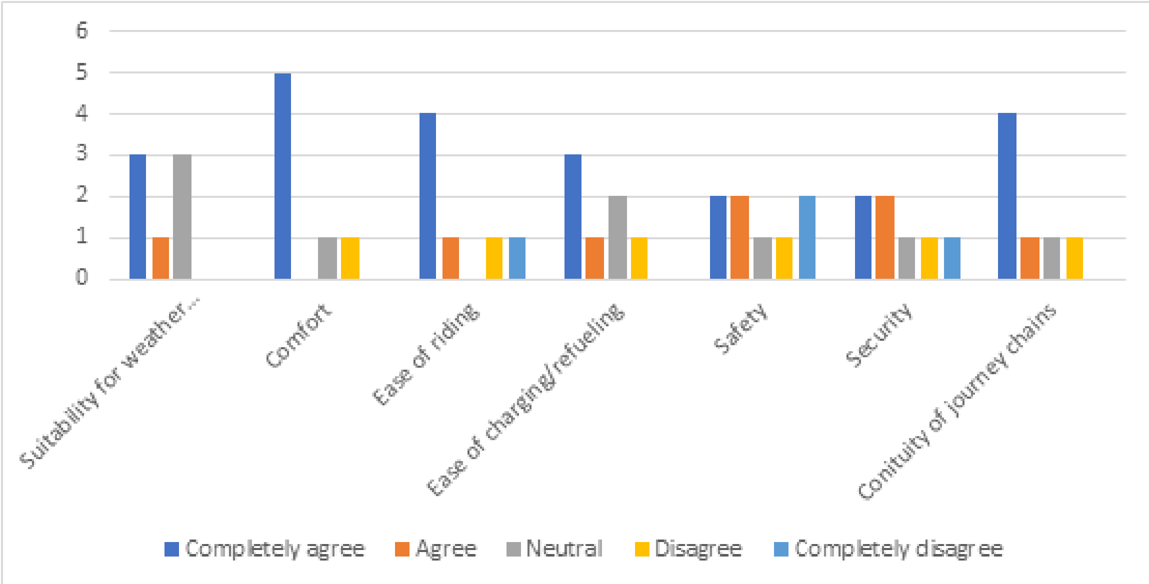


Figure 12. SOLUTIONSplus vehicles quality evaluation results.

5 COMPONENT 2 - MAAS-APPLICATION FOR PUBLIC TRANSPORT

5.1. COMPONENT DESCRIPTION

During the demonstration, a mobility as a service (MaaS) application was implemented. The application was developed by the SOLUTIONSplus consortium member PlusService to address the needs of Quito public transport companies EPMTPQ and EPMMQ. The application allowed users to plan multimodal trips, provided the user with information regarding transportation schedules, transportation lines, stations and stops, allowed users to purchase transportation tickets and provided user management. Additionally, Web Assistant application that allowed user registration and recharging mobile wallets at the ticket office, and My Check application that allowed validating digital tickets upon use, were developed.

The pilot demonstration was conducted in collaboration with the public transport company EPMTPQ, regional SOLUTIONSplus representatives, PlusSevice company, National Polytechnic School, and Mobility Secretary. The duration of the pilot implementation was one month (November 21st – December 16th, 2022). The pilot participants consisted of 45 National Polytechnic School students who volunteered to use the MaaS application for their journeys during the 1-month period.

To evaluate the MaaS application impacts, a survey was conducted among pilot users. A total of 24 users completed the survey. Additional log data was collected to assess application usage.

5.2. IMPACT ASSESSMENT

It is noteworthy that several usability issues hindered the adoption and use of the piloted MaaS application, as demonstrated by the user responses regarding their opinions of the various application features presented below in Figure 12. Although it is plausible that a MaaS application would have positive impacts on the Quito mobility system, these usability issues are likely to have affected the pilot impacts, which did not reveal the full potential that a MaaS type of service could have in the city of Quito.

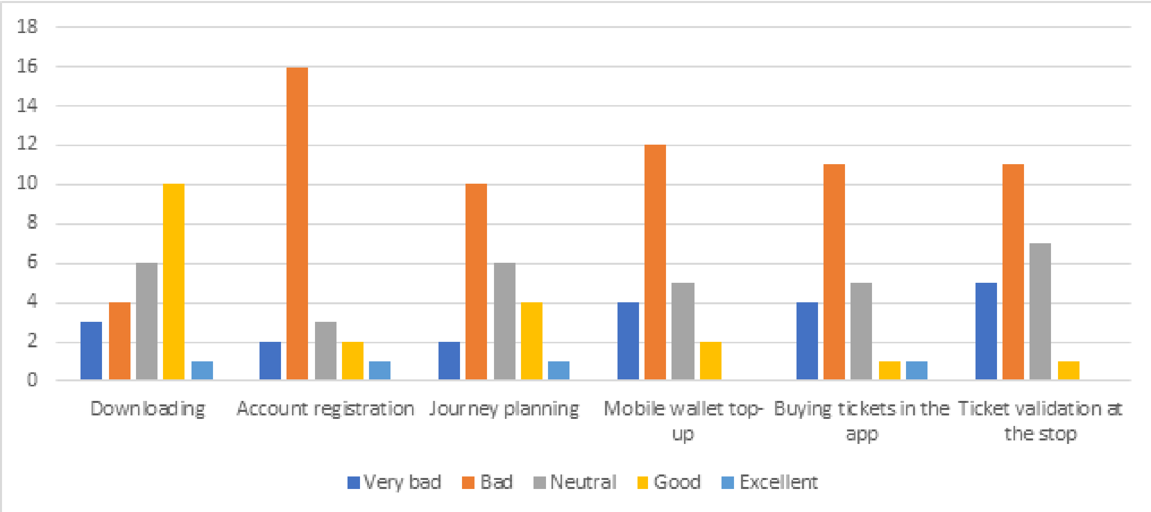


Figure 13. MaaS application usability evaluation results.

GHG emissions, air pollution, noise. Five (21%) of the surveyed pilot users responded that they used public transport more frequently, during the pilot while 19 (79%) responded that there was no difference in public transportation use due to the pilot. However, only one of the pilot participants reported using a private vehicle (car) in their journeys to the university, while public transport and walking were the most common means for traveling. This implies that, among pilot participants, the use of the MaaS app replaced journeys previously made on foot with the use of public transport. Therefore, the application demonstration is likely to have had no impact on GHG emissions, air pollution or noise. However, the number of trips made using private vehicles is expected to be smaller for the sample that consisted of university students than that of Quito in general, and a large-scale MaaS implementation might have different impacts.

Impact on accessibility. When asked whether the application allowed reaching new destinations, three (12.5 %) of the surveyed pilot users agreed, nine (37.5 %) responded 'neutral', four (16.7 %) disagreed, three (12,5 %) totally disagreed, and five (20.8 %) replied that not in this version, but the application has the potential to do so.

Moreover, when asked whether the application allowed choosing better connections to destinations, four (16.7 %) participants agreed, nine (37.5%) responded ‘neutral’, three (12.5%) disagreed, five (20.8%) totally disagreed and three (12.5%) replied that not in this version, but the application has the potential to do so. These responses imply that the developed MaaS application has little impact on accessibility. However, with further developments that tackle the usability issues hindering the use of the piloted version, a MaaS-based approach might have the potential to improve accessibility in Quito.

Impact on travel time. The user survey results imply that the piloted application had little impact on travel time. When asked whether application use reduces the total travel time, nine (37.5%) participants completely disagreed, two (8.3 %) disagreed, 11 (45.8%) responded ‘neutral’, one (4.2 %) agreed, and one (4.2 %) replied that not in the current version, but the application has the potential to do so.

Impact on road safety. Based on the responses, the use of a MaaS application did not decrease the use of private vehicles within the student population. Therefore, it is unlikely that the demo implementation has any impact on road safety. However, a large-scale implementation among citizens of Quito would be more likely to decrease the use of public vehicles, therefore reducing the number of accidents.

Quality of the service. When asked whether the application allowed choosing better connections to destinations, four (16.7 %) participants agreed, nine (37.5%) responded ‘neutral’, three (12.5%) disagreed, five (20.8%) totally disagreed and three (12.5%) replied that not in this version, but the application has the potential to do so. These results imply that the application in its current form does not enhance the perceived quality of the mobility services in terms of easing the journey planning and execution.

Modal split and multimodality. Five (21%) of the surveyed pilot users responded that during the pilot they used public transport more frequently, while 19 (79%) responded no difference in public transportation use, suggesting that the use of the MaaS app slightly contributes to the use of public transport.

Impact on traffic network efficiency. As the demonstration did not have a decreasing effect on the use of private cars among the student population that participated in the demonstration, it is likely that the demonstration had no impact on traffic network efficiency in the area.

Demand for MaaS application. On average, seven daily tickets per user were purchased and six validated at a vehicle during the MaaS demonstration pilot. The use of the MaaS application reached its peak in terms of ticket purchases (Figure 13) and validation (Figure 14) after four days into the pilot implementation, after which the use started to decline, apart from some days when the use was more frequent.

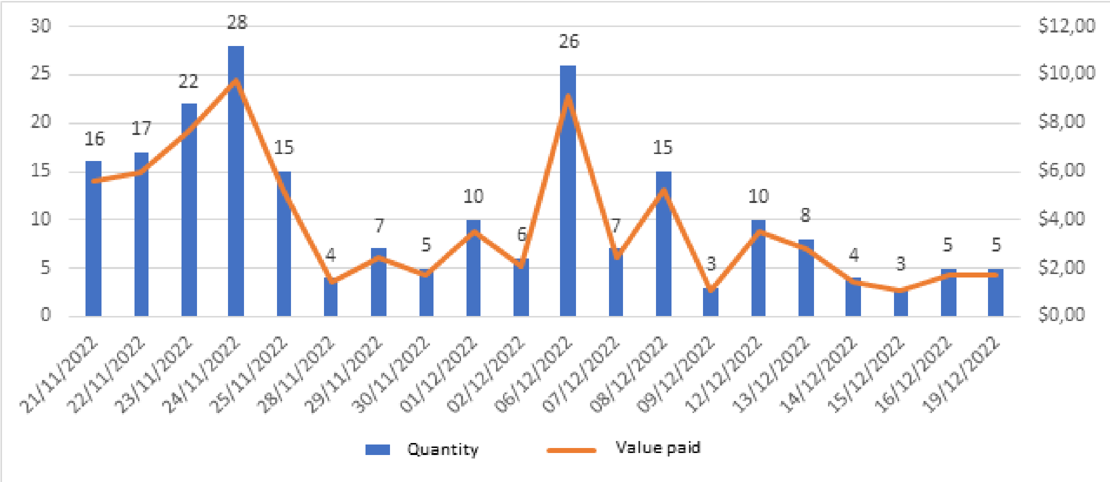


Figure 14. Ticket purchases during the pilot.

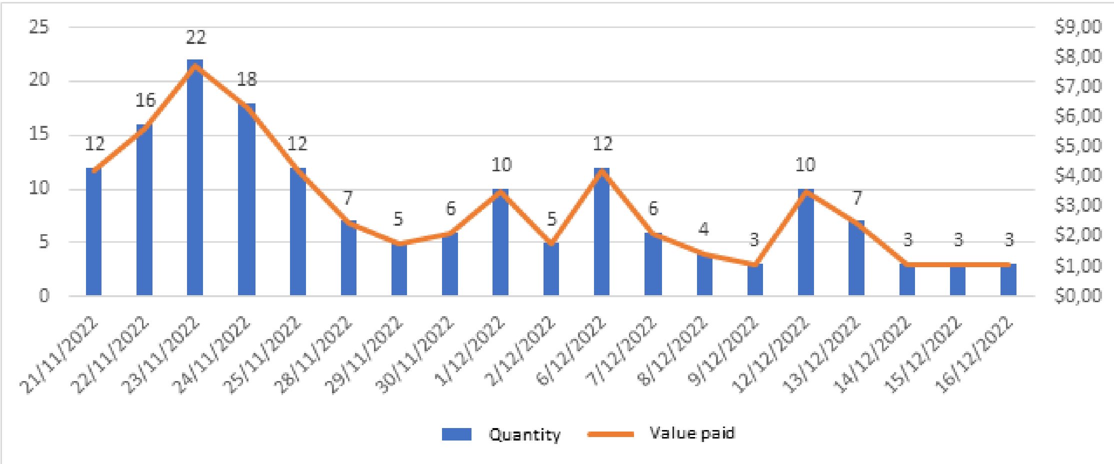


Figure 15. Ticked validations during the pilot.

While the demonstration implementation had little impact on mobility patterns among the participant population, it shed light on the feasibility and potential of MaaS. In the current form of the MaaS app, the usability issues hindered its adoption and user as well as the perceptions of usefulness. However, given the usability issues would be fixed, participants would be likely to use the various features of the app, including trip planner, topping up the mobile wallet, buying tickets and ticket validation, as presented in Figure 15.

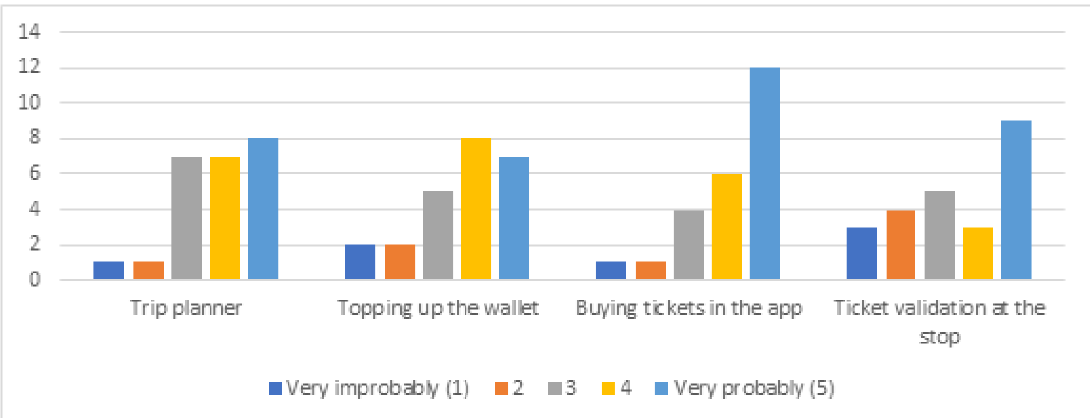


Figure 16. Intention to use different app features in the future.

The demonstration participants consisted of university students, the majority of whom did not use a car regularly. Thus, the MaaS demonstration implementation had limited impact on many of the selected KPIs as it did not contribute significantly to the reduction of private cars in the area. However, it should be noted that in the broader population, where car usage is more common, the MaaS application shows promise as an effective means of reducing private car use and the associated negative externalities.

6 SCALED-UP CONCEPT AND ASSESSMENT

The scaled-up project considers the vision of establishing 'Quito Historic Center Zero-emission logistics'. The initiative is a part of the Quito city climate action plan for mobility, with one its goals being the creation of an overall Zero-emission Historic Center in which all ICE vehicles are replaced by electric ones.
The scaled-up project is an extension of the SOLUTIONSplus demonstration implementation conducted in the Quito Historic Center in November 2022-January 2023. Therefore, the scaled-up project focuses on replacing ICE logistics vehicles with e-vehicles in the Quito Historic Center. The scaled-up evaluation uses the pilot results as the basis and therefore does not account for all the impact mechanisms that electrifying logistics could have.

6.1. BASELINE

The historic center of Quito (HCQ) is an area with a high concentration of commercial activity. It covers 376 hectares and has about 40,000 residents. Most of the logistics flows in the city originate from or pass through the HCQ, where there are around **2,000 businesses** in operation. A survey conducted in 2021 among 240 of these businesses revealed that they receive an average of 1**.7 vehicle deliveries per week or 0.24 per day** (Baseline Survey). The proportions of vehicles used to conduct the deliveries are presented in Table 14 below.

Table 14. Vehicles used for deliveries in Quito (Baseline survey)

TYPE OF VEHICLE	PROPORTION OF DELIVERIES
Small truck	30.2%
Light vehicle or motorbike	20.9%
Van	14.8%
Large Truck	11.0%
Pushcart or bicycle	6.9%
Taxi	6.7%
Other	9.4%

Based on these data, we posit an assumption that every day, roughly 1**45 small trucks, 96 light vehicles or motorbikes, 71 vans, 53 large trucks, and 32 taxis** enter the HCQ area for deliveries. Therefore, if zero-emission logistics were implemented in the HCQ, it would result in a significant **reduction of 397 internal combustion engine (ICE) vehicles** entering HCQ daily, which would be replaced by electric logistics vehicles.

6.2. SCALED UP IMPACTS

GHG emissions

The creation of zero-emissions logistics area in the historic center entails replacing all existing ICE vehicles in the area. Based on the assumption outlined above, this would mean a reduction of overall 397 internal combustion engine (ICE) vehicles, including 145 small trucks, 96 light vehicles or motorbikes, 71 vans, 53 large trucks, and 32 taxis. We base the traveled distance per vehicle on the information obtained during the pilot, that is that each vehicle travels 5 km per day, or 1,320 km per year within the HCQ area. Under the assumption that, on average, a small diesel truck consumes 0.16 liters of diesel per kilometer travelled (https://afdc.energy.gov/data/10310), the annual fuel consumption per small truck adds up to 211.2 liters. Given an emission factor of 3.17 kg CO2 / kg fuel, the annual CO2 emissions per light truck are 669.5 kg. For motorbikes and light vehicles, the assumed average annual fuel consumption is 0.05 liters per kilometer (https://afdc.energy.gov/data/10310), leading to annual CO2 emissions of 223 kg per vehicle (assuming 3.16 CO2 kg/kg fuel). For vans, the assumed annual fuel consumption is 0.16 liters per kilometer, adding up to 211.2 liters annually, leading to CO2 emissions of 669.5 kg. For large trucks, the assumed fuel consumption is 0.535 liters per kilometer, adding up to 706 liters annually, leading to CO2 emissions of 2,239 kg. For taxis, the assumed fuel consumption is 0.097 liters per kilometer, adding up to 128.3 liters annually, leading to CO2 emissions of 406.7 kg.

Therefore, altogether, replacing the entire logistics fleet entering the HCQ assumed previously with electric vehicles lead to a reduction of 296,335 kg of CO2 that is generated within the HCQ area. However, this estimate is based on several rather uncertain assumptions regarding the logistics fleet size and composition, vehicle, and fuel characteristics as well as their operational profile.

Impact on safety

The safety impacts of the scaled-up scenario were estimated by interviewing four local experts.

Table 15 presents the options each interviewee selected when asked to evaluate the scaled up project impacts on fatalities and serious injuries in the HCQ area (1 to 7 scale: significant negative effect – significant positive effect).

Table 15. Expert assessment on the impacts on road accidents with fatalities or serious injuries

INTERVIEWEE	SELECTED OPTION	JUSTIFICATION PROVIDED
Int 1	2. Negative effect on the road safety situation in the area/city (i.e., moderate increase in number of road accidents with fatalities/serious injuries)	Without additional policy measures the effect could be significant
Int 2	2. Negative effect on the road safety situation in the area/city (i.e., moderate increase in number of road accidents with fatalities/serious injuries)	Larger speed and cargo weights
Int 3	3. Slight negative effect on road safety situation in the area/city (i.e., slight increase in number of road accidents with fatalities/serious injuries).	Increase in fast and small electric vehicles, without separate infrastructure for cycling and micromobility; compounds with the lack of areas for unloading cargo, so that vehicles park in the walkways

Int 4	6. Positive effect on the road safety situation in the area/city (i.e., moderate decrease in number of road accidents with fatalities/serious injuries)	Smaller vehicles could decrease congestion and fatal accidents caused by large vehicles

Table 16 presents the options each interviewee selected when asked to evaluate the scaled up project impacts on accidents with minor injuries and material damage in the HCQ area (1 to 7 scale: significant negative effect – significant positive effect).

Table 16. Expert assessment on the impacts on road accidents with minor injuries or material damage

INTERVIEWEE	SELECTED OPTION	JUSTIFICATION PROVIDED
Int 1	1. Significant negative effect on the road safety situation in the area/city (i.e., significant increase in number of road accidents with minor injuries/material damage)	Electrification increases the speed of light vehicles and brings more vehicles to limited street space where pedestrians don't expect them
Int 2	1. Significant negative effect on the road safety situation in the area/city (i.e., significant increase in number of road accidents with minor injuries/material damage)	Lack of dedicated infrastructure for cycling
Int 3	1. Significant negative effect on the road safety situation in the area/city (i.e., significant increase in number of road accidents with minor injuries/material damage)	Great increase of e-mopeds since the pandemic, lack of regulation
Int 4	4. No change in road safety situation in the area/city	Electric cargo-bikes do not change the overall context, which is already very risky and with little consideration for road safety

Table 17 presents the options each interviewee selected when asked to evaluate the scaled up project impacts on accidents involving vulnerable road users in the HCQ area (1 to 7 scale: significant negative effect – significant positive effect).

Table 17. Expert assessment on the impacts on road accidents involving VRUs

INTERVIEWEE	SELECTED OPTION	JUSTIFICATION PROVIDED
Int 1	2. Negative effect on the road safety situation in the area/city (i.e., moderate increase in number of road accidents involving VRUs)	Electrification only means the driver or company has more economic resources, it does not imply more consideration for the less privileged
Int 2	2. Negative effect on the road safety situation in the area/city (i.e., moderate increase in number of road accidents involving VRUs)	Especially for elderly people, the main vulnerable group in the Historic Centre; on the other hand there is no regulation for electric mopeds and they are increasing, and they are more silent that combustion mopeds
Int 3	4. No change in road safety situation in the area/city	motor-normative culture, lack of respect of drivers, but also pedestrians, for road regulations
Int 4	4. No change in road safety situation in the area/city	motor-normative culture, lack of respect of drivers, but also pedestrians, for road regulations

Impact on security

The security impacts of the scaled-up scenario were estimated by interviewing four local experts. Tables 18 compiles results from all interviews.

Table 18. Expert evaluation of security risks.

Safety Standard	Aspect	Impact (consequences 0 - 4)	Probability (occurrence 0 - 4)	Score: averaged (impact x probability)
PS1 infra & op.	Infrastructure	1, 3, 0, 3 (av. 1.75)	4, 1, 3, 3 (11)	19.25
PS2 vehicles	Vehicles	2, 3, 0, 2 (av. 1.75)	4, 3, 3, 4 (14)	24.5
PS3 goods	Cargo	1, 3, 0, 2 (av. 1.5)	4, 3, 3, 4 (14)	21
PS4 people	Passengers	3, 3, 0, 0 (av. 1.5)	4, 4, 3, 1 (12)	18

Impact on charging safety

The charging safety impacts of the scaled-up scenario were estimated by interviewing four local experts. Table 19 compiles the results from all interviews.

Table 19. Expert evaluation of charging safety risks.

Category	Impact (consequences 0 - 4)	Probability (occurrence 0 - 4)	Score (impact * probability)
Electrical shock	0, 1, 0, 3 (av. 1)	0, 2, 0, 4* (av. 1.5)	1.5
Fire hazards	0, 1, 0, 2 (av. 0.75)	0, 1, 0, 4* (av. 1.25)	0.94
Power grid instability	0, 3, 0, 3 (av. 1.5)	0, 2, 0, 4* (av. 1.5)	2.25
Total:			

Notice: one interviewee brought up the issue of lack of safety in waste management in the case of the disposal of broken batteries; 4* refers to no occurrence until now, but very high risk of high occurrence if the electrification process continues without further investments (assessment of current car charging stations revealed generalized technical problems)

Impact on employment

The employment impacts of the scaled-up scenario were estimated by interviewing four local experts. Table 20 presents the options each interviewee selected when asked to evaluate the scaled up project impacts on job creation (1 to 5 scale: significant negative impact – significant positive impact).

Table 20. Expert evaluation of job creation.

INTERVIEWEE	SELECTED OPTION	JUSTIFICATION PROVIDED
Int 1	3. No impact (or cannot evaluate)	Quito is already late in the development of the necessary skills; it will be the importing foreign companies that take care of this, and there is also the risk that broken light electric vehicles are discarded to waste landfills instead of being repaired

Int 2	3. No impact (or cannot evaluate)	Considers that these impacts are very difficult to evaluate as they will be very limited.
Int 3	4. Positive impact on employment	-

The interview results regarding the expected impacts of different technical skills requirements are presented below by interviewee accompanied by the justifications provided in the interviews:

A. EV technicians

1. No further need for skilled workers
Int. 2
2. Slight further need for skilled workers
Int 1.
3. Some further need for skilled workers
4. Significant further need for skilled worker
Int. 3
5.Very significant further need for skilled workers)
Int. 4 (for the post-sale value chain)

B. EV design engineers

1. No further need for skilled workers
Int. 1, Int. 2, Int. 4
2. Slight further need for skilled workers
3. Some further need for skilled workers
4. Significant further need for skilled worker
5.Very significant further need for skilled workers)
Int. 3 (if electric delivery vehicles expand, need for specific designs for the needs of delivery in the topography and climate of Quito, there are two cycling assembly factories now)

C. IT analysts or other Industry 4.0 experts

1. No further need for skilled workers
Int. 1, Int. 2
2. Slight further need for skilled workers
3. Some further need for skilled workers
Int. 3 (very few companies use data now, difficult to find experts)
4. Significant further need for skilled worker
Int. 4 (skills shortage currently, important factor to generate employment)
5.Very significant further need for skilled workers)

7 DISCUSSION

In Quito, the most relevant transportation issues identified and tackled by the project were the unattractiveness of the public transport system due to e.g., lack of comfort, lack of reliability, high degree of redundancy, as well as narrow streets and restrictions that hinder cargo transport. To tackle these issues, the Quito demonstration consisted of two components: (1) an implementation of e-cargo bikes to serve delivery logistics, restaurant logistics and recycling and (2) piloting of a MaaS-application that integrates different personal mobility modes, allowing trip planning and payment using a single platform.

The Component 1 pilot took place between November 2022 and January 2023, during which eight e-cargo bikes of three different models were operated in Quito Historic Center. Impact assessment focused on the implementation within the Quito Historic Center. The bikes were used for food distribution from local markets to restaurants and hotels in the area, for parcels delivery, by a restaurant for daily operations, as well as in the collection of recycling materials. Overall, 16 tons of cargo were transported during the pilot, covering an overall distance of 2,547 km, 1,057 of which within the HCQ area. In April 2023, a call for expressions of interest for the permanent custody of the e-cargo bikes was launched among the participants in the pilot. The ten e-cargo bikes were handed over to the pilot participants that showed the best results in all operating schemes. Since then (April 2023 – June 2024), the SOLUTIONSplus e-cargo bikes have transported approximately 300 t, travelled 25,000 km and avoided 6 t CO2.

Based on the information obtained from the pilot, in logistics deliveries, the NPV of an e-cargo bike is 8,021 USD, IRR 97.97 % and the payback period 0.97 years. The operating schemes did not allow financial comparison with the conventional solutions as in the case of logistics deliveries, these were not owned by the company, but the logistics couriers themselves. The restaurant logistics and recycling were not revenue-generating operations, and therefore only the cost-effectiveness ratios were calculated, resulting in 1.47 USD/m3. and 7.74 USD/m3, respectively. Overall, the piloted vehicles would reduce greenhouse gas emissions and local air pollutants in logistics as well as restaurant operations, but not in recycling that was previously conducted using manual pushcarts. Moreover, the pilot had positive social impacts, and the vehicles were perceived as having high quality in terms of their suitability. For recycling operations, the implementation had a significant impact on the time needed to collect the recycled materials, while for deliveries, the operating scheme needs to be adjusted to facilitate more efficient use of e-cargo bikes as based on the information obtained during the pilot, they were not able to compete with ICE motorcycles in terms of efficiency.

The Component 2 pilot took place between November and December 2022, during which 45 students used the developed MaaS prototype application that allowed users to obtain information regarding public transport schedules, stations and stops, and purchase tickets for public transport. Several usability issues hindered realizing the full potential of the MaaS approach. However, the results obtained from the user survey implied that, given these issues are solved in the future, MaaS could be a viable approach for supporting mode shift away from private cars towards public transport, thus contributing to resolving many of the issues faced by personal mobility in the Quito area.

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