PATHWAYS TO ELECTRIC MOBILITY IN THE SAHEL

Two and three-wheelers in Bamako and Ouagadougou

THE WORLD BANK

MOLO eMobility

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LIST OF ABBREVIATIONS AND ACRONYMS

AFD	French Development Agency
ANASER	National Road Safety Agency of Mali
ANEREE	National Agency for Renewable Energy and Energy Efficiency of Burkina Faso
API	Investment Promotion Agency of Mali
AQI	Air Quality Index
ASCOMA	Association of Consumers of Mali
CCVA	Control Center on Véhicles of Burkina Faso
CEDEAO	Economic Community of West African States
CFPRZ	Reference Professional Training Center of Ziniarein Burkina Faso
DALY	Disability-Adjusted Life Years
DGD	Directorate General of Customs of Burkina Faso
DGESS	Directorate General of Studies and Sectorial Statistics of Burkina Faso
DGPE	Directorate General for Environment Preservation of Burkina Faso
DGTTM	Directorate General of Land and Maritime Transport of Burkina Faso
DNTTMF	National Directorate of Land, Maritime and River Transport - Ministry of Transport of Mali
DRCTU	Direction for Traffic and Transport Regulation of Bamako
EASI	Conceptual framework: Enable, Avoid, Shift, Improve
EB	Electric Bicycle
ECF	Energy Savings Fund
EDM-SA	Energie du Mali SA
FAFPA	Support Fund for Vocational Training and Apprenticeship of Burkina Faso
FAIJ	Support Fund for Youth Initiatives in Burkina Faso
FASI	Support Fund for the Informal Sector of Burkina Faso
GDP	Gross Domestic Product

ICE	Internal Combustion Engine
IEDES	Institute for Economic and Social Development Studies
INSD	National Institute of Statistics and Demography of Burkina Faso
INSTAT	National Institute of Statistics of Mali
LCA	Life-Cycle Analysis
LPG	Liquefied Petroleum Gas
MEEVCC	Ministry of Environment, Green Economy and Climate Change - Burkina Faso
MIE	Ministry of Infrastructure and Equipment
MTMUSR	Ministry of Transport and Urban Mobility and Road Safety
NMVOC	Non-Methane Volatile Organic Compounds
ODUO	Observatory of Urban Movements in Ouagadougou
OEM	Original Equipment Manufacturer
OICA	International Organization of Motor Vehicle Manufacturers
OMVS	Organization for the Development of the Senegal River
ONT	National Transport Office of Mali
SONABEL	National Electric Company of Burkina Faso
SONABHY	National Hydrocarbon Company of Burkina Faso
SSATP	Africa Transport Policy Programme –www.ssatp.org
TCO	Total Cost of Ownership
TOE	Tonnes of Oil Equivalent
TTW	Tank-To-Wheel
UNEP	United Nations Environment Programme
WB	World Bank
WTT	Well-To-Tank

GLOSSARY

Air quality index	An Air Quality Index (AQI) is a measure of air quality that synthesizes different data into a single value. In this study, the AQI is calculated by considering five major air pollutants: ground-level ozone, particulate matter (also known as particulate matter), carbon monoxide, sulphur dioxide and sulphur dioxide. The more polluted the air, the higher the AQI, and the greater the proportion of the population is likely to feel the negative effects of pollution. It is measured in four quality levels: 0-20 (low pollution), 21-50 (moderate pollution), 51-100 (high pollution), over 100 (very high pollution).
Electric vehicle	An electric vehicle uses one or more electric motors exclusively as its means of propulsion. It draws its energy from on-board resources such as an electric battery. For this study, the following electric vehicles are considered: electric: electric bicycle, electric scooter, electric motorcycle, electric tricycle.
Electric bicycle [e-Bike]	An electric bicycle is a bicycle equipped with pedals and an auxiliary electric motor that carries a power source, usually a rechargeable battery. Two main types of e-bike can be identified: Bicycle with pedals and an electric motor that cannot operate on its own (this is a pedal-assist cycle). Bicycle with pedals and an electric auxiliary motor that can operate on its own (usually with an accelerator).
Electric motorcycle [E-2W Moto]	A two-wheeled electric vehicle, used to transport people. In this study the equivalent non-electric motorcycle is associated with a vehicle with a power greater than 50 cm^3.
Electric scooter [E-2W Mobi]	A two-wheeled electric vehicle, used to transport people. In this study, the equivalent non-electric scooter is associated with a vehicle having a power of 50 cm^3.
Electric tricycle for passenger transport [E-3W tuk-tuk]	A three-wheeled electric vehicle, used to transport people.
Electric tricycle for freight transport [E-3W Cargo]	A three-wheeled electric vehicle, used to transport goods.
ICE vehicle	This terminology is used to indicate vehicles with an Internal Combustion Engine (ICE). For example, the report mentions "ICE two-wheel" which means two-wheelers (motorbikes or scooters) with internal combustion engines. Similarly, " ICE three-wheel " means three-wheelers (tricycles) with internal combustion engines.
ICE motorcycle [C-2W Moto]	A two-wheeled ICE vehicle, used to transport people. In this report, it is considered with a power greater than 50 cm^3.
ICE scooter [C-2W Mobi]	A two-wheeled ICE vehicle, used to transport people. In this report, it is considered with a power of 50 cm^3.
ICE tricycle for passenger transport [C-3W tuk-tuk]	A three-wheeled ICE vehicle, used to transport people.
ICE tricycle for freight transport [C-3W Cargo]	A three-wheeled ICE vehicle, used to transport goods.
Life-cycle assessment	Life-cycle Assessment (LCA) is a standardized evaluation method (ISO 14040 and 14044) that allows for a multi-criteria and multi-stage environmental assessment of a system (product, service, company, or process) over its entire life cycle. Its purpose is to know and compare the environmental impacts of a system throughout its life cycle, from the extraction of the raw materials that are necessary for its manufacture to its treatment at the end of its life (landfill, recycling, etc.), including its use, maintenance, and transport phases.
Tank-To-Wheel	The "Tank-to-Wheel" (TTW) assessment considers the energy expended and associated greenhouse gases emitted during the operation of a vehicle.
Total cost of ownership	The Total Cost of Ownership (TCO) is a financial estimate of the direct and indirect costs of a product or service. It considers all costs associated with the purchase, operation, and maintenance of vehicles over their lifetime. In this study, the TCO is used as a decision-making tool to identify the drivers and barriers to electric transition and to design appropriate interventions.
Well-To-Tank	The "Well-to-Tank" (WTT) assessment considers the energy expended and associated greenhouse gases emitted during the steps required to deliver the finished fuel to a vehicle's tank.

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EXECUTIVE SUMMARY

This study analyzes the potential for electrification of two- and three-wheelers in Sahelian cities, using Bamako and Ouagadougou as case studies. The electrification of urban mobility in the Sahel has the potential to address pressing development issues such as reducing local air pollution, decarbonizing the transport sector, reducing vulnerability to petrol imports, and creating new jobs.

The technological transition toward electric vehicles is framed within the "Improve" pillar of a broader decarbonization framework of Avoid, Shift, Improve and Resilience (ASIR). The ASIR framework aims at (i) avoiding or reducing travel or the need to travel, (ii) shifting to more energy efficient modes such as non-motorized transport and public transport, (iii) improving efficiency through vehicle technology, and (iv) enhancing resilience.

The study has a particular focus on the electrification of two- and three- wheelers due to their dominant share of total mobility in Sahelian cities. The shift from internal combustion engines to electric two- and three-wheelers has the potential to reduce local air pollution and CO_2 emissions as well as noise pollution. Globally, 25 percent of two and three-wheelers are now electric, and in 2020 most of the electric-mobility-generated GHG savings (50 Mt CO_2-eqworldwide) were achieved thanks to electric two- and three- wheelers in China [IEA, 2021]. In China, the boom in electric two-wheelers was partly due to their low price and the ban of internal combustion engine motorcycles in many cities. India and several countries in Southeast Asia have also initiated programs to promote the electrification of small vehicles. Interesting developments are also taking place in Africa, supported by both sustainable mobility policies and by private investments (e.g., trials of electric mototaxi with battery exchange programs in Rwanda).

CURRENT SITUATION IN BAMAKO AND OUAGADOUGOU

Bamako and Ouagadougou's economic and demographic growth over the last 20 years has been accompanied by an exponential increase in motorization dominated by two-wheelers, while three-wheelers are gaining in importance in recent years. The annual population growth of these capital cities is around 5 percent. Demographic growth has been accompanied by rising household income and an exponential increase in motorization, especially internal combustion engine (ICE) two-wheelers, and more recently ICE three-wheelers. The proliferation of motorized two-wheelers started in the 2000s. In the case of Ouagadougou from 2003 to 2013, the number of motorized two-wheelers multiplied by a factor of nearly nine. In Ouagadougou today, ICE two-wheelers account for 71 percent of vehicles in traffic, while ICE three-wheelers account for 1 percent of vehicles and bicycles account for 9 percent of vehicles. Some electric bicycles are beginning to be used in Ouagadougou, especially by school-age youth. In Bamako, it is estimated that two-wheelers account for 66 percent of vehicle in traffic. In comparison, three-wheelers account for only 1 percent of vehicle traffic and the use of bicycles is negligible. No electric two and three- wheelers have been identified in Bamako during this study.

In both Ouagadougou and Bamako, ICE two- and three-wheelers are responsible for a significant portion of air pollution and greenhouse gas emissions. According to this study's estimate, CO2 emissions from ICE two and three wheelers could range between 54 percent and 60 percent of total vehicle emissions in the city of Ouagadougou. In the case of Bamako, this value ranges from 52 percent to 58 percent. In addition, the CO2 emissions per capita increased at a worrisome rate of 64 percent in Burkina Faso between 2007 and 2016 while increasing by 86 percent in Bamako during the same period. It is also estimated that ICE two- and three-wheelers could be responsible for a major share (typically 60-75 percent) of harmful air pollutants emitted by motorized traffic in both cities. These pollutants include carbon monoxide (CO), nitrogen oxide (NOx), non-methane volatile organic compounds (NMVOC), and particulate matter (PM2.5). At the national level, WHO estimated that ambient (outdoor) air pollution was responsible in 2016 for the loss of 357,039 years of 'healthy' life in Burkina Faso and another 396,308 years of 'healthy' life in Mali.[1]

In Ouagadougou, two-wheelers are used mostly for private vehicle use. In Bamako, they are used for private travel as well as commercial passenger travel as mototaxis and freight transport (Figure I). Three-wheelers are used predominantly for freight transport in both cities. The motorcycles and scooters used in Bamako and Ouagadougou have four-stroke petrol engines with power ranging from 110 cc to 250 cc. Tricycles have four-stroke diesel engines with 150 cc power. Practically all two- and three-wheelers are imported and assembled locally with spare parts imported from China. Currently, vehicles can be purchased without having to order them; they are assembled practically at the time of purchase. According to dealers, buying an electric two- or three-wheeler would not be difficult because electric two- and three-wheelers can be ordered using the same supply channels as the ICE ones. Currently, the only two- and three- wheelers immediately available on the market are pedal-assist bicycles found exclusively in Ouagadougou where the supply chain is similar to the other two- and three-wheelers.

Mali and Burkina Faso present distinctive energy mixes. In 2016, Burkina Faso recorded an electricity production of about 1,620 GWh. The country's energy mix is heavily oriented towards thermal sources (oil, natural gas, coal) while only 16 percent of the national production comes from renewable sources (mainly hydroelectric and solar). In 2017, Mali's electricity production was 1,923 GWh. Mali's energy mix is generally oriented towards the use of renewable sources; about 47 percent of electricity is generated from hydroelectric sources.

Figure I.

Types of two- and three-wheelers used in Bamako and Ouagadougou

1 DALYs - Disability-Adjusted Life Years, calculated by WHO as the years of life lost due to premature mortality plus the years of healthy life lost due to disability

LOCAL MARKET FOR ELECTRIC TWO- AND THREE-WHEELERS IN OUAGADOUGOU AND BAMAKO

For the time being, potential users, policymakers, and transport service providers (operators) lack significant experience and knowledge of electric mobility (e-mobility) in both Bamako and Ouagadougou.

Analyses of the current mobility situation in Bamako and Ouagadougou as well as estimates of the impacts of the electric transition of two- and three-wheelers show significant potential for e- mobility development in those cities. This assessment considered key enablers for consumers to start considering electric vehicles in their purchasing decisions and creating niche markets. Other enablers under consideration involved government options to pursue e-mobility as a policy priority. Another consideration in this assessment is a more mature market phase that allows the market to scale up. The fact that Bamako and Ouagadougou are relatively flat cities favors the penetration of electric vehicles as a dominant means of transportation. Other key enablers for the development of e-mobility include:

- Technical performance
- Financial performance
- Environmental performance
- Initial investment
- Availability of financing
- Availability of charging network for vehicles
- Electricity supply
- Policy support.

1. TECHNICAL PERFORMANCE OF VEHICLES - IS THE PERFORMANCE OF ELECTRIC VEHICLES COMPARABLE TO EXISTING ICE VEHICLES?

The issue of technical performance concerns the possibility of using electric vehicles to carry out routine trips and activities with the same degree of technical reliability, efficiency, and overall comfort as ICE vehicles. The electric two-wheelers that dealers in Bamako and Ouagadougou might offer have similar technical characteristics to ICE vehicles, thus representing an appropriate alternative in purchasing decisions because of the relatively simple and mature technology achieved by this type of vehicle.

For three-wheelers, it is more difficult to find models that are fully comparable to ICE vehicles. A key factor will be the willingness of consumers to accept the trade-off between vehicle load capacity and maximum vehicle speed. This may be relevant in both cities given that this type of vehicle is used mainly for freight transport.

2. FINANCIAL PERFORMANCE - DO ELECTRIC TWO AND THREE-WHEELERS OFFER, IN THE LONG RUN, BETTER VALUE THAN ICE?

The Total Cost of Ownership (TCO) analysis helps to inform a purchase decision by determining the differences between the purchase price and the long-term cost (TCO) that includes purchase, operation, and maintenance of vehicles over their lifetime.

Electric two- and three-wheelers generally offer either similar or better value in the long run compared to ICE two- and three-wheelers in Bamako and Ouagadougou (Figure II and Figure IV). In Bamako, the TCO of the electric motorcycle and the electric tricycle for passenger transport (tuk-tuk) are almost the same as those of the corresponding ICE models (considering five years of use and an average of 25 km per day). On the other hand, the TCO of electric scooters and tricycles for freight transport is lower than those of the corresponding TCO for ICE scooters and tricycles. In Ouagadougou, all electric vehicles show lower TCO than ICE vehicles. It is estimated that in the two cities, the TCO of electric freight three-wheelers is 34-47 percent lower than that of the ICE models, while the TCO for electric scooters is estimated to be 6-10 percent lower than that of the corresponding ICE models. The electric motorcycle TCO is 1 percent higher than ICE models in Bamako while it is 6 percent lower in Ouagadougou. Similarly, the electric tuk-tuk shows a TCO that is 1 percent higher in Bamako and 4 percent lower in Ouagadougou than its corresponding ICE vehicle.

Figure II.

TCO in Bamako (left) and in Ouagadougou (right).

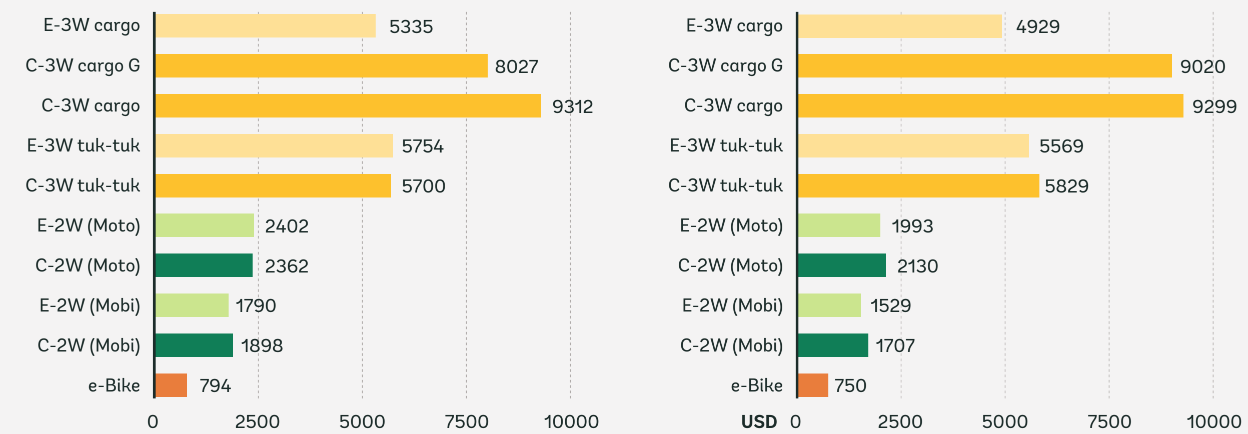


Figure III.

TCO by category in Bamako (left) and Ouagadougou (right).

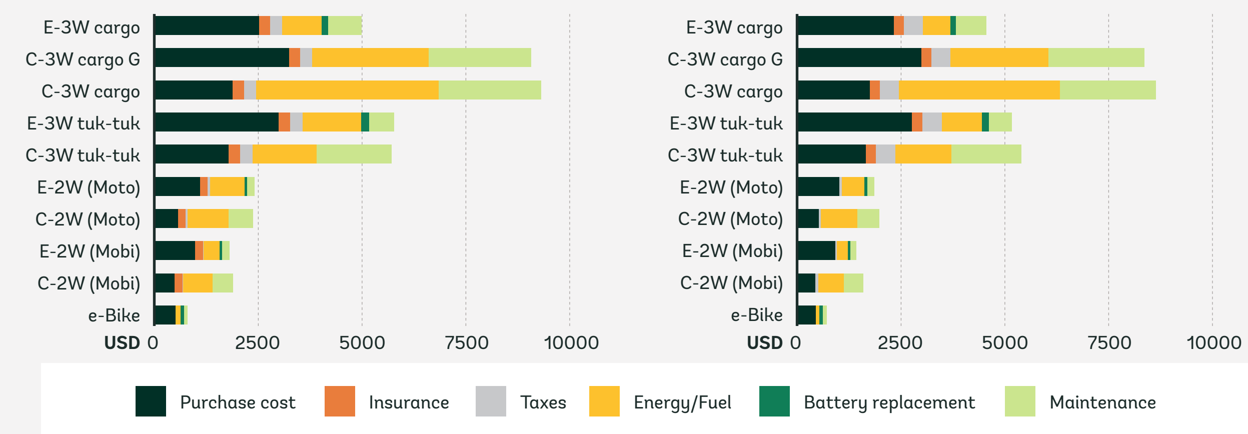
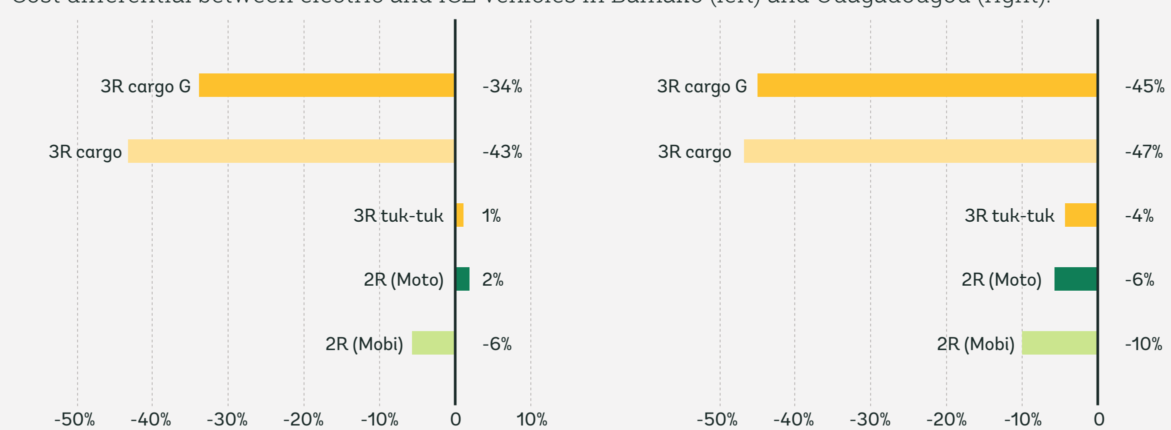


Figure IV.

Cost differential between electric and ICE vehicles in Bamako (left) and Ouagadougou (right).



Source: Authors

Finally, electric bicycles are a very competitive alternative to scooters and motorcycles in terms of TCO.

The purchase cost[2] remains significantly higher for electric vehicles, while the cost of fuel and maintenance is significantly higher for ICE vehicles. This indicates that the expected reduction of purchase cost of electric vehicles in the coming years will make electric two- and three-wheelers even more cost-competitive. The breakdown of TCO (Figure III) data shows that the most important cost category for electric vehicles is purchase cost, while for ICE vehicles the most important cost category is fuel consumption.

As the TCO analysis has shown in Bamako and Ouagadougou, electric vehicles are competitive with ICE models although competitiveness varies by vehicle type and depends on the total distance travelled by the vehicle.

- The most cost-effective type of electric vehicle (in terms of TCO per km) relative to its ICE counterpart is the three-wheeler for freight transport. Nevertheless, the profitability of such a change for vehicles with an annual mileage equal to or greater than 20,000 km per year is conditioned by the availability of an appropriate battery charging or exchange system.
- Electric scooters are the second most cost-effective category for all categories of mileage, sharing many of the same characteristics of electric three-wheelers used for freight (availability of a charging or battery exchange system) with respect to mileages above 21,000 km/year.
- Three-wheeled electric vehicles for passenger transport are the third most cost-effective mode for all mileage in Ouagadougou and for mileage of 10,000 km/year or more in Bamako; nevertheless, this mode is used only marginally as an alternative in both cities.
- Electric motorcycles are profitable in Ouagadougou for mileage above 5,000 km per year, whereas a more "oscillating" pattern can be found in Bamako where electric motorcycles are slightly profitable for mileage ranges of 15,000-20,000 km and 33,000-55,000 km per year. This difference in profitable ranges between Ouagadougou and Bamako is explained by the relatively higher cost of electricity in Bamako compared to gasoline[3] which undermines the potential gains to be made from using electric vehicles more efficiently than ICE vehicles.
- As the cheapest mode of electric transportation, electric bicycles could compete directly with ICE scooters rather than being merely an alternative to non-electric bicycles, especially in the lower mileage ranges.
- A sensitivity analysis shows the use of electric vehicles is penalized in both cities due to a reduction in the life span caused by the higher purchase cost over the period of use and the corresponding decrease in economic benefits in terms of energy consumption. An increase in maintenance cost for electric vehicles does not significantly change the TCO. An increase in energy consumption of electric vehicles does not have a significant impact on the TCO of e-scooters and freight e-three-wheelers. For more details on the sensitivity analysis, see Annex 3.
- A sensitivity analysis of distance travelled shows that the electric transition could be profitable for all vehicles used for private and professional purposes with a few exceptions concerning motorcycles and three-wheelers for passenger transport for specific annual mileages (see Figure V and VI and Annex 3). With increasing annual mileage, the TCO decreases and electric scooters and three-wheelers for freight transport become progressively more attractive than ICE vehicles. For other types of vehicles, there are differences between the two cities that should be noted. This can be observed in Figure V for Bamako and Figure VI for Ouagadougou, where data shows that the TCO of the electric vehicle is lower than that of the ICE vehicle.[4] In Bamako, electric motorcycles achieve cost parity with

2 In addition to the purchase cost, this study considers a residual resale value at the end of the technical life of the vehicle (considered as equal to the period of ownership). This assumed residual resale value is10 percent of the purchase cost for

3 ICE vehicles (due to the existence of a secondary market for spare parts) and 0 percent for electric vehicles.

4 In Bamako, the average cost of electricity is US$0.237/kWh (CFAF 130/kWh) while the average cost of gasoline is US$0.143/kWh (CFAF 77/kWh). In Ouagadougou, the average cost of electricity is US$0.185/kWh (CFAF 100/kWh) while the average cost of gasoline is US$0.134/kWh (CFAF 73/kWh).

The circles on the graph show the mileages requiring the purchase of an additional battery to cover the daily distance without recharging.

Figure V.

TCO differential between ICE and electric vehicles in Bamako

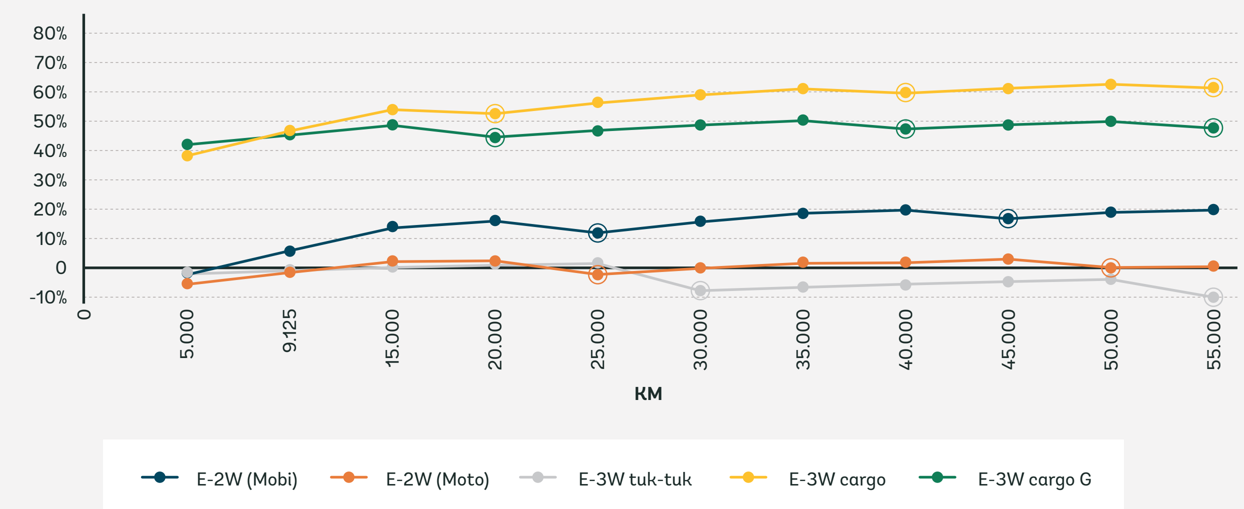
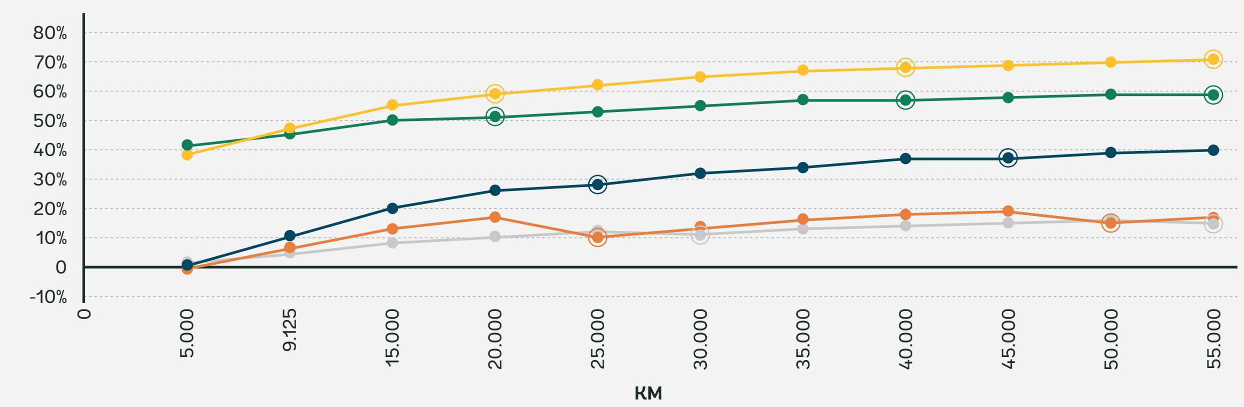


Figure VI.

TCO differential between ICE and electric vehicles in Ouagadougou



ICE motorcycles at around 11,000 km driven per year, although the differential becomes negative in the range of 25,000-30,000 km because of the need for an additional battery. In Bamako, electric three-wheelers for passenger transport are more economical than ICE vehicles for distances between 14,000 and 25,000 km, while for longer distances they are negatively affected by the cost of additional batteries. In Ouagadougou, electric motorcycles achieve cost parity with ICE motorcycles at around 6,000 km, and electric motorcycles maintain a positive differential between 6 percent and 19 percent in comparison to ICE vehicles. For other vehicles in Ouagadougou, ICE vehicle types have a higher TCO for all mileages.

3. ENVIRONMENTAL PERFORMANCE - DO ELECTRIC TWO AND THREE-WHEELERS OFFER, IN THE LONG RUN, BETTER ENVIRONMENTAL OUTCOMES THAN ICE?

The Life Cycle Assessment (LCA) is used to respond to the question of better environmental outcomes. LCA evaluates the environmental impact from a product during the whole life cycle. It has been used to assess both the pollutant emissions and the energy consumption of two- and three-wheelers for the following phases of the vehicle life cycle: production, transport, use, maintenance, and end-of-life.

Impact on environment

Electric two- and three-wheelers offer an opportunity to reduce CO2 emissions during the life cycle of vehicles (Figure VII). Electric vehicles always have less of an impact on global warming (measured as the amount of CO_2 equivalent emitted per km travelled) when compared to the same type of vehicle (e.g., ICE motorcycle versus electric motorcycle).

In the **production** phase (Figure VIII), electric two- and three-wheelers generally have a higher impact on emissions than their ICE counterparts. For example, the production of electric scooters has a 20 percent greater impact than the production of an ICE scooter, but also has 14 percent less impact than the production of an ICE motorcycle.

The impact of the transport phase of electric two- and three-wheelers is slightly higher than that of ICE two- and three-wheelers. The differences are due to the higher weight of electric vehicles compared to their ICE counterparts.

In the **use** phase of the vehicle, the environmental impact of ICE two- and three-wheelers is much higher than that of their electric counterparts, both in terms of emissions of CO2 equivalent and air pollutants.

- In Bamako, electric scooters have 83 percent lower CO_2 emissions than ICE scooters during the use phase. Electric motorcycles and tricycles reduce CO_2 equivalent emissions by 67 percent compared to their ICE counterparts. In addition, electric tricycles have 42 percent lower CO2 emissions than ICE scooters.
- In Ouagadougou, the environmental benefits of electric vehicle use are important but less extensive than in Bamako. Even under these conditions, electric scooters have 78 percent lower CO2 emissions compared to ICE scooters. Electric motorcycles and tricycles reduce CO2 equivalent emissions by 57 percent compared to their ICE counterparts. In Ouagadougou as well, the use of electric tricycles has less of a negative environmental impact than an ICE scooter with 24 percent lower CO2 emissions.

Differences between ICE and electric vehicles during the use phase (i.e., on a Tank-to-Wheel basis) are linked to their respective energy efficiency.

Moreover, electric two- and three-wheelers produce zero tailpipe emissions in the use phase of the vehicle. This is a significant advantage given the acute problem of air pollution in Bamako and Ouagadougou.

There is a significant difference between ICE vehicles and their electric counterparts in terms of energy requirements of each city. A major disadvantage in meeting these energy requirements is the lower efficiency of ICE vehicles which is partially offset by the lower average weight of ICE vehicles compared to electric vehicles with their heavy batteries.

The negative environmental impact caused by the **end-of-life** phase is greater for electric two- and three-wheelers than those with internal

Figure VII.

Comparison of total CO_2 equivalent emissions

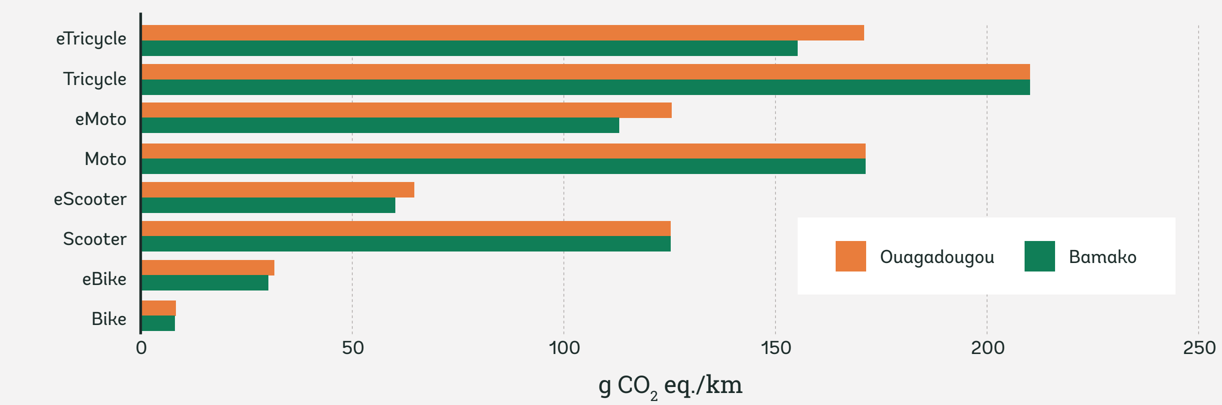


Figure VIII.

Equivalent CO_2 Emissions by Life Cycle Phase in Bamako (left) and Ouagadougou (right)

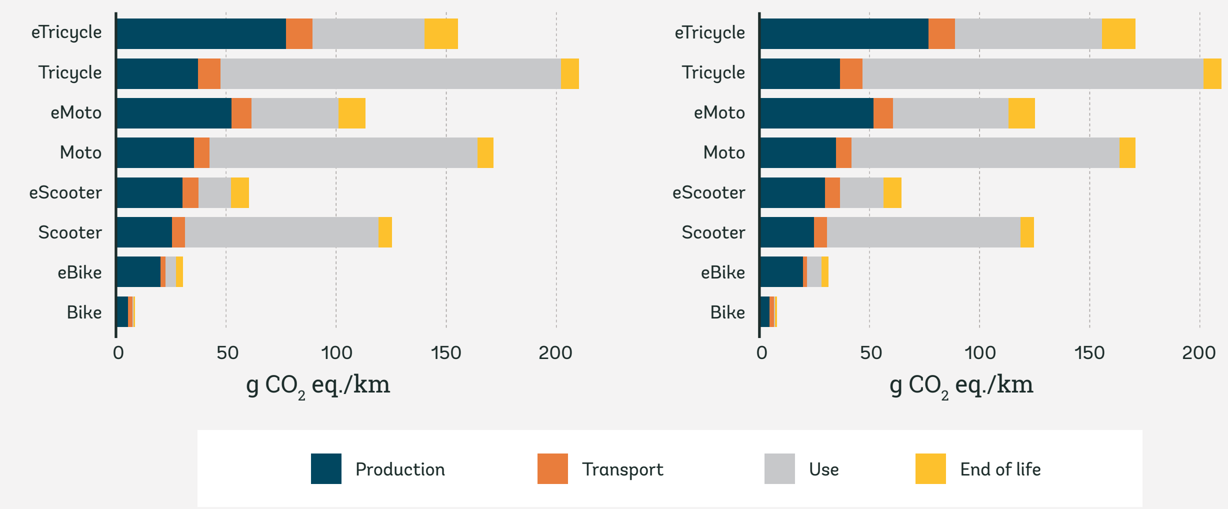
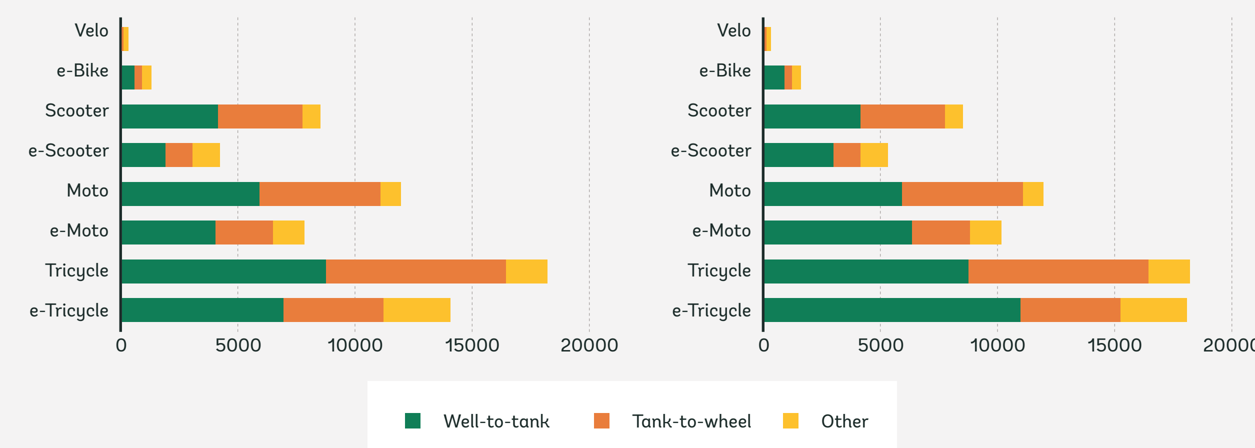


Figure IX.

Energy consumption of the "fuel" and "vehicle" cycles in Bamako (left) and in Ouagadougou (right)



Source: Authors

combustion engines. This is mainly because the batteries of the electric vehicles have a number of different metals that require a more complicated recycling process. The environmental impact increases with the size of the battery (and therefore the size of the vehicle).

As Mali and Burkina Faso are transitioning towards a greener energy mix, a different energy mix for production of electricity can have an impact on the amount of CO_2 emissions from electric vehicles. This is especially relevant for Ouagadougou where the electricity currently produced from renewable sources is only 17 percent of the total production of electricity. Increasing the share of renewable sources in total energy production would reduce CO_2 emissions in two- and three-wheelers by a significant amount. In Ouagadougou, increasing the use of renewable sources to 45 percent of total electricity production (up from the current 17 percent) would reduce equivalent CO_2 emissions for electric two- and three-wheelers by 7 percent for electric bicycles and 14 percent for electric motorcycles and electric tricycles. Increasing renewable energy to 75 percent of energy production would reduce equivalent CO_2 for electric two- and three-wheelers from 15 percent for electric bicycles and 29 percent for electric motorcycles.

In contrast, renewable sources are currently responsible for 47 percent of total electricity production in Bamako. As with Ouagadougou, increasing the share of renewable sources in total energy production would reduce CO_2 emissions in two- and three-wheelers by a significant amount. If Bamako were to increase the use of renewable sources to 65 percent of the total energy production (up from the current 47 percent), this would reduce the equivalent CO_2 emissions by 5 percent for electric bicycles and 10 percent for electric motorcycles. Increasing the amount of renewable electricity to 85 percent of total electricity production would reduce equivalent CO_2 emissions 12 percent for electric bicycles and 25 percent for electric motorcycles.

Impacts on energy consumption

Electric two- and three-wheelers generally have a lower energy consumption[5] than ICE two- and three-wheelers (Figure IX). An electric scooter consumes 40 percent less energy than an ICE scooter, while an electric motorcycle consumes 19- 23 percent less energy and an electric tricycle consumes 5-10 percent less energy than the ICE homologue. The highest gain obtained by switching from an ICE to electric vehicle comes from the reduction in "Tank-to-Wheel" energy consumption.

Total energy consumption, for all vehicles, is lower in Bamako than in Ouagadougou. In Bamako, the better energy mix for electricity production plays an important role in lowering the energy consumption during the "Well-to-Tank" phase.

In the case of ICE two- and three-wheelers, the "fuel cycle" accounts for more than 90 percent of total energy consumption, while this value is around 80 percent for electric vehicles. As a consequence, the "vehicle cycle" has a relatively low impact on energy consumption for both types of technologies.

While ¨Tank-to-Wheel¨ energy consumption is always lower for electric vehicles, the energy consumption of electric two- and three-wheelers is not always lower than that of ICE vehicles during the "Well-to-Tank" phase. In Ouagadougou, electric motorcycle and electric tricycles consume more energy during the "Well-to-Tank" stage than their ICE counterparts due to the city's low use of renewable sources to produce electricity.

4. INITIAL INVESTMENT - IS THE HIGHER PURCHASE COST OF ELECTRIC VEHICLES A BARRIER?

Electric vehicles generally have higher purchase costs than ICE models. These high purchase costs were reportedly the most adverse factor in user decisions, and they are not offset by lower operating costs. Currently, this problem is not mitigated by any public incentives or by financial programs to avoid upfront costs. Incentives are needed to make the cost of purchasing an electric vehicle affordable.

5 The energy consumption is calculated for both the "fuel cycle" and the "vehicle cycle". Fuel cycle includes: (i) Well-to-Tank (WTT), i.e., extraction, production, and transport of raw materials as well as refining, production and distribution of gasoline and electricity, and (ii) Tank-to-Wheel (TTW), i.e., the gasoline or electricity used by vehicles in the use phase. Vehicle cycle includes (i) Production (raw materials, vehicle, assembly), (ii) Transport of the vehicle from the production site to the place of use, (iii) Use (maintenance of the vehicle throughout its life), and (iv) End-of-life (disposal of the vehicle and battery).

5. AVAILABILITY OF FINANCING - IS THERE AVAILABLE OR POSSIBILITY OF NEW FINANCING OPTIONS?

A well-developed financial ecosystem is essential to address the problem of upfront costs of electric vehicles, which are generally less affordable than ICE models. Strengthening the financial ecosystem would also include the emergence of new business models, such as vehicle subscription / rental models, battery subscription / rental models, etc. Vehicle leasing could be particularly promising in Bamako and Ouagadougou, as it would also address the problems associated with the lack of experience with electric vehicles, particularly in terms of avoiding the "fear" of owning an electric vehicle due to negative perceptions related to limited range and technical failures. Green financing options could be also explored.

6. AVAILABILITY OF CHARGING NETWORK AND VEHICLES - IS THERE AVAILABLE CHARGING NETWORK? ARE THERE AVAILABLE VEHICLES FOR PURCHASE?

The availability of an adequate charging network (charging stations or battery exchange services) is seen as a fundamental condition for market adoption of electric vehicles bigger than two-wheelers. However, there is still no consensus on whether a dedicated charging network is necessary for two-wheelers. Currently, there is no such network in Bamako and Ouagadougou. It does not appear to be a short-term constraint since most two-wheelers could be easily recharged in a few hours via a standard plug at home or at the office. But the lack of a charging network could limit the large-scale penetration of electric three-wheelers and even two-wheelers in the medium/long term, when mobility patterns may create a new need for charging that is different from simply plugging at home or the office. Stakeholders are quite divided as to what type of infrastructure would be more appropriate in the two cities. While public institutions would seem to be more oriented to the development of public charging infrastructure, users and service providers are more likely to consider battery changing services. It is worth noting that from a technical, regulatory, and economic point of view, a battery exchange service is more feasible in Bamako and Ouagadougou than the installation of charging stations. The use of solar panel installations for battery recharging could also be worthy of consideration.

Ease of purchase of electric two- and three-wheelers is not perceived as a problem, as all the dealers consulted confirmed that it was easy to order electric vehicles through the usual supply chain which also includes the availability of spare parts. In addition, the sale of electric bicycles appears to be an emerging trend among school-age youth in Ouagadougou.

7. ELECTRICITY SUPPLY - IS THE EXISTING ELECTRICITY PRODUCTION IN BAMAKO AND OUAGADOUGOU ENOUGH FOR A TRANSITION TOWARDS ELECTRIFICATION OF TWO- AND THREE-WHEELERS?

To respond to the question of adequate electricity production, we have analyzed scenarios where a number of electric two- and three-wheelers of different types (e.g., bicycles, motorcycles, tricycles) are introduced into the current mobility system of both cities. The energy assessment also considered three conditions of driving style: normal, relaxed, and stressed. Two penetration scenarios are analyzed here:

- *Slow penetration of electric two and three-wheelers.* Electric two- and three-wheelers would replace 5 percent of current two- and three-wheelers.
- *Fast penetration of electric two- and three-wheelers.* Electric two- and three-wheelers would replace 70 percent of current two- and three-wheelers.

The impact on the grid depends on several factors such as characteristics of existing and future energy production, market penetration of electric vehicles, driving styles, traffic conditions, and vehicle parameters. Under the existing energy conditions, **changing 5 percent of current two- and three-wheelers to electric models in both capital cities would lead to a consumption of 1.3 percent of Mali's total energy production and**

6.9 percent of Burkina Faso's total electricity production. Changing 70 percent of current two- and three-wheelers to electric models in both capital cities would lead to a consumption of 19.5 percent of Mali's total electricity production and 82 percent of Burkina Faso's total electricity production.

Overall, these results indicate that the transition to electricity should occur in a phased manner. Towards the medium term, the electrification of transport should be accompanied by a large increase in electricity production at the national level. Furthermore, a significant increase in electricity demand due to the fast electrification of the vehicle fleet is likely to increase electricity prices.

An important issue concerning the stability of electricity provision through the grid is the fact that peak loads can cause power outages and blackouts, a frequent problem in Bamako and Ouagadougou. Introducing a certain number of electric vehicles to the system should therefore be managed attentively to avoid further deficits in electricity load caused by recharging of these vehicles. This means that recharging of electric vehicles should not be concentrated during particular periods of the day.

8. POLICY SUPPORT - IS THERE POLICY SUPPORT AND COULD MOMENTUM BE GENERATED?

A cross-cutting catalyst for improved e-mobility would be policy support. To be successful, public policies could set clear scopes of work and target dates of completion, define comprehensive and sustainable intervention programs, and ensure their implementation. Electricity-oriented policies, including well-defined regulations, will need to be developed from scratch in Bamako and Ouagadougou. According to stakeholders, transport pollution in both cities is a significant problem and represents an opportunity to communicate the benefits of an "electric transition." The general impression is that the message would be well received by users but should be addressed carefully, especially in relation to vehicle costs. The consultants made it clear that environmental benefits and lower operating costs could take a back seat to the higher purchase costs.

Other impacts: road safety

There is currently no scientific evidence regarding the impact of electric two- and three-wheelers on road safety. A study performed by Malaysian researchers in 2013 [99] focused on the potential impact of low sound frequencies produced by electric vehicles but did not refer to field data. No research was found on the impact of lower speeds of electric two- and three-wheelers compared to their ICE counterparts.

Generally, there are two main aspects of electric two- and three-wheelers that could influence the rate of road traffic crashes:

- While electric two- and three-wheelers can help decrease noise pollution in cities, the absence (or limitation) of sound could be a safety concern especially for pedestrians in mixed environments.
- Electric two- and three-wheelers have lower maximum speed compared to their ICE counterparts. According to stakeholders, motorcycle speeding is one of the biggest road safety challenges. The fact that the maximum speed of electric two-wheelers is limited could help lower the risk of injury on the road.

POTENTIAL FOR ADOPTION OF ELECTRIC VEHICLES AND EARLY USE CASES BASED ON THE LOCAL MARKET

Analysis of the local market allows officials to identify early potential uses of different types of electric two and three-wheelers vehicles. Table I summarizes the strengths and weaknesses of each vehicle in terms of its potential for adoption and identifies potential cases for early use. As indicated by several stakeholders, **particular attention should be paid to young people as a target group**, as they are more likely than other social groups to be open to innovative experiences.

Table I.

Strengths and weaknesses for potential adoption of each type of electric vehicle

Vehicle type	Strengths	Weaknesses	Potential use
Electric bicycle	• Lowest TCO in both cities • More affordable purchase price than scooter • Less demanding charging operations • Models already in circulation in Ouagadougou	• Higher purchase cost than non-electric bicycles • Lack of financial incentives to reduce initial cost in both cities • Problems with road conditions	Private use for short distances (10 km per day - limited charging needs) in both cities by students/workers
Electric scooter	• Technical performance comparable to that of ICE vehicles • Availability per order • Competitive TCO in both cities	• Higher purchase cost than ICE models • Lack of financial incentives to reduce initial cost in both cities	Private use for short to medium distances (20-25 km per day - limited charging needs) in both cities by students/workers
Electric motorcycle	• Technical performance comparable to that of ICE vehicles • Availability per order • Competitive TCO in both cities	• Higher purchase cost compared to ICE model • TCO differential in Bamako very sensitive to mileage • Lack of financial incentives to reduce initial cost in both cities • Lack of charging infrastructure in place in both cities	Mototaxi services in Bamako, managed by companies able to meet the initial costs, benefit from a lower TCO and can set up an appropriate recharging system (e.g., battery exchange).
Electric three-wheelers for passenger transport	• Technical performance comparable to that of ICE vehicles • Availability per order • Competitive TCO in both cities	• Higher purchase cost than the ICE model • Lack of financial incentives to reduce initial cost in both cities • Lack of charging infrastructure in place in both cities	Marginal mode of transport in both cities No market segment identified
Electric three-wheelers for goods transport	• Higher availability per order • Competitive TCO in both cities	• Limited technical comparability with ICE vehicles • Higher purchase cost than ICE vehicles • Lack of financial incentives to reduce initial cost in both cities • Lack of charging infrastructure in place in both cities • Possible overloads limiting technical performance	Private use for short and medium distance freight transport (limited charging needs) in both cities

INVESTMENT CONCEPTS FOR UPTAKE OF E-MOBILITY

Based on the early use cases presented in the previous section, this section selects and develops four investment concepts that could be implemented in the short term (e.g., within a period of one to three years) to start an uptake of e-mobility in Ouagadougou and Bamako. The following investment concepts are proposed as shown in Figure X.

1. ELECTRIC MOTOTAXIS IN BAMAKO

The objective of this investment concept is to introduce, in the short term, several electric motorcycles to be used for mototaxi services. This concept should be realized in close collaboration with one or more official mototaxi companies already operational in Bamako.

Under this concept, battery charging should be performed through a battery swapping system for use with specific motorcycle models. The system would include “swapping points” for this purpose to be established according to the city’s zoning rules and the riders’ usual routes. The “ swapping points” could be established in garages, service stations, or similar venues.

This investment concept should be carried out according to the same franchise formula currently in place for ICE mototaxis in Bamako. To ensure that the periodic amount paid by the riders to the mototaxi company does not increase, it will be important to select electric motorcycles that are relatively low-cost compared to petrol-powered ones.

The investment concept could be initiated as a pilot project with a limited number of electric motorcycles. For example, if 20 electric motorcycles (i.e., 20 riders) are involved in a transaction, at least 50-60 batteries should be available for use in the exchanges.

Figure X.

Investment concepts

2. ELECTRIC BICYCLES FOR STUDENTS AND EMPLOYEES IN OUAGADOUGOU

A pilot project deploying 50 electric bicycles is currently underway in Ouagadougou targeting each of the following groups:

- Students in higher education (secondary and/or university level)
- Public sector employees
- Administrative staff of the Joseph Ki-Zerbo University (Ouaga1) for travel within the campus (currently done mostly by motorcycle).

Students should be the main target group, as they are most likely to use bicycles already and are probably unable to switch to ICE two-wheelers because they lack an operating license or enough income to afford these vehicles. Deploying available electric bicycles among this target group would increase the propensity of students to use this type of environmentally friendly vehicle, while reducing their desire to switch to ICE vehicles in the near future. In addition, schools should allow charging of bicycle batteries during school hours, especially since schools are expected to have a more reliable electricity supply than private homes.

Employees in the public sector (e.g., municipalities or national ministries) could be another suitable target group, as they should be able to charge their batteries relatively easily at their workplace; public buildings are supposed to have a more reliable electricity supply than private homes.

Administrative staff who travel around the Joseph Ki-Zerbo University campus could also be a target group, as they travel with private vehicles (ICE two-wheelers or cars) and the distances are relatively short.

Participants in the pilot project could be chosen on a voluntary basis and receive the vehicle free of charge from the sponsoring institutions, or they could be selected through an auction.

The pilot project could be a little different on the university campus. Here the electric bicycles could be made available to staff without the need for a reservation in a so-called "free floating" way. However, this method implies that a bicycle management service would have to be organized by the university for recharging the bicycles and for repositioning them daily in different areas of the campus.

The type of electric bicycle used for this pilot could be the same model as the one already circulating in Ouagadougou, due to its familiarity and acceptance among existing users as well as its low price. It may also be preferable to use another model of electric bicycle for this pilot with different technical characteristics that would allow for greater comfort of use given the poor state of the roads in the city.

Universities and schools should be able to deploy the service without incurring any costs; they should receive the electric bicycles from the central government or the municipality, and have the operational costs covered by these entities.

3. ELECTRIC SCOOTERS FOR MAIL OR NEWSPAPER DELIVERY SERVICES IN BAMAKO AND OUAGADOUGOU

The objectives of this investment concept are to introduce, in the short term, a few electric scooters to be used for mail or newspaper delivery services and to test the use of these "light" electric vehicles on targeted and fixed routes. This concept will have to be realized in close cooperation with the company (public or private) in charge of the delivery services.

The same concept could be implemented in both Bamako and Ouagadougou, targeting the following groups:

Bamako:

- Postal staff of the Mali Post Office.
- Distribution agents of the national daily newspaper (L'Essor).

Ouagadougou:

- Postal staff of the Burkina Faso Post Office.
- Liaison officers from the municipality or other public institution, if applicable.

The pilot projects in Bamako and Ouagadougou can be implemented independently of each other.

The investment concept foresees the deployment in each city of 20 electric scooters that should be used for daily mail or newspaper delivery activities. Each electric scooter should be provided to a single postman for a fixed period (e.g., 6 months), in order to collect sufficient information on driving habits and possible problems with the electric vehicle. The electric scooters should only be used for delivery services and not for the commute of post office staff.

By recharging at a reliable source of electricity, such as the headquarters of the companies involved, this method makes it possible to recharge the batteries of the scooters during non-working hours.

The purchase of the electric scooters could be performed by the company itself, the central government, or the municipality. Operational costs (charging, maintenance, etc.) should be covered by the company receiving and using the vehicles.

4. ELECTRIC SCOOTERS FOR EMPLOYEES IN BAMAKO AND OUAGADOUGOU

Deploying electric scooters among public sector employees for their daily "home-to-work" trips could help replace the use of ICE vehicles for this purpose without any difficulties.

Given local conditions with limited accessibility to electricity at home as well as an unstable electricity supply due to weaknesses in the grid, a first deployment of electric scooters could impose challenges for people commuting from home to their office.

Offices could be the main place to recharge electric scooters, as they generally have better access to the electricity grid than private homes. In addition, charging during working hours would avoid time wasted on waiting for the charging to finish. Finally, it is very likely that the travel needs of many employees are well-suited to the mileage provided by the electric scooter battery.

The investment concept could be implemented by deploying 20 electric scooters among public sector employees who could be selected on a voluntary basis or through an auction. Participants would be considered for their usual travel patterns and a rotation mechanism could be applied for all those involved.

The purchase and operational costs of electric scooters should be covered by the government or municipality, as the main objective of the pilot project is to allow users to experiment with electric vehicles and pave the way for electric vehicles as an alternative to traditional means of transport.

STRATEGIC RECOMMENDATIONS FOR THE DEVELOPMENT OF E-MOBILITY

Based on the analyses carried out during the study, consultations with stakeholders, and international experience in e-mobility, the following strategic recommendations were developed to achieve the goal of a sustainable transition to e-mobility in Bamako and Ouagadougou (see table II):

Priority	Recommendations
Skills and knowledge	
High	The governments of Burkina Faso and Mali should improve specific **knowledge** of electric mobility, particularly on electric two- and three-wheelers, and related **skills** at the level of the **ministries**. They should focus on the potential for electric transition and design **public policies** to support the transition. The same applies to local governments.
High	National and local policies should be put in place to **raise awareness of the environmental and health costs of conventional mobility.** **Raising awareness of environmental and health issues** should be a prerequisite for the dissemination and promotion of e-mobility on two- and three-wheelers. Indeed, the analyses conducted in Ouagadougou and Bamako have shown that the transition to e-mobility also requires a cultural change that should be supported by public authorities.

High	Public authorities in Burkina Faso and Mali should be active in **communicating and disseminating information on the technical characteristics of electric two- and three-wheelers** to fill the current knowledge gap, which prevents citizens from perceiving electric vehicles as an alternative to the ICE vehicles currently in use. This activity should also include **training sessions** for users and service providers (e.g., garages, mototaxi companies) on how to correctly manage technical problems.
High	The national and local governments of both countries should implement **pilot projects** to allow users to gain first-hand experience with electric vehicles, thus going beyond the phase of mere "perception" of their characteristics. The pilot projects should focus on the investment concepts described in the study for the cities of Ouagadougou and Bamako.
High	End-of-life management, especially of batteries, should be built into the structure of the different scenarios as a critical way of minimizing negative environmental impacts in the medium/long term.
Medium	The establishment of a local (public) system of **periodic assessment of transport pollution** is an important activity to support the development of effective mobility policies.
Economic and financial aspects	
Medium	The governments of Burkina Faso and Mali should consider the introduction of **public subsidies** to reduce the purchase cost differential of electric two- and three-wheelers compared to their ICE counterparts. Cost of ownership analyses and consultations with stakeholders in Ouagadougou and Bamako have shown that this is a relevant issue in both cities. A higher purchase cost of electric two- and three-wheelers compared to the ICE equivalents currently in use could limit the attractiveness of electric vehicles and slow down the transition. The reduction of **import taxes** and the easing of **custom procedures** could contribute to the attractiveness of electric vehicles as well. Similarly, **policies that support the development of a financial ecosystem** that allows for the payment of vehicles in installments should be encouraged. Currently, vehicles are paid in cash at the time of purchase in both Ouagadougou and Bamako. The possibility of making installment payments would attract more buyers by allowing them to split up their charges.
Public policies	
High	**Public policies** of the sectors involved in electric mobility should be **interrelated** so that the developments of the different sectors are consistent with each other. If the governments of Burkina Faso and Mali develop e-mobility policies on two- and three-wheelers, these policies should be strictly coordinated with energy policies to ensure harmonious development and avoid an unsustainable demand on national electricity production.
High	From a normative point of view, e-mobility on two- and three-wheelers would require **a revision of transport standards.** Indeed, current legislation in Burkina Faso and Mali does not include electric vehicles in the codification of transport modes.
Medium	The development of electric two- and three-wheelers should be **coordinated with local public transport development plans** in order to increase the overall efficiency of the transport system. As the development of public transport in Ouagadougou and Bamako progresses, e-mobility on two- and three-wheelers should be progressively oriented towards integration services without competing with public transport.
Medium	The definition of public policies for the **management of e-mobility products**, especially for battery recycling, is an issue that should be carefully addressed to prevent a lack of management from causing environmental problems. Currently, the recycling systems in Bamako and Ouagadougou are not able to cope with the high demand for battery recycling. Policy guidelines should aim to adapt local systems, encouraging the establishment of specialized structures and companies.
Low	Local mobility management should anticipate disincentives to the use of ICE vehicles in both cities, such as **restrictions on circulation** in specific areas (e.g., central areas).
Energy sector	
Medium	The governments of Burkina Faso and Mali should **improve the national energy mix**, focusing on increasing electricity production from renewable sources to enhance the environmental benefits of electric two- and three-wheelers. The improvement of the national energy mix should focus on the **development of solar power generation.**
High	The transition to electric vehicles should be accompanied by a **monitoring of charging** patterns to identify peak periods which could happen at established peak periods or constitute new ones. This should be used to assess an eventual revision/adaptation of the current hourly tariff regimes with the objective of setting efficient **hourly rates** to incentivize off-peak charging.
Infrastructures	
High	The **development of a charging infrastructure network (charging stations and/or battery exchange services)** should be designed and implemented in both Ouagadougou and Bamako in the medium term. In both cities, neither infrastructure nor services for e-mobility currently exists. This is not a short-term constraint for two-wheelers that would be used for limited distances and can be easily recharged via a standard plug at home or at the office. The penetration of electric two- and three-wheelers on a large scale could be limited in the medium-long term, however, when mobility patterns with charging needs different from merely plugging at home/office could arise.

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1.

INTRODUCTION

This study analyzes the potential for electrification of two- and three-wheelers in Sahelian cities, using Bamako and Ouagadougou as case studies. The electrification of urban mobility in the Sahel has the potential to address pressing development issues such as reducing localized air pollution, decarbonizing the transport sector, reducing vulnerability to petrol imports, and creating new local jobs.

This technological transition toward electric vehicles is framed within the ¨Improve¨ pillar of a broader decarbonization framework of Avoid, Shift, Improve and Resilience (ASIR). The ASIR framework aims for (i) avoiding or reducing travel or the need to travel, (ii) shifting to more energy efficient modes, and (iii) improving efficiency through vehicle technology, and (iv) enhancing resilience.

Sahelian cities are developing rapidly due to significant population growth that is compounded by the migration of many rural inhabitants fleeing poverty and insecurity. According to the report "Sustainable Mobility and Accessibility Policies in Malian Cities"**[1]**, for example, the annual population growth rate of Bamako between 2015 and 2030 is estimated at 5.3 percent, which would bring the city's population in 2030 to approximately 4.8 million inhabitants. According to the report "Sustainable Mobility and Accessibility Policies in the Cities of Burkina Faso"**[2]**, the population of Ouagadougou is expected to reach about 4.4 million in 2030, corresponding to an average annual growth rate of about 4.7 percent (Ouagadougou's population in 2018 was about 2.53 million).

As a corollary to population growth, there is a proliferation of two- and three-wheeled vehicles in Burkina Faso and Mali. In Burkina Faso, for example, the 2017 annual report of the National Institute of Statistics and of Demographics (INSD) shows individual motorcycles increased by about 3.5 times between 2010 and 2017, while the average annual growth rate for motor vehicles was about 10 percent over the same period (Figure 1.1).

For Mali, according to the National Institute of Statistics (INSTAT), the rate of household ownership of two-wheelers increased from 17 percent in 2001 to 57 percent in 2017. Sikasso and Bamako are the cities where households own the most vehicles (75 percent and 66 percent, respectively). The number of motorcycles on the road is increasing rapidly; there are likely more than 500,000 of them nationwide, with more than a third in the capital (Figure 1.2).

The way in which two- and three-wheeled vehicles are used in Burkina Faso and Mali is different. In Burkina Faso, mototaxi services for passenger transport have been banned in the two main cities (Ouagadougou and Bobo-Dioulasso). In contrast, mototaxi services have recently expanded in Mali. ICE three-wheeler freight services are widespread in both Ouagadougou and Bamako.

Regarding bicycle use, counts conducted in 2019**[3]** show a modal split of bicycles of about 9 percent in Ouagadougou. In contrast, bicycle use is negligible in Bamako.

Electric two- and three-wheelers offer a high potential to decarbonize the urban transport sector in cities such as Ouagadougou and Bamako. Several international experiences show that switching from internal combustion engines to electric two- and three-wheelers has a high potential to reduce local air pollution and CO2 emissions as well as noise pollution.

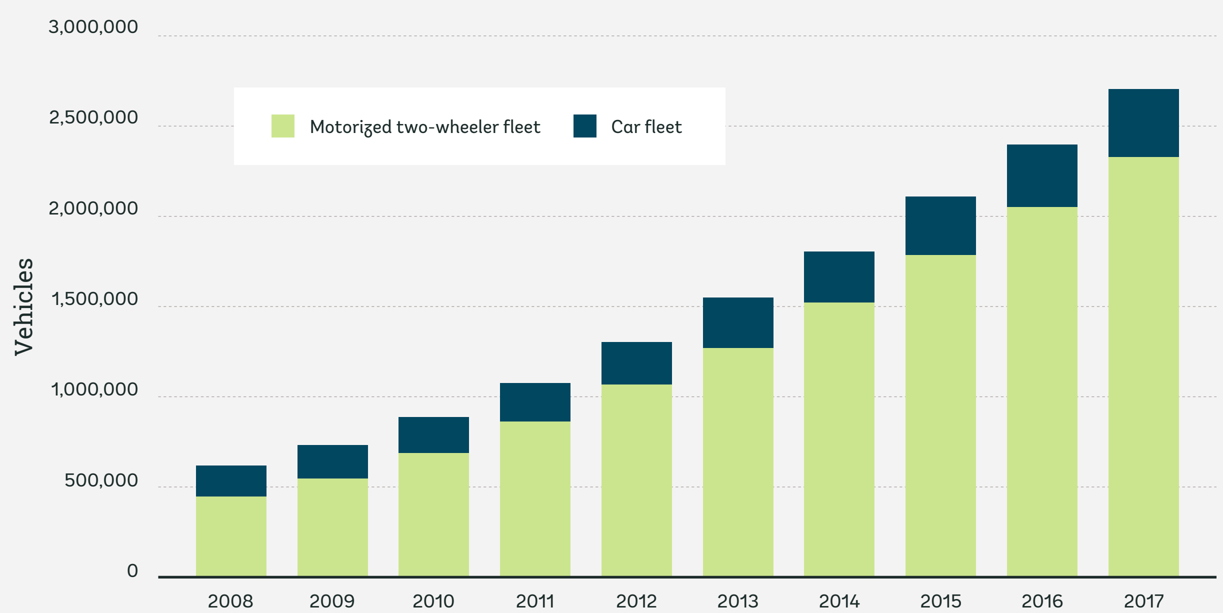
In contrast to high-income countries, the general delay in electric mobility deployment in low-income countries is largely due to inadequate regulatory policies, lack of infrastructure, and poor performance of the electricity grid. The key factors to success and failure that emerge from the analysis of international practices are summarized in Figure 1.3 (see Annex 1 for more details on international practices).

The World Bank aims to develop a dialogue with the governments of the Sahel region regarding the transition to two- and three-wheelers in cities, and consequently the reduction of carbon emissions, air pollution and dependence on fossil fuels.

Based on the analysis of the mobility situation in the cities of Ouagadougou and Bamako, independent recommendations were prepared on how to develop a roadmap for transformation to e-mobility in Sahelian cities. The study focuses on all types of two- and three-wheeled vehicles, both motorized and non-motorized. Thus, in addition to scooters, motorcycles and tricycles, bicycles are also included in the study. Similarly, the study considers two- and three-wheeled vehicles for the transport of people and goods.

Figure 1.1

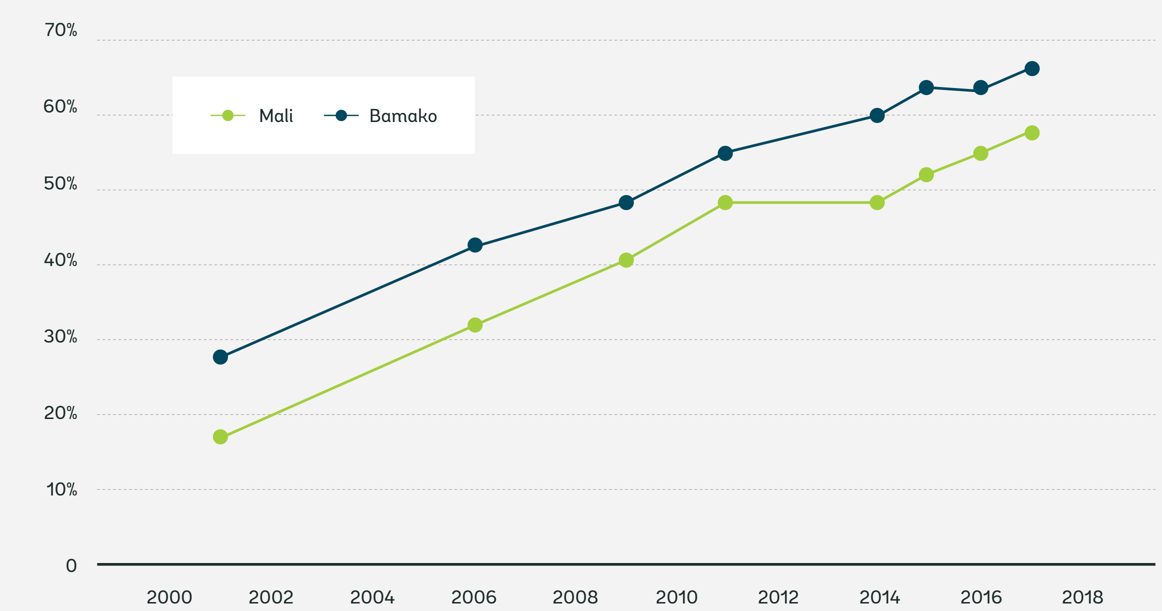
Trend of registered vehicles in Burkina Faso



Source: SSATP (2019). «Policies for Sustainable Accessibility and Mobility in the Cities of Burkina Faso. Diagnostic Study»

Figure 1.2

Trends in motorcycle ownership in Mali



Source: SSATP (2020). «Policies for Sustainable Accessibility and Mobility in Urban Areas of Mali, Diagnostic Study»

Figure 1.3

Success and failure factors for electric mobility

- Public policies supporting the electric transition with clearly defined objectives and appropriate interventions (e.g., well-positioned incentives and regulations).
- Practical experience of electric vehicles by potential users to reduce the information and knowledge gap with combustion engine vehicles.
- Existence of a developed financial ecosystem to support access to electric vehicles and the establishment of financing schemes.
- Research and investment in cheaper energy sources to increase the cost effectiveness of the transition.
- Initiating the transition to electric mobility by identifying specific target groups and use cases.
- Encouraging private investment and innovation.
- Development of innovative charging systems to improve operations and/or reduce vehicle costs (e.g., battery exchange services, battery leasing).

- Deployment of vehicles not adapted to the use cases (e.g., electric tricycles with low engine power, used for freight transport).
- Balance of interests between different stakeholders not ensured by policy makers.
- Lack of infrastructure for electric mobility, such as vehicle charging stations, battery exchange services, etc.
- Poor grid performance (e.g., load shedding problems, poor coverage of the territory).

Source: Authors

R1. REFERENCES

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2.

THE CURRENT SITUATION IN OUAGADOUGOU

Box 2.1: Key factors in the transport system of Ouagadougou

- The transport system is dominated by two-wheelers; they account for 71 percent of vehicles in traffic.
- In 2019, the registered motorcycle fleet reached 1.2 million units.
- The number of tricycles for freight transport is constantly increasing.
- 84 percent of national electricity production comes from non-renewable sources.
- Transportation is responsible for 80 percent of CO_2 emissions and 90 percent of NMVOC emissions.
- Between 2007 and 2016, CO_2 emissions per capita have increased by 64 percent.
- ICE Two-wheelers and three-wheelers are responsible for the annual emission of about 940 Ggeq of GHG.
- Currently, there are no policies or plans for the development of electric mobility in Ouagadougou, and no infrastructure dedicated to electric mobility.

According to estimates by the National Institute of Statistics and of Demographics (INSD), the population of Ouagadougou in 2020 was approximately 2.7 million (i.e., about 12.6 percent of the national population). The city has experienced significant growth resulting from both a rising birth rate and rural-urban migration **[2]**. At the same time, the city has also experienced rapid urban sprawl encompassing seven neighboring communities, now grouped together in the "Greater Ouaga" Area. It is estimated that if the same population density is maintained in 2025, the metropolitan area with its 3.2 million inhabitants will cover 700 km², compared to 400 km² in 2014. The radius of the city is currently about 10 km and could reach 15 km by 2025. The city of Ouagadougou is mainly monocentric, with most of the flow-generating poles concentrated in the center of the agglomeration **[3]**.

2.1. MOBILITY CONDITIONS IN OUAGADOUGOU

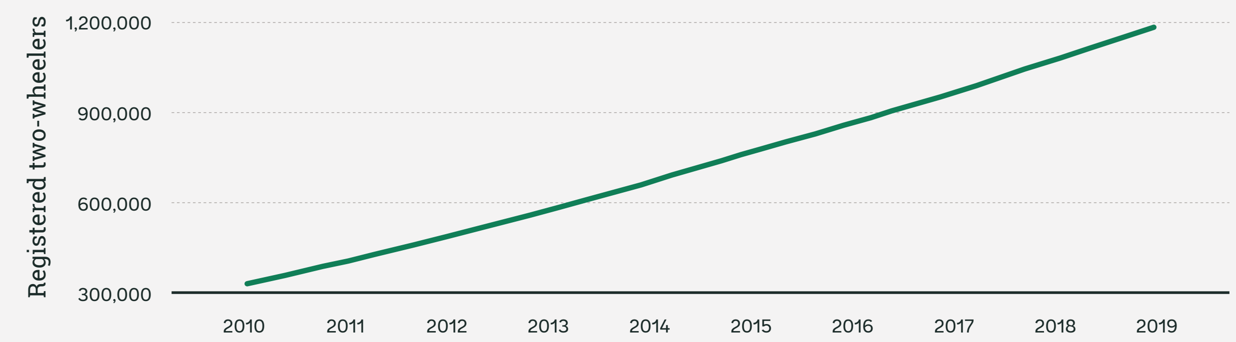
Burkina Faso is characterized by the presence of a very high number of two-wheelers. This is a phenomenon observed throughout the country. According to the International Organization of Motor Vehicle Manufacturers (OICA), the rate of motorization in Burkina Faso for vehicles with four or more wheels in 2015 was only 16 vehicles per 1,000 inhabitants. If motorized two-wheelers are included in this statistic, the motorization rate rises to about 116 vehicles per 1,000 inhabitants.

The 2019 INSD statistical yearbook **[4]** notes a motorized vehicle fleet of about 0.45 million motor vehicles and 2.9 million ICE two-wheelers subject to registration. In 2019, there were 283,800 new ICE two-wheeler registrations and 34,800 motor vehicles in Burkina Faso. The average annual growth rate of registrations are high: 17 percent from 2010 to 2019 for ICE two-wheelers and 10 percent for motor vehicles.

Most of the vehicle ownership in Burkina Faso is therefore made up of ICE two-wheelers, and the capital of Ouagadougou is no exception. According to data from the Directorate General of Land and Maritime Transports (DGTTM), the number of ICE two-wheelers registered each year in the center region (i.e., mainly in Ouagadougou) has increased almost constantly between 2010 and 2019 (Figure 2.1).

Figure 2.1

Evolution of registered two-wheelers in the Center region of Burkina Faso from 2010 to 2019



Source: National Institute of Statistics and Demography - INSD (2020). "Statistical Yearbook 2019"

According to INSD data, the number of ICE two-wheelers registered in Ouagadougou reached about 1.2 million in 2019. These figures could be higher. Almost all stakeholders consulted indicated that many of the two- and three-wheelers that are purchased are not registered. If, for example, one imagines that three-quarters of the population of Ouagadougou could own a two- or three-wheeled vehicle, this illustration could be as high as two million units (although this does not consider vehicles that have reached the end of their life cycle and are no longer used).

In addition, there is also a recent trend toward ICE tricycles which were introduced in Burkina Faso in the early 2000s to transport goods in areas where the road infrastructure was not suitable for trucks. Since then, their numbers have been steadily increasing. Nationally, the customs service reported clearing about 100,000 ICE tricycles between 2012 and 2018. 71 percent of these tricycles were cleared through the Ouagadougou customs office. Currently, tricycles are not used as a mode of public transportation.

Figure 2.2

Three-wheeler

Figure 2.3

Share of vehicles in traffic by type

Motorised two-wheelers	Cars	Bicycles	Trucks/Buses/ Minibuses	Tricycles	Taxis
71%	**16%**	**9%**	**2%**	**1%**	**1%**

Source: OPTIS (2020) «Ouagadougou Public Transport Implementation Study. Activity Report 1»

In 2019, according to the DGTTM, the number of tricycles registered in Ouagadougou was approximately 13,140. The number of ICE three-wheelers registered in Ouagadougou increased by about 55 percent between 2015 and 2019.

The use of bicycles in Ouagadougou is not negligible. It is interesting to note that electric bicycles have recently begun to be extensively, especially by school-age youth. These electric pedal-assisted bicycles could represent an interesting opportunity for market growth in the future.

According to a 2014 mobility survey conducted by the Urban Movements Observatory in Ouagadougou (ODUO), about 66 percent of trips in the city (excluding walking) are made by ICE two-wheelers, while about 15 percent are made by cars and about 16 percent are made by bicycles.

More recent counts, conducted in 2019 as part of a feasibility study for the implementation of an integrated public transport network (Ouagadougou Public Transport Implementation Study – OPTIS **[3]**), show a modal share of bicycles of about 9 percent (Figure 2.3). This may reflect a shift from bicycles to ICE two-wheelers.

The study shows about 70 percent of vehicles used in the Ouagadougou urban area are ICE two-wheelers.

ICE tricycles account for about 1 percent of vehicles counted. However, local stakeholders consulted during this study indicated that tricycles are a rapidly expanding mode of transport for freight.

Several problems associated with public transportation in Ouagadougou have resulted in a system that is not very attractive in terms of services offered. In 2017, only eight buses were operational. That year, about 800,000 passengers were transported, a very low number and a sharp decline compared to the year 2005. In 2018, however, efforts to strengthen public transport included the purchase by the state of a fleet of 130 buses, 30 of which are operational in Ouagadougou. This has helped increase the number of passengers transported to about 150,000 per month between December 2018 and June 2019. The modal share of public transport is estimated to be about 1 percent of trips. In 2018 the price of a bus ticket (single ride) was CFAF 200 (about US$0.36)**[2]**.

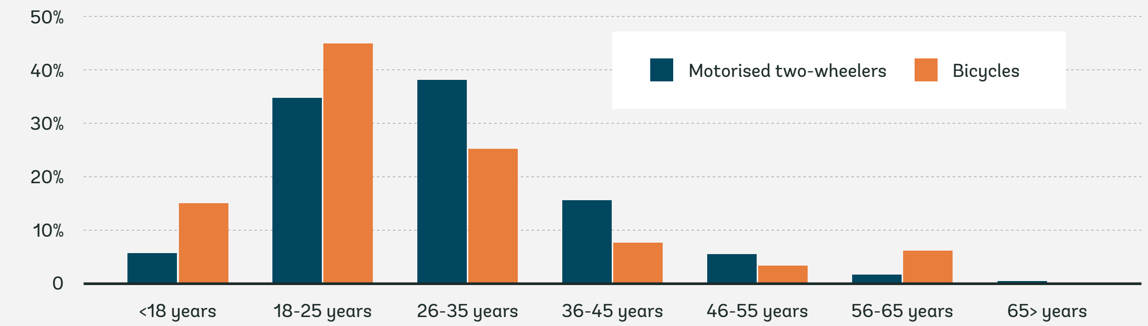
A 2009 study by the Institute for Studies on Economic and Social Development (IEDES) and the University of Paris 1 Panthéon Sorbonne **[5]** estimated the modal share of walking at 54 percent of trips. The study also indicated a volume of about 4.7 million trips per day.

The OPTIS study **[3]** recently modelled the volume of travel by mode to represent current mobility conditions. The following percentages indicate the share of total travel per mode of transportation:

- Car: 5.8 percent
- Motorized two-wheelers: 27.7 percent
- Bus: 0.5 percent
- Walking: 50.5 percent

Figure 2.4

Distribution of two-wheeler use by age



Source: OPTIS data processing

The modal share of ICE two-wheelers seems to be increasing compared to 2009. While ICE two-wheelers represent most travel modes, a very large share of trips is also made on foot, especially for short-distance trips. This may be a good indicator with respect to potential development of "electric micro-mobility" (i.e., light electric vehicles such as folding bikes, monowheels, etc.).

Data collected during the OPTIS study show that two-wheelers (motorized and non-motorized) are used primarily by people under 36 years of age (Figure 2.4).

According to the information collected during the OPTIS study, most trips are conducted between the periphery and the city center, primarily for commuting to work or school. This information was also corroborated by the stakeholders consulted for this study. Some of the trips involve freight transport, which,although marginal in relation to the movement of people, still has a significant impact on urban mobility.

On average, the duration of a trip changes by mode (Figure 2.5). ICE two-wheelers are on average the fastest (33 minutes per trip), while bicycles are the slowest (43 minutes per trip). ICE tricycles do not differ significantly in travel time (41 minutes per trip) from bicycles (43 minutes). Indeed, several stakeholders consulted indicated that tricycles are often overloaded and slow which causes congestion problems.

According to OPTIS data, the average trip with ICE two-wheelers is 10 km long. The average distance of a bicycle trip, on the other hand, is about 9 km which is quite similar to the distance covered by ICE two-wheelers.

Precise data on the number of trips made per day are not available. According to the stakeholders consulted, public sector employees make only one round trip per day (i.e., about 20 km with ICE two-wheelers), while other road users tend to make more than one round trip per day. The same applies to ICE three-wheeled users. On average, two- and three-wheelers travel about 25 km per day.

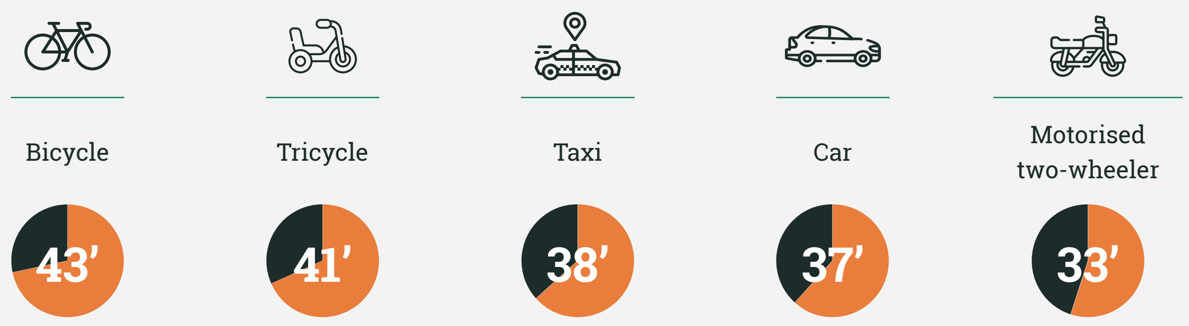
Information on travel costs by mode (including the cost of fuel and maintenance) shows that the cost of a private vehicle is certainly the highest (about US$1.5 - or CFAF 820 - in 2009), compared to about US$0.7 (CFAF 400) for buses (in 2018) and between US$0.5 (CFAF 290) and US$0.7 (CFAF 380) for motorcycles.

The available data on travel costs are not very homogeneous or consistent for the different categories of transport. In any case, it is quite clear that the most economical and flexible mode of transport remains ICE two-wheelers.

It is also interesting to note that, according to the OPTIS analyses, Ouagadougou has no congestion problem at the city level. Vehicles circulate relatively smoothly except for areas with congestion on certain main roads.

Figure 2.5

Average travel time by mode



Source: OPTIS (2020) «Ouagadougou Public Transport Implementation Study. Rapport d'Activité 1»

In the 1980s, bicycle paths were built along five major roads in Ouagadougou to facilitate bicycling in the city, but they are frequently invaded by street vendors or other unauthorized road users.

There are currently no electric vehicle charging stations in Ouagadougou. The only electric vehicles in circulation are electric bicycles, which have recently been used by people of school age.

In contrast to ICE vehicles, no specific regime and custom regulations apply to the import of electric vehicles in Ouagadougou. According to the World Trade Organization **[98]**, the country's overall custom formalities require the following documents: import declaration (DPI) for transactions with a free on-board value equal or greater than US$925 (CFAF 500,000); foreign exchange authorization; foreign exchange commitment; import certificate; export declaration from the country of origin; and import insurance certificate. The clearance system is based on a time-consuming (taking about four days) risk management system envisioning the following outputs: green (good for release), blue (a posteriori control), yellow (inspection of documents) and red (full-scale physical inspection of the goods). Taxes on trade are based on the following types: custom duty, VAT, statistical tax, and toll.

2.2. THE ENERGY SECTOR IN OUAGADOUGOU

The energy sector in Burkina Faso comprises three main areas: electricity, hydrocarbons, and renewable energy. The electricity sector is managed by the National Company for Electricity in Burkina Faso (SONABEL) and any other entity that has obtained a concession or authorization in accordance with the laws in force.

Increased economic activity as well as population growth and urbanization have led the country to face a high demand for electricity. In recent years, the demand for electricity has increased and more and more people have access to electrical energy **[6]**. National electricity generation in 2016 was about 990 GWh with a high percentage coming from fossil fuels (about 834 GWh) (Table 2.1). A significant portion of the power (about 39 percent) was imported from other countries such as Ghana (mostly hydroelectric power) and Côte d'Ivoire (mostly thermal power).

Table 2.1

Electricity generation and consumption in Burkina Faso in 2016

	GWh	Percent
Consumption	1,550	-
Generation		
Renewable	156	9,6 percent
Hydroelectric	139	8,6 percent
Solar	15	0,9 percent
Biomass and waste	2	0,1 percent
Fossil fuel	834	51,5 percent
Net imports	630	38,9 percent
Total	**1,620**	**100 percent**

Oil, natural gas, and coal accounted for about 84 percent of the electricity produced in Burkina Faso and other countries, while hydroelectricity and solar energy accounted for about 14 percent and 1.52 percent of the electricity produced, respectively, in Burkina Faso and other countries. Solar energy systems are currently used for communication (telephone, television, etc.), lighting, refrigeration, and water pumping. Biomass energy (firewood and charcoal) is used by about 90 percent of the population, while the rest use hydrocarbons, hydroelectricity, and other renewable energies (mainly solar). Wind energy is not ideally suited to Burkina Faso. The average wind speeds recorded are between only 1 and 3 m/s, with faster speeds recorded in the northern parts of the country. The minimum wind speed required to start a wind turbine is about 4 m/s.

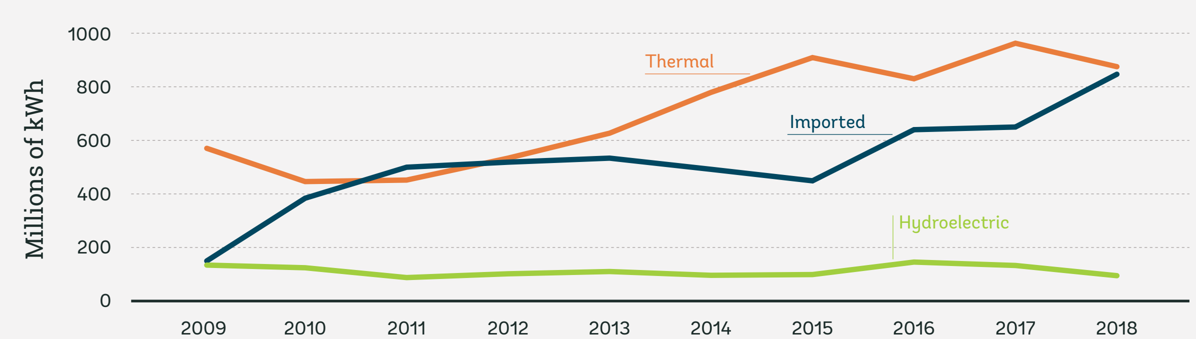
According to SONABEL data, the energy produced or imported increased to about 1,800 GWh in 2018. Figure 2.6 confirms the strong dependence on other countries; about 46 percent of electrical energy is imported. This dependence has increased since 2009 by a factor of three (in 2009 only 17 percent of electricity came from other countries), due to limited growth in national production systems. According to the statistical yearbook of the Ministry of Energy **[35]**, the share of renewable energy in terms of national production was 16.9 percent in 2018, while the share of renewable energy in the total electricity supply was 9.4 percent.

The energy mix used in Ouagadougou is more or less the same as in the whole of Burkina Faso. Indeed, when considering the energy sold, SONABEL services are mostly concentrated in the central region (i.e., Ouagadougou), which absorbs about 55 percent of its sales.

Although Burkina Faso has strong solar energy potential, solar energy accounted for only 1.15 percent of total national energy consumption in

Figure 2.6

Evolution of electricity production and imports between 2009 and 2018 in Burkina Faso



Source: Ministry of Environment, Green Economy and Climate Change - MEEVCC (2019) "Yearbook of environmental statistics 2018".

2016. In November 2017, the 33 MW Zagtouli solar power plant near Ouagadougou was connected to the grid and contributed about 5 percent of the national electricity production with production costs of US$0.06/kWh (CFAF 32/kWh) **[9]**. In January 2018, the Ministry of Energy announced plans to build eight more solar parks totalling 100 MW **[10]**. In addition, SONABEL has been working to increase generation capacity by 55MW with the expansion of one of its thermal power plants**[11]**.

According to data from the Directorate General of Energy **[8]**, the consumption of energy products in road transport was approximately 8 million Tons of Oil Equivalent (TOE) in 2003, divided almost equally between gasoline and diesel. In 2002, the transport sector consumed about 4.4 percent of energy products. More recent data are not available, and it is possible that the consumption of the transport sector has changed due to the growth in the number of vehicles in Burkina Faso.

About 885,000 vehicles were registered in Burkina Faso in 2010, while about 3.3 million were registered in 2019. Accounting for the same growth rate, about 311,000 vehicles were registered in the country in 2003 (with a consumption of about 8 million TOE). Without accounting for the technological changes in vehicles (which today consume less than in 2003), a projection of consumption would bring TOE to about 87 million in 2019 for all vehicles combined. Given that about 1.2 million ICE two- and three-wheelers are registered in Ouagadougou, the consumption of these vehicles in the capital can be estimated at about 30 million TOE.

Burkina Faso lacks sufficient access to electricity and has one of the lowest electrification rates in the world (about 38.6 percent in 2018, according to Ministry of Energy data). The electrification rate is much higher in Ouagadougou and reaches about 95 percent coverage.

The cost of producing electricity is one of the highest in the sub-region. A study by SONABEL shows that within the Economic Community of West African States (ECOWAS), Burkina Faso has the highest average domestic kWh rate **[12]**. In 2017, it was US$0.20/kWh (CFAF 112/kWh) compared to US$0.11/kWh (CFAF 60/kWh) in Côte d'Ivoire. The ECOWAS average is US$0.18/kWh (CFAF 103/kWh). SONABEL's average electricity tariff for domestic use in 2018 decreased to US$0.185/kWh (CFAF 102/kWh). The tariff regime provides for a two-part tariff composed of a fixed component and a variable component linked to the kWh consumed. There is a distinction between the following tariff bands: "domestic use" for individuals and administration; "domestic use and industrial and agricultural driving force"; and "hourly tariffs" for individuals and administration. Compared to the population's ability to pay, electricity tariffs are high and require public subsidies to fully cover the cost of service.

The details for tariff bands are as follows.

"Domestic use" is divided in two types and three tranches:

- Type A (from 1A to 3A):
  - From 0 to 75 kWh (US$0.15/kWh).
  - From 76 to 100 kWh (US$0.23/kWh).
  - More than 100 kWh (US$0.25/kWh).
- Type B (from 5A to 30A):
  - From 0 to 50 kWh (US$0.17/kWh).
  - From 51 to 200 kWh (US$0.18/kWh).
  - More than 200 kWh (US$0.20/kWh).

"Domestic use and industrial and agricultural driving force" are divided in three tranches:

- Type C (from 10A to 30A):
  - From 0 to 50 kWh (US$0.17/kWh).
  - From 51 to 200 kWh (US$0.19/kWh).
  - More than 200 kWh (US$0.21/kWh).

"Hourly tariffs" are divided in two periods:

- Peak hours from 10:00 to 14:00 and from 16:00 to 19:00 (US$0.30/kWh).
- Full hours from 0:00 to 10:00, from 14:00 to 16:00 and from 19:00 to 0:00 (US$0.16/kWh).

Based on the above tariff bands, it would be advisable to apply for an "hourly tariff" and to recharge electric vehicles during the "full hours" (i.e., avoiding peak hours that could impact negatively on stability of electricity grid).

According to the INSD, the average price of fuel was US$1.14 per liter (CFAF 630 per liter) for gasoline and US$1.00 per liter (CFAF 551 per liter) for diesel in 2020.

2.3. ENVIRONMENTAL QUALITY IN OUAGADOUGOU

According to national greenhouse gas inventories **[13]**, transport is responsible for 80 percent of CO_2 emissions, 30 percent of CO emissions, more than 90 percent of NMVOC[6] emissions, and more than 60 percent of SO_2 emissions as well as a significant share of suspended particulate emissions. In order of importance of the volumes emitted, the greenhouse gases are CO_2, CH_4, CO, N_2O, and NO_x.

ICE two-wheelers in Ouagadougou represent about 71 percent of the traffic and are responsible for a large portion of CO_2 emissions. The contribution of transport modes used on CO_2 emissions in Ouagadougou has been calculated (Table 2.2) based on ranges of emission factors by type of vehicles **[95]** and their average distance travelled (derived from OPTIS study **[3]**). Despite the smaller engines of two-wheelers, their substantial presence in traffic leads to a significant percentage of total CO_2 emissions.

Estimations of contribution of transport modes for other pollutants are given in Annex 8. It is estimated that ICE two- and three-wheelers could be responsible for a major share (typically 60 percent-75 percent) of harmful local air pollutants emitted by motorized traffic such as carbon monoxide (CO), nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOC), and particulate matter (PM2.5).

Table 2.2

CO_2 emissions by type of vehicle in Ouagadougou

Transport modes	Share in traffic	g CO_2 / km		CO_2	
		Low	High	Low	High
Two-wheelers	71 percent	0.13	0.30	54 percent	60 percent
Three-wheelers	1 percent	0.20	0.35	1 percent	1 percent
Cars/taxis	17 percent	0.40	0.70	39 percent	33 percent
Trucks/buses/minibuses	2 percent	0.50	1.00	6 percent	6 percent

Source: Authors

Between 2007 and 2016, CO_2 emissions per capita increased by about 64 percent in Burkina Faso (Figure 2.7 - left). This significant increase is partly related to the economic growth of the country. Indeed, CO_2 emissions compared to Gross Domestic Product (GDP) also show a less significant growth of about 31 percent in the same 10-year period (Figure 2.7 - right). The level of CO_2 emissions is rising faster than economic growth. This could be caused, in part, by the growth of private motorized mobility.

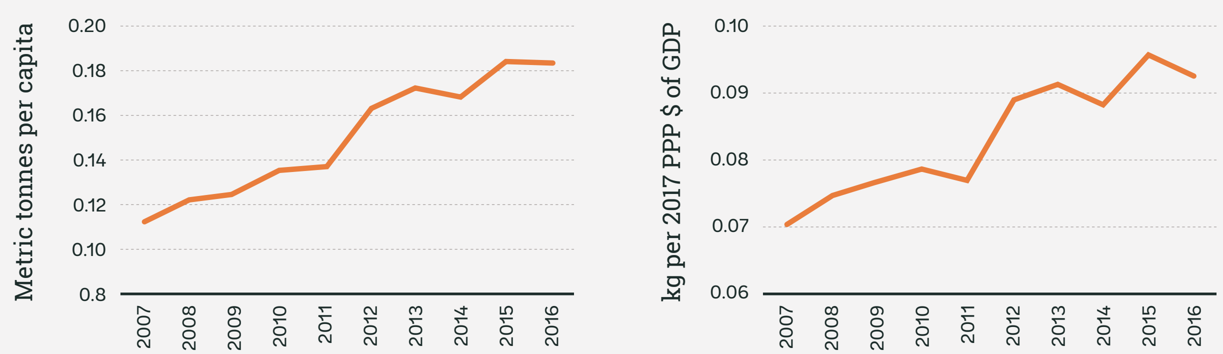
Air quality monitoring relates to the pollutants of greatest public health concern. These pollutants are composed of fine particles less than or equal to 10 microns in size (PM10). For the city of Ouagadougou, the average value of PM10 (about 825 $\mu g/m^3$) recorded at different sites in 2018 is well above the national standard of 300 $\mu g/m^3$[7] and the WHO standard of 50 $\mu g/m^3$. The highest value was 1,125 $\mu g/m^3$ and the lowest value was 525 $\mu g/m^3$ (Figure 2.8). The red line indicates the national standard value.

6 Non-methane volatile organic compounds

7 Decree No. 2001-185 of the Council of Ministers

Figure 2.7

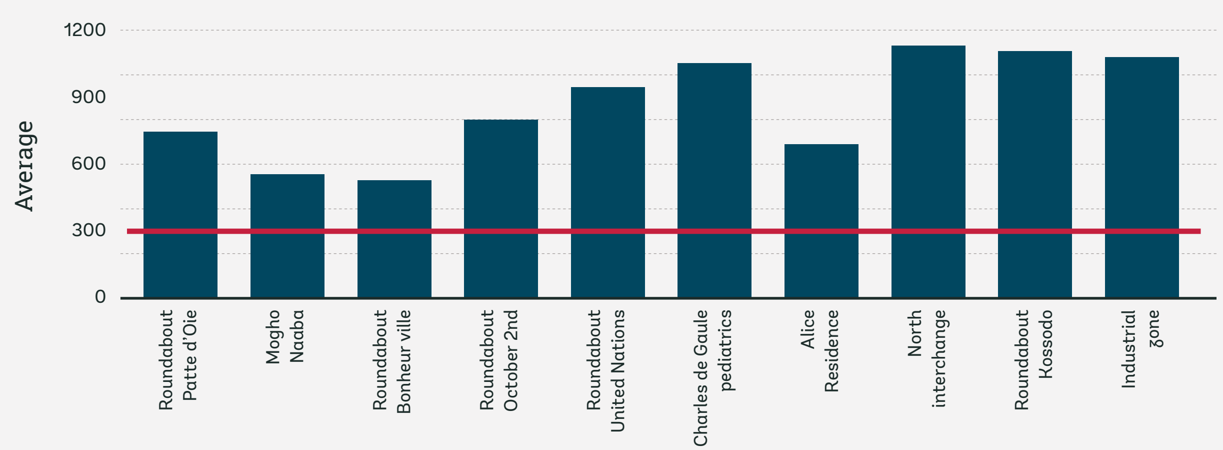
CO_2 emissions per capita (left) and per GDP (right) in Ouagadougou between 2007 and 2016



Source: World Bank

Figure 2.8

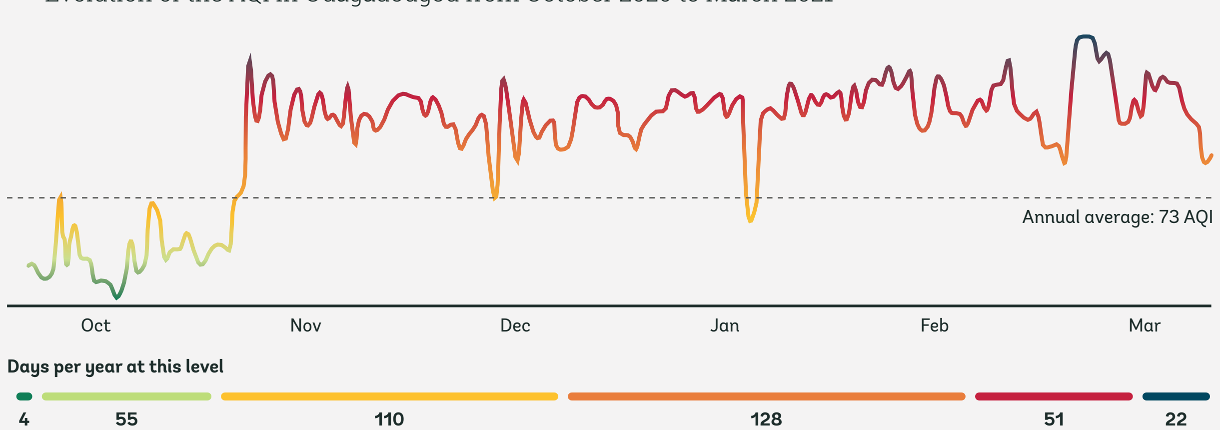
Average PM10 concentration in different areas of Ouagadougou in 2018



Source: Ministère de l'Environnement, de l'Economie Verte et du Changement Climatique - (2018) «Annuaire des statistiques de l'environnement 2017»

Figure 2.9

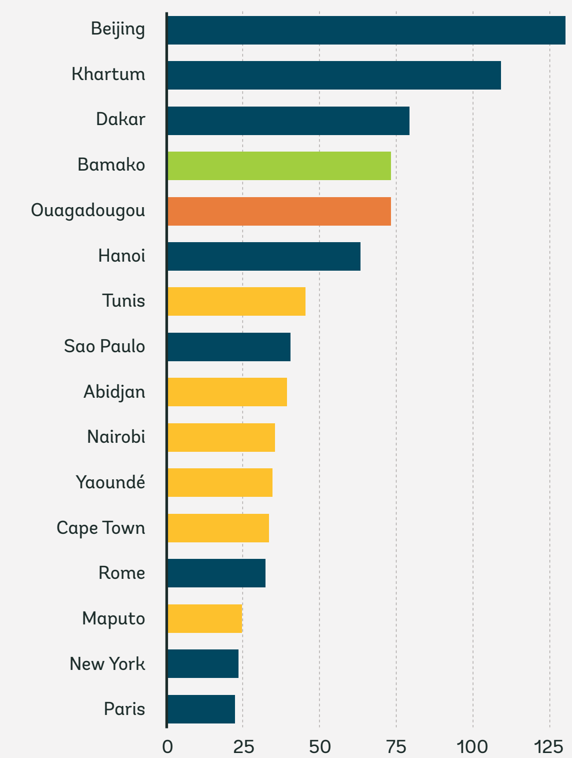
Evolution of the AQI in Ouagadougou from October 2020 to March 2021



Source: https://plumelabs.com/

Figure 2.10

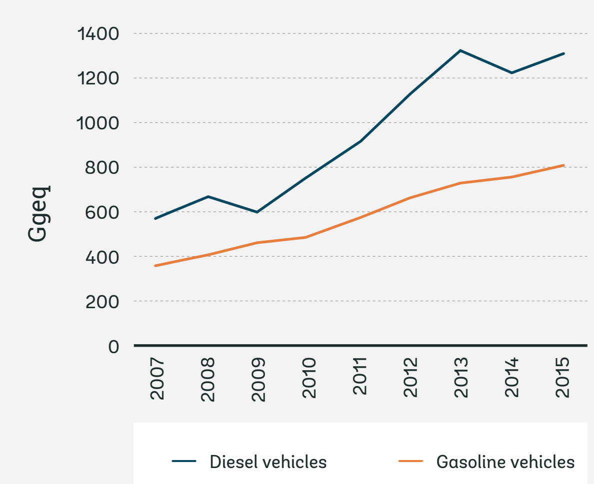
Comparison of Annual Average AQI



Source: https://plumelabs.com/fr/

Figure 2.11

Evolution of national GHG emissions by vehicle type between 2007 and 2015



Source: Diallo M. (2015). "Study for the development of Nationally Appropriate Mitigation Measures of the road transport sector". Permanent Secretariat of the National Council for Environment and Sustainable Development (SP/CONEDD).

Using the Air Quality Index (AQI), the air quality in Ouagadougou is considered poor to average (Figure 2.9). According to this index, over the past few months, the air has been very polluted on 55 percent of the days (i.e., air quality has been above the WHO 24-hour exposure guidelines) from October 2020 to March 2021. Under these conditions, some negative health effects may occur and people who are particularly sensitive to pollution should limit their outdoor activities. The below average AQI values recorded before mid-October may be related to the rainy season, as atmospheric precipitation lowers pollutant concentrations.

Ouagadougou's average annual AQI is often higher than that of other African cities and other regions of the world (Figure 2.10).[8]

At the national level in Burkina Faso, WHO estimated in 2016 that ambient (outdoor) air pollution has been responsible for the loss of 357,039 years of 'healthy' life (DALYs - Disability-Adjusted Life Years, calculated by WHO as the years of life lost due to premature mortality plus the years of healthy life lost due to disability).

The limit values of air pollutants are regulated by the Decree No. 2001-185 of the Council of Ministers. As far as emissions from motorcycles are concerned, the standards for four-stroke engines are:

- CO: 12 g/km.
- NO_x: 3.5 g/km.
- HC: 3 g/km.
- COV: 0.3 g/km.

A study conducted in 2015 by the Permanent Secretariat of the National Council for the Environment and Sustainable Development **[16]** shows the evolution of greenhouse gases (GHG) for light petrol vehicles (including ICE two-wheelers) and for heavy diesel vehicles (Figure 2.11). The indicator used in this case is a composition of the main pollutants (CO_2, CH_4 and NO_2).

8 African cities are shown in yellow (except Ouagadougou and Bamako) and non-African cities are shown in blue.

The data show a strong increase in emissions during the years 2007 to 2015 (Figure 2.11). Emissions from gasoline vehicles increased by about 125 percent, while emissions from diesel vehicles increased by about 128 percent.

The increase appears to be consistent with the growth of the vehicle fleet in Burkina Faso over these years. Specific data on ICE two- and three-wheelers are not available. In 2015, about 41 percent of vehicles were registered in Ouagadougou and contributed about 866 Ggeq[9] of GHG. ICE two-wheelers and three-wheelers in Ouagadougou accounted for about 71 percent of traffic, with an estimated contribution to GHG emissions of about 610 Ggeq of GHGs. ICE two-wheelers and three-wheelers in Ouagadougou in 2019 increased by about 54 percent compared to 2015, bringing estimated GHG emissions to about 940 Ggeq of GHGs.

In particular, the estimated GHG emissions caused by ICE two- and three-wheelers in Ouagadougou are listed by the following types of pollutants:

- CO_2: 921 Gg (that is to say, about 85 g/km considering 25 km driven per vehicle per day).
- CH_4: 3.7 Gg (that is to say, about 0.3 g/km considering 25 km driven per vehicle per day).
- NO_2: 15.3 Gg (that is to say, about 1.4 g/km considering 25 km driven per vehicle per day).

No data are available on noise pollution from transport in Ouagadougou. Stakeholders who were consulted often mentioned, however, that this phenomenon is a common problem in Ouagadougou, linked particularly to the high presence of ICE two- and three-wheelers. A few stakeholders mentioned the lack of noise produced by electric vehicles could lead to road safety problems and be a possible constraint to electric mobility. This suggestion is mainly based on personal experiences and impressions. It should be noted that above a certain speed, the noise caused by the friction of the tires on the road becomes predominant over the engine noise from 50 km/h for a light vehicle.

2.4. PUBLIC TRANSPORT POLICIES IN OUAGADOUGOU

Currently, there are no national or local public policies focused on the development of electric mobility. This is a sector that has not yet been explored by the public authorities, who have little knowledge on the subject.

Urban developments are strongly oriented towards strengthening public transport. Urban mobility is at the forefront of the 2016-2021 agenda of the Municipality of Ouagadougou, with four main development axes focused on traffic fluidity, improvement of road infrastructure, improvement of public transport, and improvement of parking infrastructure.

The main strategy currently under development concerns the modal transition to public transport through the OPTIS project, which aims to create a new high-capacity public transport network including the creation of Bus Rapid Transit corridors.

The development of electric mobility should necessarily be focused in this sector to define services that are complementary to public transport needs (and certainly not competitive). For example, electric mobility services in support of public transport feeder lines could be envisioned for this purpose.

9 Giga grams equivalent

R2. REFERENCES

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3.

THE CURRENT SITUATION IN BAMAKO

Box 3.1: Key facts about transport in Bamako

- 66 percent of households in Bamako own a motorcycle.
- In 2014, about 30 percent of trips were made by motorcycle and 26 percent were made by foot.
- Official mototaxi services have been increasing in recent years.
- The number of tricycles for transporting goods is also increasing.
- 41 percent of electricity generation is from renewable sources (mainly hydroelectric).
- Between 2007 and 2016, CO_2 emissions per capita increased by 86 percent.
- ICE two-wheelers and three-wheelers are responsible for annual emissions of about 2,400 kt of CO_2 equivalent.
- Currently, there are no policies or plans for the development of electric mobility in Bamako, and no infrastructure is dedicated to electric mobility.

According to the projections of the National Institute of Statistics (INSTAT), the population of Bamako was 2.6 million (i.e., about 12.7 percent of the national population) in 2020. The city has the endemic problems typical of West African capitals: proliferation of slum neighborhoods, lack of network infrastructure (water, electricity, transportation), difficulties in managing urban services, etc. **[1]**

The average population density in Bamako is estimated at about 8,300 inhabitants per km² in a total area of about 26,750 hectares. The urban structure of Bamako is monocentric, resulting in a high proportion of daily travel from the residential areas on the outskirts of the city to the city center where most jobs and urban services are located.

A major constraint to travel is caused by the fact that the two parts of the city are separated by the Niger River and connected by only three bridges. Approximately 50 percent of trips are made between the two banks of the river (40,000 to 60,000 exchanges during peak hours) **[17]**. Some stakeholders who were consulted mentioned that at certain times of the day, a 15-20 km trip can take 2-3 hours.

3.1. MOBILITY CONDITIONS IN BAMAKO

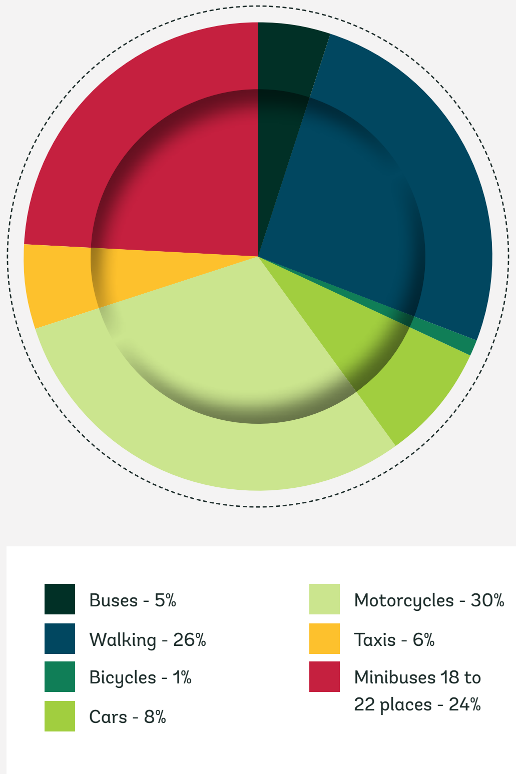
Currently, it is difficult to assess the number of vehicles used in Mali and cities like Bamako. According to an estimate by the Regional Directorate of Land Transports of Bamako District, there were about 108,000 passenger vehicles (excluding ICE two-wheelers) and heavy vehicles in the capital in 2018.

It is even more difficult to estimate the number of ICE two- and three-wheelers, as they are not officially counted. Nevertheless, INSTAT estimates that about 66 percent of households in Bamako own a motorcycle. This would correspond to about 414,000 motorcycles if only one motorcycle per household is counted (the illustration could be higher since each household probably owns more than one motorcycle).

Recent information on travel patterns in Bamako is not readily available. The most recent data (Figure 3.1) appear in the report "Stratégie opérationnelle vision Bamako 2030. Dossier de contexte" which cites the Direction of Traffic Regulation and of Urban Transport of Bamako (DRCTU) as the source [17].

Figure 3.1

Distribution of travel modes in Bamako in 2013



Source: Yalcouye H.B. (2014) "Operational strategy vision Bamako 2030. Background file".

Public transport in Bamako is composed of eight-seat mini-buses (called "duruni"), 18-22 seat mini-buses, and buses. These are mostly informal modes of transport. In 2014, very few companies were contracted **[17]**.

Private vehicle ownership (excluding ICE two-wheelers) is quite low in Bamako. According to the latest estimates, it is about 46 vehicles per 1,000 inhabitants. If ICE two-wheelers are also included, the private vehicle ownership rate rises to 150 vehicles per 1,000 inhabitants **[1]**.

The DRCTU estimates that there are currently about 9,000 cabs in Bamako, which combine different types of service such as on-demand, shared cabs, and services on regular routes. These services are often unregulated and uncontrolled.

It is worth noting the formal emergence of motorcycle taxi services in recent years. Currently, three formal mototaxi companies are operational in Bamako, and institutions have initiated a process of regulation of these services, especially to frame them as formal commercial services. These companies provide an attractive franchise for riders, allowing them to buy the motorcycle by paying a daily fee (around US$3.6 or CFAF 2,000) instead of paying the full cost upfront. These services are positively perceived and provide users with benefits (e.g., booking and paying for the service by App). In addition, Teliman is one of at least three mototaxi companies using Japanese imported motorcycles, and the company claims they are more reliable than Chinese ones. Teliman initiated this type of service in Bamako by CFAO Motors (Toyota's African subsidiary) **[18]**.

Although mototaxi services are common in Bamako (both formal and informal services), the ownership structure of ICE two- and three-wheelers is mainly oriented towards private ownership. ICE two-wheelers provided for hire by mototaxi companies are a small part of the total (e.g., the Teliman company had 600 riders in 2019).

Naturally, mobility rates are related to a variety of factors including the lifestyle of the population and the structure of urban centers. Bamako has an average trip rate of 2.8 trips per person. The average distance of a trip is about 10 km. The average distance travelled per day is 25 km per person.

Personal mobility is also affected by an individual's gender, age, and disability. In many parts of the world, women are less likely to have access to individual means of transport such as cars or bicycles. In Bamako, 87 percent of women versus 57 percent of men rely on walking for almost all of their trips.

Currently, there are no electric vehicles in Bamako, and there is no infrastructure for recharging electric vehicles if they are to be introduced. A trial sale of electric three-wheelers was reported in Bamako, where a retailer tried to introduce these vehicles to the market for the transport of goods. The trial was not successful and virtually no vehicles were sold. The reasons for the failure are not clear (the dealer in question is no longer in the market), but it is likely that the high purchase cost of electric three-wheelers was a significant barrier to market entry.

In contrast to ICE vehicles, there is no specific regime as far as customs regulations regarding the import of electric vehicles that apply in Bamako. According to the World Trade Organization [98], all imported goods are subject to a custom declaration (single detailed declaration), accompanied by the following documentation: a notice of intent to import; an inspection certificate; the invoice; a declaration of the elements of value; a certificate of origin; and other documents like insurance, quality, and the tax identification of the importer. Customs clearance is based on a risk management system producing the following outcomes: green (good for clearance), yellow (inspection of documents) and red (physical inspection of the goods). Customs clearance takes an average of 77 hours to complete. Import taxes include the following: ECOWAS common external tariff, statistical tax; ECOWAS community levy; community solidarity levy on behalf of West African Economic and Monetary Union; and VAT. An excise duty is levied on a list of imported goods including passenger vehicles.

3.2. THE ENERGY SECTOR IN BAMAKO

Mali is a member of the "West African Power Pool," a specialized institution of ECOWAS whose objective is to integrate the operations of national power systems into a unified regional power block. In addition, the country is part of the ECOWAS Regional Electricity Regulatory Authority, which is responsible for regulating cross-border electricity trade. Along with Guinea, Mauritania and Senegal, Mali is a member of the Organization for Development of the Senegal River (OMVS). Within this organization, Mali participated in the construction and development of the Manantali and Félou hydroelectric power plants, completed in 2001 and 2013, respectively. These hydroelectric plants have a potential to produce 800 GWh per year and have over 1,500 km of 225 kV transmission lines. The Sélingué hydroelectric dam has also been operational since 1980 and produces approximately 247 GWh (28 percent of Mali's production in 2006) of electricity annually for Bamako and other cities in Mali. In addition to the completion of the 225 kV line between Mali and Côte d'Ivoire in 2012, other interconnections such as the one between Mali and Guinea are planned to meet electricity demand.

Given the region's hydroelectric potential, the share of renewable energy in the energy mix could increase. For petroleum products, Mali is entirely dependent on imports. The country gets firewood (wood fuel) from its natural forests. The country also imports electricity from neighboring countries. Mali's electricity system includes a national grid owned and operated by "Energie du Mali SA" (EDM SA) that supplies 35 cities, including Bamako.

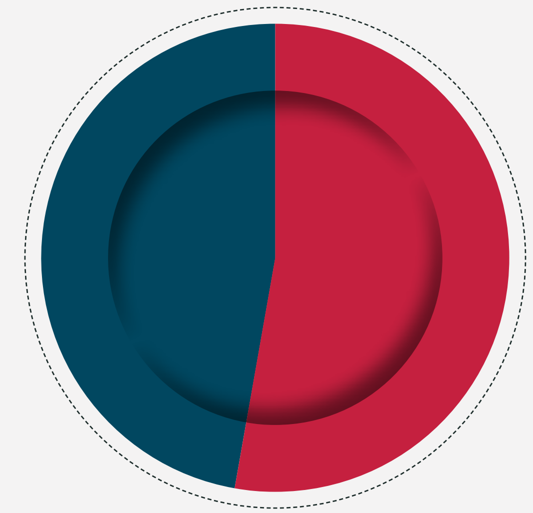
According to the report "*Mali's Sustainable Energy for All Investment Prospectus*" **[19]**, biomass (wood energy) is the main source of energy for households, accounting for 78 percent of total national energy consumption in 2014. Biomass is followed by hydrocarbons for 17 percent of energy production and electricity for the remaining 5 percent. All hydrocarbons for energy consumption are imported.

Mali's energy potential has been estimated at 1,150 MW (thanks to the presence of two major rivers), of which 840 MW is currently available. However, it is important to note that the annual flow of these rivers is rapidly decreasing due to global warming. Finally, the photovoltaic potential is also considerable with a very high solar irradiation (5 to 7 kWh/m^2/day) and a sunshine duration of about 10 hours per day.

The Malian government has developed energy transition objectives that aim to reach a renewable energy capacity of 52.5 percent in 2030 (of which about 29 percent is solar, 21 percent hydroelectric, and the rest wind and bioelectric).

Figure 3.2

Energy mix for power generation of electricity in 2017 in Mali



Source: YSee4All (2019) "Investment prospectus of Mali's Sustainable Energy for All". Sustainable Energy for All. United Nations.

In 2017, EDM-SA's electricity production was 1,923GWh (i.e., about 50 percent more than in 2012). The consumption of petroleum products per year was about 1.4 million TOE (also about 50 percent more than in 2012).

Electricity consumption in 2016 represented about 4.6 percent of the total. In 2017, EDM data showed that energy production was distributed as follows (Figure 3.2):

- 41.3 percent thermal energy (24 percent produced by EDM-SA and 17.3 percent purchased)
- 41.4 percent hydroelectricity (11.8 percent produced by EDM-SA and 29.6 percent purchased)
- 17.3 percent of energy imported from Côte d'Ivoire (67.2 percent from thermal sources and the rest from hydroelectric sources).

Bamako is part of EDM-SA's "interconnected network" and therefore benefits from the diverse energy mix indicated above.

Table 3.1.

Energy consumption sectors in 2014 in Mali

Sector	Percent
Residential	72.5 percent
Transport	13.5 percent
Industry	5.4 percent
Others	8.6 percent

Source: irena.org/publications/2019/Sep/Renewables-Readiness-Assessment-Mali

Energy consumption for economic purposes is low in Mali, as shown in Table 3.1. The industrial sector represents only 5.4 percent of the total energy consumption. Although the agricultural sector contributes significantly to Mali's GDP, there is a low level of energy consumption in this sector. About 10 percent of the country's GDP is generated by the gold industry and about 15 percent of GDP by the industrial ginning of cotton for export. These two industrial sectors account for much of the overall industrial energy consumption.

The transport sector has a significant percentage of energy consumption, which is probably even higher today due to its rapid growth. Considering the growth rate of ICE two- and three-wheelers in households (about 1.5 percent more each year for each type of vehicle), the energy consumption of these vehicles alone could account for 23 percent of the nation's total energy consumption in the transport sector. Half the national energy consumption of ICE two- and three-wheelers occurs in Bamako.

Due to the high production costs of thermal power plants and excessive technical and non-technical problems in the network, energy costs (all sectors combined) are particularly high. Access to electricity in Mali is also low, with large disparities between urban and rural areas.

In 2020, the average gasoline price in Bamako was US$1.22/L (CFAF 671/L), while the average electricity price was US$0.237/kWh (CFAF 131/kWh). Within ECOWAS, the average electricity price was US$0.18/kWh (CFAF 103/kWh) in 2017.

The energy tariff regime separates households and business activities and is comprised of a variable component related to kWh consumption and a fixed component. For medium voltage electricity, hourly tariffs apply. Social tariffs apply to electricity consumption below 50 kWh per month, a rare exception within the costly electric regime. Nevertheless, the overall tariff level does not cover the production costs requiring public subsidies. On the other hand, a fixed tariff regime is in place in rural areas with tariffs set according to production costs that result in much higher tariffs than in urban areas (about US$48-55/kWh – CFAF 26,000-30,000/kWh).

The hourly tariffs are as follows:

- Peak hours from 18:00 to 24:00 (US$0.24/kWh).
- Full hours from 0:00 to 18:00(US$0.16/kWh).

It would be advisable to recharge electric vehicles during the "full hours" (i.e., avoiding peak hours that could impact negatively on the stability of electrical grid).

3.3. ENVIRONMENTAL QUALITY IN BAMAKO

Based on the range of emission factors by type of vehicles **[95]**, assumptions on the share of vehicles in traffic, and their average distance travelled, calculations were made on the contribution of transport modes used on CO_2 emissions in Bamako (Table 3.2 CO_2 emissions by type of vehicle in Bamako).

Estimates of how various transport modes contribute to other pollutants are given in Annex 8. It is estimated that ICE two- and three-wheelers could be responsible for a major share (typically 60-75 percent) of harmful local air pollutants emitted by motorized traffic, including carbon monoxide (CO), nitrogen oxides (Nox), non-methane volatile organic compounds (NMVOC), and particulate matter (PM2.5).

According to World Bank data, per capita CO2 emissions in Bamako increased by about 86 percent between 2007 and 2016 (Figure 3.3 - left), likely due to population growth and mobility. The country's GDP has grown less rapidly than CO_2 emissions per capita (Figure 3.3 - right).

According to the Air Quality Index (AQI), air quality is rated as poor on average (Figure 3.4) **[21]**.

The average annual AQI of Bamako is quite high compared to other African cities and other regions of the world (Figure 3.5).[10]

Table 3.2

CO_2 emissions by type of vehicle in Bamako

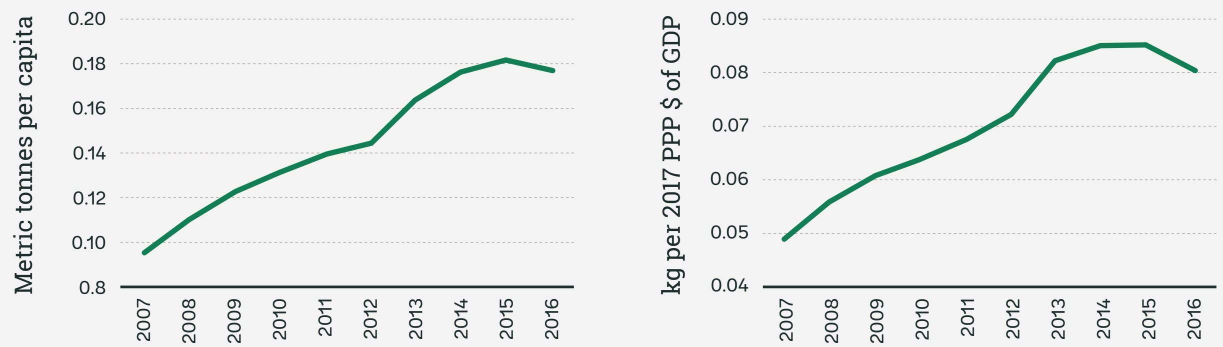
Transport modes	Share in traffic	g CO_2 / km		CO_2	
		Low	High	Low	High
Two-wheelers	76 percent	0.13	0.30	52 percent	58 percent
Three-wheelers	1 percent	0.20	0.35	1 percent	1 percent
Cars/taxis	19 percent	0.40	0.70	36 percent	31 percent
Trucks/buses/minibuses	4 percent	0.50	1.00	11 percent	10 percent

Source: Authors

10 In yellow are the African cities (except Ouagadougou and Bamako) and in blue are the non African cities.

Figure 3.3.

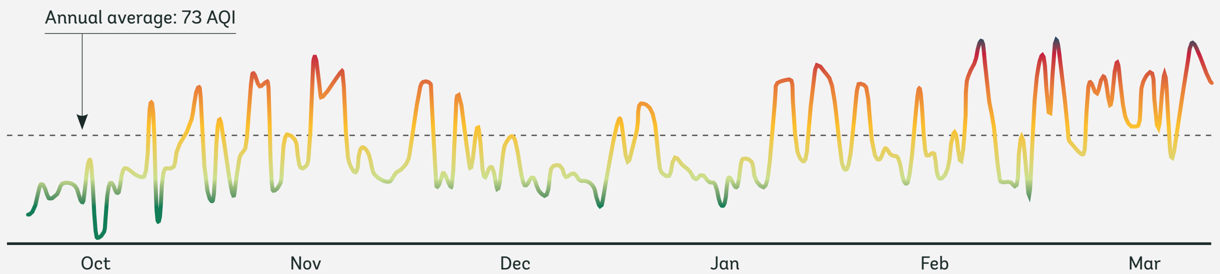
CO_2 emissions per capita (left) and per GDP (right) in Bamako between 2007 and 2016



Source: World Bank

Figure 3.4.

Evolution of the AQI in Bamako from October 2020 to March 2021



Source: https://plumelabs.com/

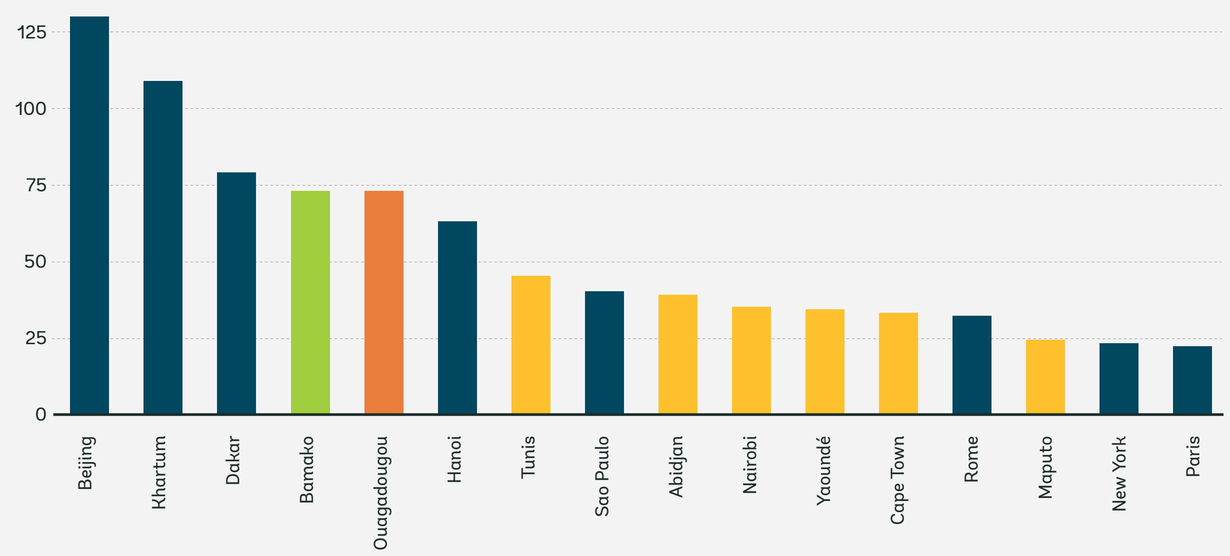
In Bamako, the main pollutants include the following (information in parenthesis are estimates obtained from the Copernicus atmosphere monitoring service **[22]**):

- PM2.5 (average 34 µg/m³ during the last year)
- PM10 (average 72 µg/m³ during the last year)
- NO2 (average 4 µg/m³ during the last year)
- O3 (average 47 µg/m³ during the last year).

Official estimates of greenhouse gas (GHG) emissions or other pollutants are not available. The "World Perspective" website **[23]** provides data from the World Bank and indicates that Mali emitted about 29,130 kt CO_2 equivalent in 2012 (compared to a population-weighted average of 343,000 kt CO_2 equivalent in the African region). In 2016, CO_2 emissions were about 0.18 metric tons per capita (compared to a population-weighted average of 3.9 metric tons per capita of CO_2 in the African region). Information is neither available for Bamako nor Mali for emissions caused by transportation. The same applies to noise pollution, for which no data are available. Several stakeholders who were consulted acknowledged that the use of ICE two- and three-wheelers has a significant impact on air quality and noise.

Figure 3.5.

Comparison of Annual Average AQI



Source: https://plumelabs.com/

At the national level in Mali, WHO estimated in 2016 that ambient (outdoor) air pollution has been responsible for the loss of 396,308 years of 'healthy' life (DALYs – 'Disability-adjusted life years,' calculated by WHO as the years of life lost due to premature mortality plus the years of healthy life lost due to disability).

Assuming that about 40 percent of vehicles in Bamako are ICE two- and three-wheelers and transport could be responsible for about 63 percent of total CO2 emissions in the city, we can estimate that these ICE two- and three-wheelers emit about 2,400 Gg of CO_2 equivalent (i.e., about 160 g/km considering 25 km driven per vehicle per day).

3.4. PUBLIC TRANSPORT POLICIES IN BAMAKO

The vision for transport policies in Bamako is summarized in the report "Stratégie opérationnelle vision Bamako 2030. Background Paper" **[17]**. Most urban mobility projects in the capital focus on the development of public transport and road infrastructure including the following projects:

The "SOTRAMA ring" project focused on the creation of a site reserved for minibuses as well as a site reserved for buses (this project has been completed).

The feasibility project of two tramway lines (image on the right), which would provide between 130,000 and 205,000 trips/day. This project is a study that dates from 2014 but does not have a current forecast for its ultimate realization.

A working group on urban mobility was created in 2019 through an initiative sponsored by the Ministry of Transport and Urban Mobility (MTMU). The group included technicians from MTMU, the Ministry of Infrastructure and Equipment (MIE), representatives of the Governor of the District of Bamako, the District Council of Bamako, the six other cities in the district and the surrounding communities, as well as the urban transport operators of Bamako.

Four main projects are planned for the medium term, three of which concern public road transport and the fourth being a water taxi project.

In order to deal with the severe congestion in Bamako, especially during peak hours, the principle of alternating traffic was introduced in 2019. Under this alternating method, the main roads are one-way from 7:00 to 9:00 a.m. and again in the opposite direction between 4:00 and 7:00 p.m. Unfortunately, this solution does not yet seem to have produced significant results.

The Malian government has officially initiated the regulation of mototaxi services given the recent creation of new companies working in this sector (e.g., Teliman). The use of ICE two-wheelers for now seems unavoidable.

R3. REFERENCES

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[17] Yalcouye H.B. (2014) «Stratégie opérationnelles vision Bamako 2030. Dossier de contexte».

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[21] *https://plumelabs.com/*

[22] *https://ads.atmosphere.copernicus.eu/cdsapp#!/home*

[23] *https://perspective.usherbrooke.ca/*

[98] World Trade Organization (2017). Trade Policy review. Trade Policy Review Body.

4.

TYPES OF TWO- AND THREE-WHEELERS USED IN OUAGADOUGOU AND BAMAKO

Box 4.1: Key facts about two- and three-wheelers in Ouagadougou and Bamako

- Two-wheelers and three-wheelers are almost all imported in parts from China.
- The ICE two- and three-wheelers have four-stroke engines with power ranging from 110 cc to 250 cc.
- Some electric bicycles are used by young students in Ouagadougou.
- Non-electric bicycles are still used in both cities but are declining.
- The average life span of motorized two- and three-wheelers is 5-8 years.
- The supply chain for ICE two- and three-wheelers is well structured.
- According to dealers, buying an electric vehicle would not be difficult.

The ICE two- and three-wheeled vehicles used in the two cities are four-stroke petrol engine vehicles with power ranging from 110 cc to 250 cc, depending on the model. ICE three-wheelers are only used for private goods transport. Currently, there are no electric motorcycles, scooters, or tricycles in circulation.

In Ouagadougou, there are a few electrically powered bicycles that are mostly used by school-age youth (consulted stakeholders indicated this use as a "fad"). The use of non-electric bicycles exists but is declining.

In Bamako, e-bikes are not yet used. The use of non-electric bicycles has declined significantly in recent years. Bicycles were used primarily for freight delivery. With the advent of alternative, faster means of travel (especially motor tricycles), the bicycle delivery business is disappearing **[36]**.

Examples of two- and three-wheelers currently in use in Ouagadougou and Bamako are shown in Annex 2.

4.1. THE SUPPLY CHAIN

Currently, there is no production facility for two- and three-wheelers in either Burkina Faso or Mali. These vehicles are assembled locally with components imported from China. In Ouagadougou, there were ICE two-wheeler factories in the past but they had to close mainly because of strong competition from Asian vehicles.

The supply chain for two- and three-wheeled vehicles in Burkina Faso and Mali is highly structured from the purchase of the vehicles to the delivery of the products to the consumer. All stakeholders who were consulted indicated that purchasing an ICE two- or three-wheeler is not currently a problem.

There are several dealers ranging from large companies (e.g., Megamonde, Apsonic, Royal Moto, etc.) to small vendors in both Ouagadougou and Bamako. In general, ICE two- and three-wheelers are available in "semi-assembled" parts and vehicles are assembled at the time of purchase. Consumers generally do not wait for the vehicle to be delivered; it is picked up the same day as the purchase. Dealers also provide vehicle maintenance under warranty packages. If necessary, vehicle parts are changed but rarely repaired.

The dealers have constant relations and direct contacts with the manufacturers of two- and three-wheelers, almost all Chinese. The flow of spare parts from China to the two countries is quite constant; a large dealer, on average, transports about 50 containers of ICE two- and three-wheelers per year (a container has between 44 and 180 vehicles, depending on the type).

Containers are transported from the manufacturer's country to the dealer mainly by sea and land. The containers arrive primarily at the ports of Dakar and Abidjan. They are then transported to Ouagadougou and Bamako by truck. This transport method has a negative impact on air pollution since these are long distances -- about 1,000 km for Abidjan and 1,700 km for Dakar.

Currently, the only electric bicycles available on the market are pedal-assisted bicycles (only in Ouagadougou). The supply chain for these bicycles is similar to that of ICE two- and three-wheelers except that electric bicycles are not supplied with spare parts.

Other than e-Bikes, electric two- and three-wheelers are not yet available on the market In Bamako and Ouagadougou. Resellers who were consulted have limited knowledge of electric vehicles and said that suppliers in China have models on sale that could be ordered. The supply chain in this case would also be similar to that of ICE vehicles. Delivery times to the dealer would be about 3-4 weeks after the order is placed, using the same supply chain as ICE vehicles (with delivery as spare parts by container).

According to the consulted dealers, the assembly and maintenance of electric two- and three-wheelers should be similar to ICE vehicles. As long as the vehicles arrive in semi-detached parts, the assembly of parts or their substitution should remain quite simple. It is worth noting that none of the consulted dealers indicated that they had any previous experience or knowledge of electric vehicles.

R4. REFERENCES

[36] https://benbere.org/terre-dopportunites/livraison-velo-metier-voie-disparition-bamako/

5. DEVELOPMENT SCENARIOS FOR ELECTRIC MOBILITY OF TWO- AND THREE-WHEELERS

5.1. THE SUPPLY CHAIN

Box 5.1: Total Cost of Ownership

- The Total Cost of Ownership (TCO) of an electric bicycle is lower than that of other electric vehicles.
- In both Bamako and Ouagadougou, electric scooters have a lower TCO than ICE scooters.
- Electric motorcycles become less expensive than ICE motorcycles as their total mileage increases.
- Three-wheel electric passenger vehicles have similar total cost of ownership to their ICE counterparts.
- Three-wheelers for freight transport have a lower TCO than their ICE counterparts (but their technical performance is not comparable with that of ICE counterparts).

The Total Cost of Ownership (TCO) analysis considers all costs associated with the purchase, operation, and maintenance of vehicles over their lifetime. The TCO is a useful decision tool which can be used to identify the driving forces and barriers to electric transition and to design appropriate interventions. In particular, users can receive useful information on the overall cost of owning and operating a vehicle, which enhances their ability to make the right choices. Governments can also use elements of this information to design appropriate financial incentives. Finally, transport operators can assess the economic viability of their business choices with this information.

Below, a TCO analysis comparing electric and ICE two- and three-wheelers is presented for Bamako and Ouagadougou that considers the diversity of local conditions and checks how they affect the overall results. The structure of the analysis compares the electric and ICE versions of the following two- and three-wheelers which are representative of the types in use:

- Bicycles.
- Scooters/Mopeds.
- Motorcycles.
- Tricycles (transport of persons –tuk-tuk type).
- Tricycles (transport of freight – gasoline and diesel).

The TCO analysis considers the following costs:

- Vehicle purchase cost (D) including the loss of value of the vehicle over the years of ownership (residual resale value). In the analysis, the years of ownership in relation to the technical life of the vehicle were considered.
- Annual cost of vehicle insurance (AC).
- Annual and flat taxes (TA).
- Vehicle consumption (CO) (kWh or liters of fuel consumed by vehicles).
- Replacement cost of batteries exhausted during the considered life (CR).
- Additional battery for better range (CB). Cost of additional batteries for certain daily mileage that cannot be driven with the limited range of a single battery. The cost is included if drivers intend to swap batteries instead of recharging them or use battery swapping services. In the latter case, the cost is considered a proxy for the cost of the service.
- Maintenance costs (CM) (e.g., tire changes).

The formula used is as follows:

$$\sum_{t=1}^{5} (CAt + TAt + COt + CRt + CBt + CMt) + D$$

Note: *t* is the year of use.

Concerning the cost per km, the sum of the costs is divided by the total mileage accrued during the five years of use.

The analysis was conducted under conservative assumptions (i.e., unfavorable conditions for electric vehicles) including the following:

- The purchase of electric vehicles includes the purchase of batteries (systems such as battery leasing, which would reduce the cost, have not been considered)
- The absence of a secondary market and therefore a higher depreciation of electric vehicles compared with ICE vehicles
- The presence of the same level of taxes as ICE vehicles.

The main characteristics of the two- and three-wheelers under analysis and the assumptions of the analysis are summarized in Annex 3. Regarding three-wheelers for freight transport, it should be noted that there is not yet perfect comparability with ICE vehicles, as these electric vehicles have lower speeds and transport capacities.

The purchase prices are given as average values based on a market survey of available vehicles. The depreciation of the vehicles (linear over five years of useful life) has been estimated at 90 percent for ICE vehicles and 100 percent for electric vehicles (assuming the users own the vehicles until the end of their technical life). In addition, while there is a mature secondary market for ICE vehicles (which allows for the sale of spare parts, hence the 10 percent residual value), this is not the case for electric vehicles. As a matter of prudence, no residual value has been defined for these vehicles.

The vehicle market is essentially absent of financial operators, therefore no financial cost for the purchase of vehicles has been considered in this analysis. Most of the stakeholders who were consulted indicated that two- and three-wheelers are purchased without using financial credit and by paying the full amount directly.

As reliable data on annual maintenance costs for two-wheelers are not available, these costs were considered parametrically, calculated as 3 percent and 18 percent of the purchase value respectively for electric and ICE vehicles while taking as reference the values provided by UNEP.[11]

For ICE three-wheelers, the annual maintenance costs were provided in consultation with transport professionals. The costs for the electric version were assumed to be a percentage of those for the ICE version (32 percent), in line with what was observed on average for two-wheelers.

The cost of replacing the depleted battery in electric vehicles was also considered in the analysis; battery degradation was related to years of use, rather than km driven and charge cycles. It is assumed that the battery would be replaced at the end of the third year for electric bicycles and at the end of the fourth year for all other electric vehicles. In the absence of specific data, the cost of the battery was estimated to be equal to 25 percent of the purchase price of the vehicle.

For the analysis in Bamako, an annual insurance charge of about US$37 (CFAF 20,000) and US$54 (CFAF 29,300) was considered for two-wheelers (motorcycles and scooters) and three-wheelers respectively. An annual tax of US$3 (CFAF1,600) also exists for bicycles.

For the analysis in Ouagadougou, annual insurance of about US$54 (CFAF 29,300) was considered for three-wheelers, while no insurance is required for two-wheelers. Annual taxes for three-wheelers (including municipal tax, registration tax, technical inspections) are about US$83 (CFAF 45,000), while for two-wheelers (excluding e-bikes) they are about US$4 (CFAF 2,200). In addition, the flat fee is US$89 (CFAF 48,300) for three-wheelers (including compliance check, first technical inspection, registration) and US$36 (CFAF 19,500) for two-wheelers (including first technical inspection and registration).

The baseline scenario for the TCO analysis was developed assuming an average daily distance travelled of 25 km for all vehicles, corresponding to an annual mileage of 9,125 km (considering 365 days). Different mileage scenarios were also provided. The results of the analysis were expressed in undiscounted values although the use of discounted values does not alter the results of the analysis.

The results of the baseline scenario (Figure 5.1) show that electric two-wheelers and three-wheelers are competitive with ICE vehicles, although there

11 1E-MOB two-wheeler calculator 1.3

are small differences between the two cities. Three-wheel electric freight vehicles have lower costs than their ICE counterparts in both cities. However, these electric models have lower speeds and transport capacities. Electric three-wheelers for passenger transport and electric motorcycles are a cheaper alternative to their ICE counterparts in Ouagadougou. In contrast, they cost almost the same as ICE models in Bamako. Electric scooters are less expensive than ICE models in both cities. Among the electric vehicles, the bicycle is the cheapest.

The comparison between electric and ICE models is also reported in terms of their percentage cost differential (Figure 5.2).

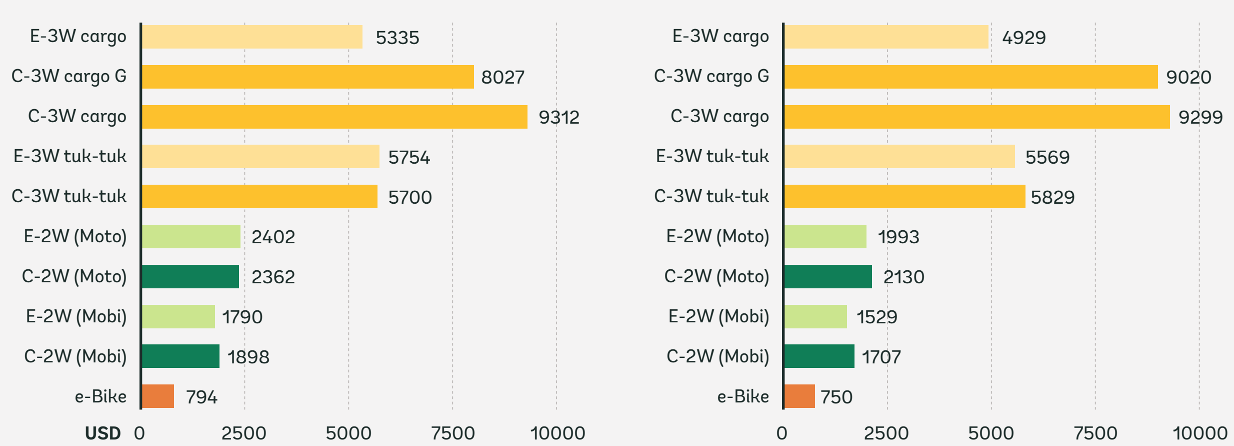
The breakdown of the TCO shows that the most important cost category for electric vehicles is purchase cost (including depreciation), while for ICE vehicles it is operational fuel consumption (Figure 5.3 and Figure 5.4).

In these figures, the cost of the additional battery is not shown; it is not necessary for the "baseline" because the mileage can be covered by one battery.

Electric bicycles are a very competitive alternative to scooters and motorcycles in terms of TCO given appropriate operating conditions (e.g., not used for freight transport).

Figure 5.1.

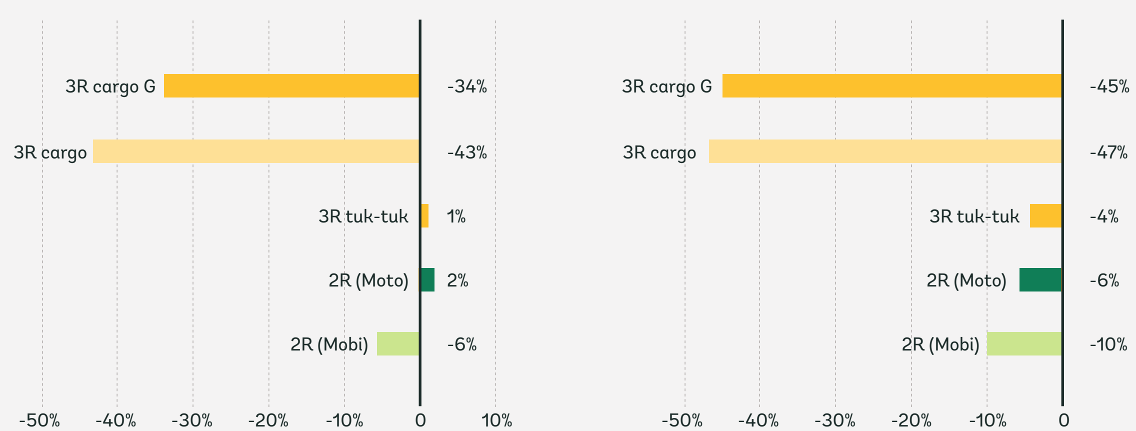
TCO in Bamako (left) and Ouagadougou (right) - baseline scenario[12]



Source: Authors

Figure 5.2.

TCO differential in Bamako (left) and Ouagadougou (right) - baseline scenario



Source: Authors

12 Meaning of acronyms used in the figures are given in Annex 3.

Figure 5.3.

TCO by category in Bamako - baseline scenario

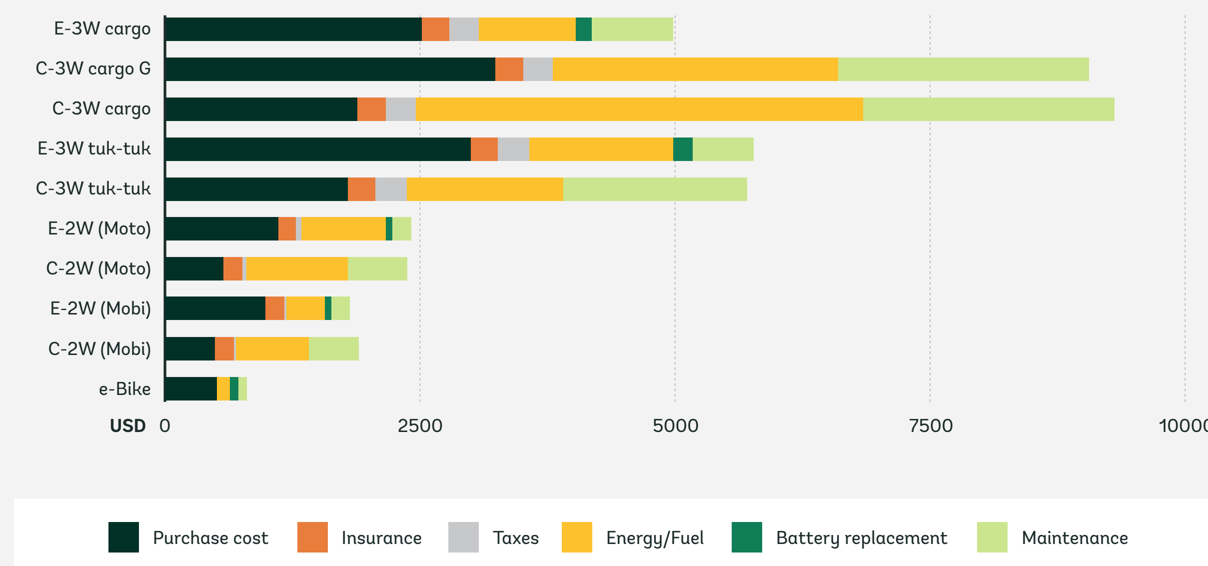
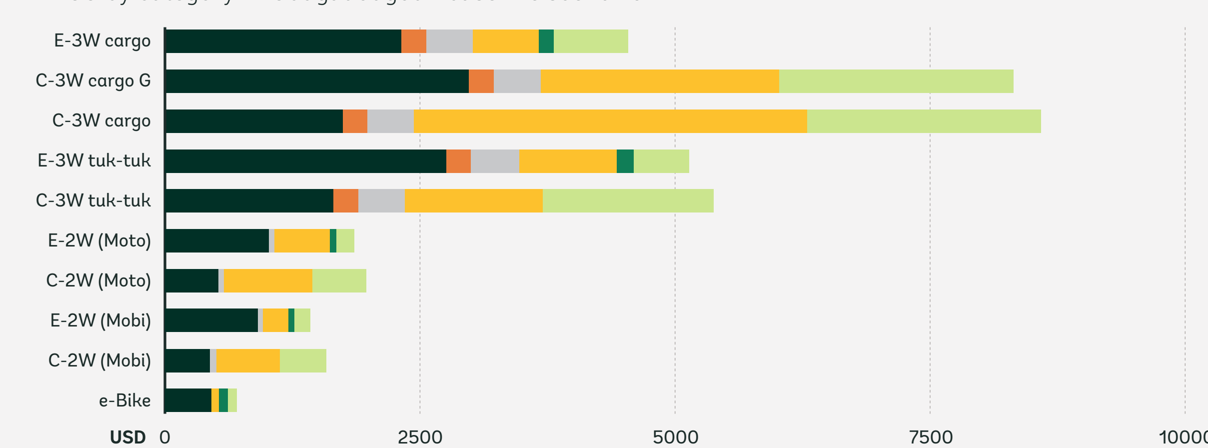


Figure 5.4.

TCO by category in Ouagadougou - baseline scenario



Source: Authors

A sensitivity analysis was conducted with respect to the baseline scenario by considering certain key assumptions and variables. The following four scenarios were analyzed:

- **Scenario a:** The lifetime of the vehicle is reduced from 5 to 3 years, to consider a higher degradation due to operational conditions (e.g., road infrastructure conditions). In this case, no battery replacement cost is considered for two-wheelers.
- **Scenario b:** The purchase price of electric vehicles increases by 25 percent.
- **Scenario c:** The energy consumption per km of electric vehicles increases by 25 percent (e.g., to consider an overload of the vehicles).
- **Scenario d:** The maintenance costs of electric vehicles increases by 25 percent.
- **Scenario e:** Taxes for electric vehicles are eliminated.

The results show that the reduction in lifetime (Scenario a) penalizes electric vehicles in both cities except for three-wheelers for goods transport (Figure 5.5). This is related to the higher impact of the purchase cost over the period of use and the concurrent lower impact of the economic benefits in terms of energy consumption.

The increase in the purchase price of electric two- and three-wheelers (Scenario b) also penalizes their TCO compared to their ICE counterparts.

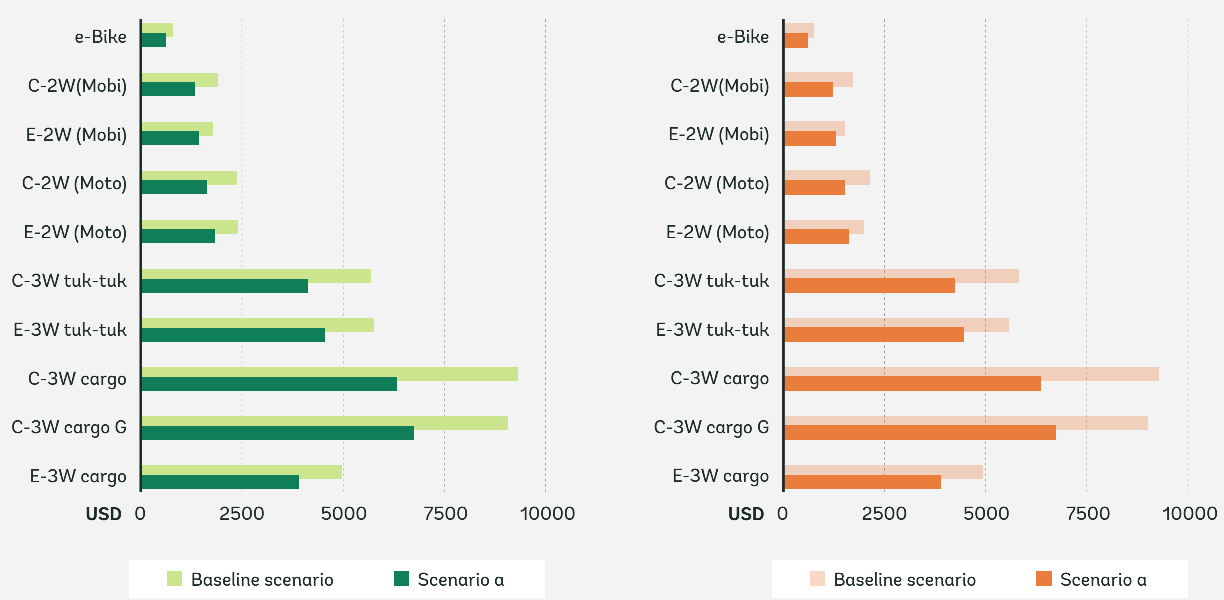
An increase in the maintenance costs of electric two- and three-wheelers (Scenario d), on the other hand, does not significantly change their TCO compared to the baseline scenario.

An increase in the energy consumption per kilometer of electric two- and three-wheelers (Scenario c) does not significantly change the TCO of electric scooters which continue to be cheaper than ICE models. The same rule applies to electric three-wheelers for freight transport. In Ouagadougou, the TCO of electric motorbikes and three-wheelers for passenger transport, compared to the baseline scenario, is similar to that of ICE vehicles (Figure 5.6).

The elimination of the current taxes for electric vehicles (Scenario e) does not affect the cost-effectiveness of electric and ICE models in Ouagadougou. In Bamako, on the other hand, these tax incentives make electric motorcycle and electric tuk-tuk more convenient to purchase than their ICE counterparts.

Figure 5.5.

TCO in Bamako (left) and Ouagadougou (right) - Scenario a



Source: Authors

TCO analysis for electric vehicles also takes into consideration different annual mileage scenarios that are compared to the baseline scenario of 9,125 km per year (25 km per day) while assuming a vehicle lifetime of 5 years. With increasing annual mileage, the TCO decreases and electric scooters and three-wheelers for freight transport become progressively more attractive than their ICE counterparts. The results show that electric transition could be profitable for vehicles used for both private and professional purposes. A few exceptions in Bamako may include motorcycles and three-wheelers used in passenger transport based on their specific annual mileages. Details of these sensitivity analyses are provided in Annex 3.

5.2. USER VIEWS ON ELECTRIC MOBILITY

Online questionnaires were used in Bamako and Ouagadougou to collect opinions on electric two- and three-wheelers from end users. These opinions have no statistical value, as the small sample of respondents is not necessarily representative of the population in each city. Nevertheless, these opinions are useful to get a first glimpse of the level of knowledge people have about electric mobility and to get some preliminary indication of potential interest and challenges.

In Bamako, 31 people responded to the questionnaire (15 men and 14 women). Most respondents were in the 25-44 age group, followed by the 18-24 age group. Most reported having a university education.

In Ouagadougou, 93 people responded to the questionnaire (72 men and 19 women). Most respondents were in the 25-44 age group, followed by the 45-64 age group. Most reported having a university education.

The main take-away messages from this survey are summarized in Table 2.1 for both cities (more information is provided in Annex 4).

Figure 5.6.

TCO in Bamako (left) and Ouagadougou (right) - Scenario c

Source: Authors

Table 5.1.

Summary of user's views about eMobility in Bamako and Ouagadougou.

BAMAKO	OUAGADOUGOU
About half of the users think that the most polluting mode of transport is the truck. Less than 10 percent of people think that motorcycles are the most polluting. This perception is more pronounced among young people under 25 (about 62 percent think trucks are more polluting and none think ICE two-wheelers are polluting). More women than men think that trucks are the most polluting mode of transportation. This is a misperception considering that the information on pollutant emissions indicates that ICE two-wheelers are the most polluting mode of transportation.	Most respondents to the questionnaire believe that trucks are the main cause of air pollution. Motorcycles and mopeds are also considered polluting by about 40 percent of people. This perception of trucks is most common among people between the ages of 25 and 44. Young people under 25 and people between the ages of 45 and 65 tend to perceive motorcycles as more polluting. There are no significant differences between men's and women's perceptions on this topic. Emissions data indicate that ICE two-wheelers are the main contributors to air pollution.
More than 60 percent of the respondents think that the battery life of an electric two- or three-wheeler would not be sufficient for their trips. Men are more concerned about battery life than women (46 percent of women think the battery would be sufficient). No one over the age of 44 thinks the battery would be sufficient for their travel. This indicates a lack of knowledge about battery life (batteries can reach 80 km for scooters and motorcycles).	More than 60 percent of respondents think that the battery life of an electric two- or three-wheeler would not be sufficient for their travel. This perception is more pronounced among women (89 percent think that the battery would not be sufficient) than among men. All young people between 18 and 24 years old think that the battery would be sufficient. This indicates a lack of knowledge about battery life (batteries can reach 80 km for scooters and motorcycles).
About 80 percent of respondents think that buying an electric two- or three-wheeler is not easy in Bamako. In addition, they think that the purchase cost would not be similar. Half of the people between 45- and 65-years-old think that it is easy to buy an electric two- or three-wheeler in Bamako. The perception of difficulty in purchasing is higher among men. There are no significant differences in opinion by gender or age regarding the cost of purchase. These are not entirely correct perceptions. According to the consulted dealers, importing and purchasing an electric vehicle is no more difficult than purchasing an internal combustion vehicle. The perceptions on the purchase cost are fairly correct, but also indicate a lack of knowledge on the total cost of ownership.	About 80 percent of respondents believe that buying an electric two- or three-wheeler would not be in Ouagadougou and think that the purchase cost would not be similar. The difficulty of purchase is mostly perceived by people between 25- and 44-years-old, while there are no differences in opinion between men and women. The opinion about higher purchase costs is more important among women (95 percent) and people over 45-years-old (96 percent) These are not entirely correct perceptions. According to the dealers consulted, importing and purchasing an electric vehicle is not more difficult than purchasing an internal combustion vehicle. Perceptions about the cost of purchase are fairly correct, but also indicate a lack of knowledge about the total cost of ownership.
Bicycles are the least indicated mode of transportation to begin electric mobility, especially for men and for those over the age of 24. In addition, those who indicated this preference do not find it easy to use the electric vehicle in Bamako. This could mean that, with electric motorcycles available on the market, purchase choices could be influenced by this negative perception and thus move toward ICE models.	More than one in five people think that electric mobility could start with bicycles, and this idea is more common among men (21 percent) than women (17 percent). No one under the age of 24 and no one over the age of 65 would introduce electric mobility with bicycles. This may be due to the current presence of pedal-assist bicycles (these vehicles are somewhat familiar). However, three-quarters of those who selected this vehicle as a primary initiator of electric mobility do not fully agree on its ease of use.
Just under a quarter of the respondents think that tricycles should be the first choice, with a stronger propensity towards passenger transport. There are no significant differences between men and women on this topic. However, no one between the ages of 45 and 64 would introduce electric mobility with this mode of transportation. This mode of transportation would be, according to the respondents, quite easy to use.	Tricycles would be the mode of transport to start with for less than 10 percent of respondents, whether for transporting people or goods. People over 65 would be especially likely to introduce electric mobility with tricycles. No women thought it would be the best mode to start with. The ease of use of tricycles is perceived rather positively for passenger transport and, on the contrary, rather negatively for freight transport.
Almost 25 percent of respondents think that electric mototaxis should be the first mode of transport to start. Indeed, this seems to be consistent with the current development (since a few years) of mototaxis. However, this concerns only people under 45 years old. No older person would start with an electric mototaxi. Women are more likely than men to introduce electric mobility with this mode of transport (31 percent versus 13 percent of men). About 60 percent of those who would introduce electric mobility with this mode of transportation, however, believe it would not be easy to use.	About 13 percent of respondents would introduce electric mobility with mototaxi. This percentage, although quite low, is notable due to the fact that mototaxis in Ouagadougou are prohibited. This may indicate a perceived need for this mode of transport by some users. Women are more likely than men to introduce electric mobility through the use of this mode of transport (22 percent versus 10 percent of men). People over 65 years old are more interested in this mode of transport. No young people under 24 years of age would begin the introduction of electric mobility with the electric mototaxi. About half of the people oriented towards this mode of transport believe it would be easy to use.
About half of the respondents would introduce electric mobility with privately used two-wheelers. However, about 33 percent believe that motorcycles are more suitable. This is especially true for men (47 percent compared to 15 percent of women). All people between the ages of 45 and 64 would introduce electric mobility with the motorcycle. This opinion, however, is not consistent with the motorcycle's perceived ease of use or lack thereof. About half of the people do not fully agree on the motorcycle's ease of use. On the contrary, mopeds are perceived by most people as more usable than motorcycles.	About 56 percent of the respondents would introduce electric mobility with privately used motorcycles. However, most would start the process with mopeds. This could indicate a basic knowledge of the longer battery life of these vehicles (compared to motorcycles). More simply, it could be related to the mobility conditions of the city. Indeed, mopeds are also perceived to be more usable than motorcycles. All young people under 24 years of age would introduce electric mobility with this mode of transport (motorcycle or moped). There are no significant differences between men and women.

5.3. LIFE CYCLE ANALYSIS

Box 5.2: Key facts about the life cycle of electric vehicles

- Electric two- and three-wheelers have a lower impact on CO_2 emissions than an equal number of ICE two- and three-wheelers.
- The production of electric scooters has a 20 percent greater environmental impact than the production of an ICE scooter, but also 14 percent less of an environmental impact than the production of an ICE motorcycle.
- In use, electric scooters have an environmental impact that is 83 percent lower in Bamako and 78 percent lower in Ouagadougou than ICE scooters.
- An electric scooter consumes 40 percent less energy than an ICE scooter.
- An electric motorcycle consumes between 19 percent and 23 percent less energy than an ICE motorcycle.
- An electric tricycle consumes between 5 percent and 10 percent less energy than an ICE tricycle.

The Life-Cycle Assessment (LCA) aims to answer questions about the environmental sustainability of a new strategy (e.g., the use of two- and three-wheel electric vehicles).

The methodology used for LCA is based on the ISO 14040 series of standards which consists of four phases (Figure 5.8):

- Definition of the objective and scope
- Analysis of the resources used to manufacture the product
- Evaluation of the impacts
- Interpretation of the results.

The scope of the LCA for this study focuses on two-wheelers (bicycles, scooters, motorcycles) and three-wheelers (both ICE and electric) for the mobility of people or goods.

Both emissions of pollutants and energy consumption were analyzed for the following vehicle life cycle stages: production, use, maintenance, and recycling.

The following two "cycles" are given consideration in this study:

"Fuel cycle":

- Well-to-Tank (WTT) (i.e., extraction, production, and transportation of raw materials, as well as refining, production and distribution of gasoline and electricity).
- Tank-to-Wheel (TTW) which is the gasoline or electricity used by vehicles in the use phase.

"Vehicle Cycle":

- Production of raw materials and vehicle assembly (e.g., body, traction, battery, fluids).
- Transportation of the vehicle from the production site to the place of use.
- Use (maintenance of the vehicle throughout its life - fuel consumption is considered in the TTW phase).
- End-of-life (disposal of the vehicle and battery).

The LCA was performed in consideration of the fact that Ouagadougou and Bamako are mainly flat cities, which favor the penetration of electric vehicles. The poor quality of the roads were also taken into consideration when calculating the higher fuel or energy consumption compared to normal conditions and a reduced vehicle life.

In order to perform the Life Cycle Analysis, assumptions must be made about vehicle characteristics such as engine type, battery, vehicle use, and end-of-life (vehicle and battery). The assumptions are described in Annex 5.

The life cycle analysis was conducted according to the scheme shown in Figure 5.9[13], where the raw and recycled materials are considered the starting point in obtaining the final product. Manufacturing is the second phase of a vehicle's life cycle and takes into consideration the energy and water needed for production. Assuming that the vehicles (or parts) are manufactured outside the country where they are used (in this case Burkina Faso and Mali), the environmental impact of transporting these vehicles to their destination (Ouagadougou and Bamako) is then analyzed. When the vehicle arrives at its destination, a phase begins in which the environmental impacts are analyzed in relation to the use of the vehicle, its degree of maintenance and the charging and discharging of the battery. Finally, the environmental impacts caused by the end-of-life of the vehicle and the battery are analyzed by estimating the amount of energy it takes to recycle these materials.

The life cycle analysis also considered the energy mix of the two countries, which affects the environmental impact and energy consumption caused by electric vehicles during their use. In Burkina Faso, most of the electrical energy is produced by fossil fuels (about 84 percent) and the rest is produced by renewable energy. In Mali, about 53 percent of electrical energy is produced by fossil fuels and the rest by renewable sources.

13 The figure shows the life cycle of any vehicle using a car as an example. However, it is also valid for the life cycle of a two-wheeler or three-wheeler.

Figure 5.7

Life Cycle Assessment

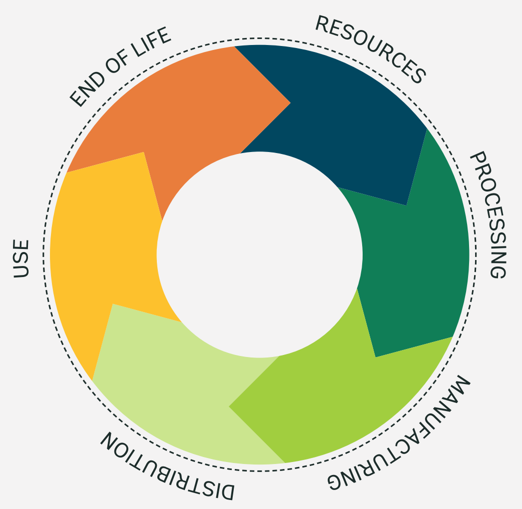


Figure 5.8

Main LCA phases

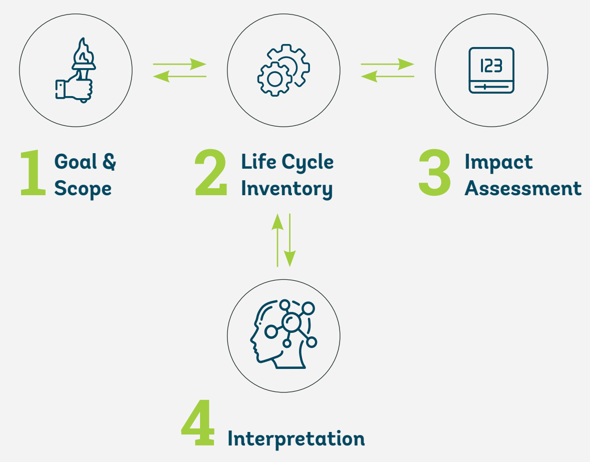
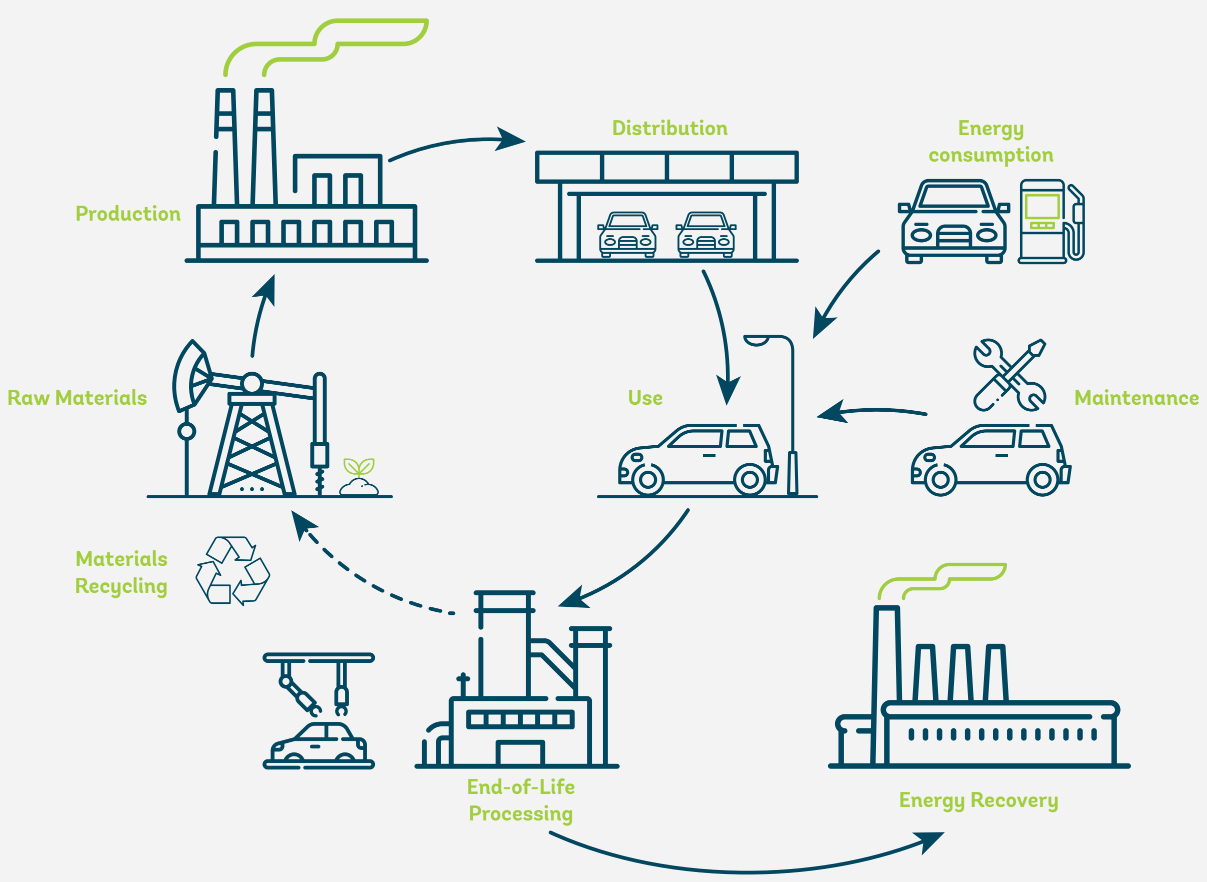


Figure 5.9

Schema of life cycle of a vehicle



5.3.1. ENVIRONMENTAL IMPACTS

One of the main environmental impact indicators concerns a value associated with global warming that is assigned according to a type of vehicle depending on the amount of CO_2 equivalent emitted per km driven.[14]

Environmental impacts are assessed without separating the "fuel cycle" and the "vehicle cycle." Therefore, environmental impacts of the "fuel cycle" in the Well-to-Tank (WTT) and Tank-to-Wheel (TTW) phases are not explicitly separated between the production and transport phase and the use phase of the gasoline or electricity that is consumed.

Figure 5.10 indicates the emissions from the well to the wheels (WTW)[15] by comparing CO_2 emissions for various vehicles in Bamako and Ouagadougou. The global warming impact is the same in Bamako and Ouagadougou for all ICE vehicles. In the case of electrically powered vehicles, the different energy mixes of the two cities have a significant influence on the results.

The global warming impact when considering the same type of vehicle (e.g., ICE motorcycle vs. electric motorcycle) is always lower in electric vehicles. This is not the case when comparing different types of vehicles (e.g., electric tricycles have a similar environmental impact compared to ICE motorcycles and a higher environmental impact than scooters and electric bicycles).

Non-electric bicycles also have an impact on global warming (albeit quite limited) because of their production, transportation from the production site to Bamako or Ouagadougou, daily use, and end-of-life.

ENVIRONMENTAL IMPACTS BY LIFE-CYCLE PHASES

Figure 5.12 illustrates the environmental impacts in Bamako and Ouagadougou, respectively, according to the four phases of the analysis (production, transport, use, and end-of-life).

The impact of the **production** phase was assessed using international studies as a reference **[24][25][26][27][28][29][30][31]**. This indicator is highly dependent on where the vehicle is manufactured. Most of the ICE two- and three-wheelers imported into Burkina Faso and Mali are manufactured in China, and electric vehicles and bicycles are also widely manufactured in China.

In the production phase, electrically powered vehicles generally have a higher impact on emissions than their ICE counterparts. The production of electric scooters has a 20 percent higher environmental impact than the production of an ICE scooter, but also has a 14 percent lower impact than the production of an internal combustion motorcycle.

The same environmental impacts are calculated for Bamako and for Ouagadougou since the same vehicles and the same production sites are involved.

Calculation of the **transport** impact first took into consideration that the vehicles are transported by boat (container) to the main African port of Dakar. The containers are then transported by truck to Bamako or Ouagadougou. General calculations for trucks were based on an internal combustion engine running on diesel with a low emission class (i.e., very polluting). For this study, an average truck carries a container with 44 tricycles or 120 scooters/motorbikes or 180 bicycles.

The transport phase does not show significant differences in environmental impact between Bamako and Ouagadougou, although the distances for the trucking phase (after the containers arrive at the port of Dakar) are not the same.

The environmental impact of the transport phase for electric vehicles is somewhat higher than that of ICE vehicles due to the heavier weight of electric vehicles compared to their ICE counterparts.

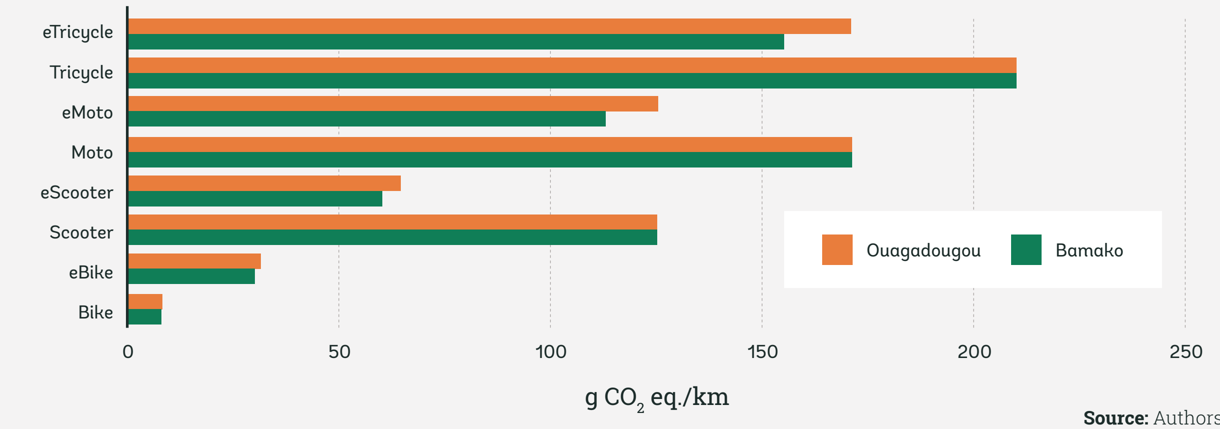
The third aspect included in the analysis is the environmental impact caused by the **use** of the vehicle which is much greater in ICE vehicles

14 It is the sum of greenhouse gas emissions (CO2, N2O, CH4 and VOC) multiplied by their global warming potential.

15 The well-to-wheels phase is also indicated with the acronym WTW.

Figure 5.10.

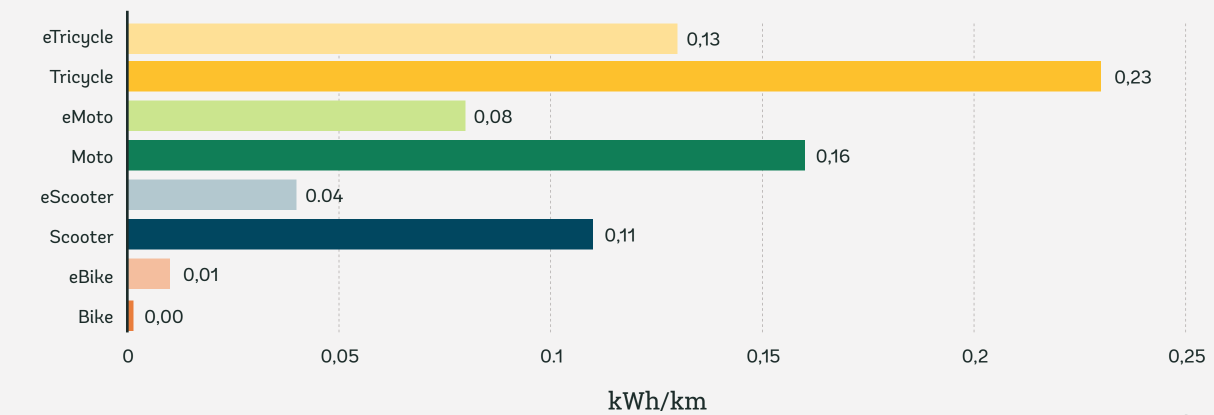
Comparison of total CO_2 equivalent emissions



Source: Authors

Figure 5.11.

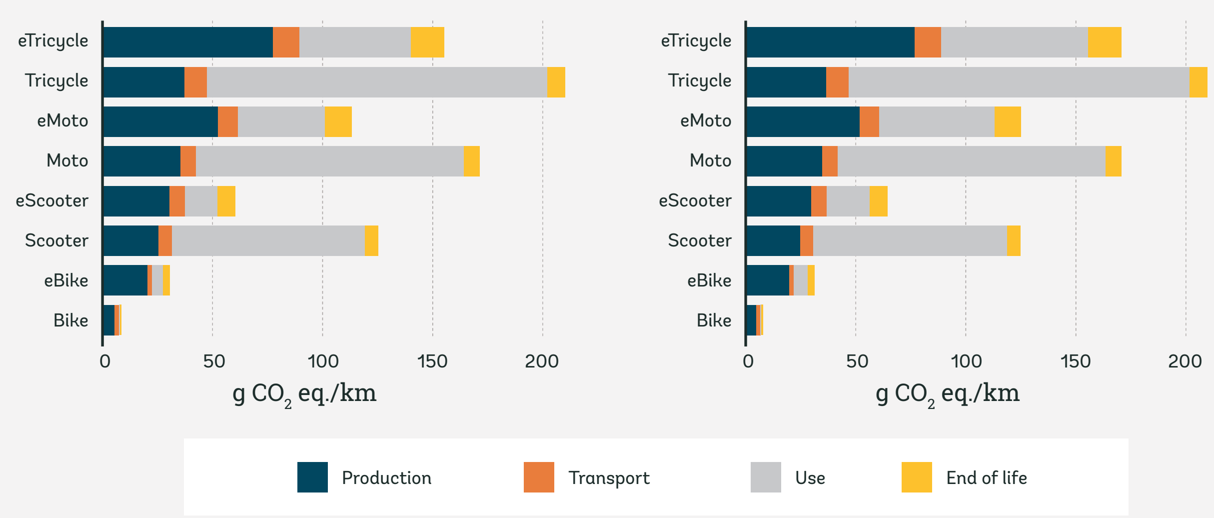
Tank-to-wheel energy requirements by vehicle type



Source: Authors

Figure 5.12.

Equivalent CO_2 Emissions by Life Cycle Phase in Bamako (left) and Ouagadougou (right)



Source: Authors

compared to their electric powered counterparts. In addition, electric vehicles do not have a negligible impact on the environment because the energy mix of both countries is derived in part from fossil energy sources.

The environmental impacts during the use phase are related to the energy needs of the vehicles.

Figure 5.11 shows the energy requirements of two-wheelers and three-wheelers in the use phase also known as Tank-to-Wheel.[16] There are significantly greater energy requirements for ICE vehicles than their electric counterparts. Since this analysis takes into account the energy requirements during the use phase, the lower efficiency of ICE vehicles accounts for much of their higher energy demand. This disadvantage is partially offset by the lower average weight of ICE vehicles compared to electric vehicles and their heavy battery weight.

The use phase accounts for the greatest difference in environmental impact between electric and ICE vehicles and the consistently lower impact for electric vehicles.

In Bamako, electric scooters have an impact on CO_2 equivalent emissions that is 83 percent lower than ICE scooters. Electric motorcycles and tricycles reduce CO_2 equivalent emissions by 67 percent compared to their ICE counterparts. In addition, the use of electric tricycles has a 42 percent lower environmental impact compared to an ICE scooter in terms of CO2 equivalent emissions.

In Ouagadougou, the environmental benefits of electric mobility during the use phase are less significant than in Bamako. In any case, electric scooters have a 78 percent lower environmental impact on CO_2 equivalent emissions than ICE scooters. Electric motorcycles and tricycles reduce emissions of CO_2 equivalent by 57 percent compared to their ICE counterparts. In Ouagadougou, the use of electric tricycles causes a 24 percent lower environmental impact in terms of CO_2 equivalent emissions compared to an ICE scooter.

Moreover, electric two- and three-wheelers produce zero tailpipe emissions in the use phase of the vehicle, which is a significant advantage given the acute problem of air pollution in Bamako and Ouagadougou. Emissions may be produced, however, by the source of electrical power such as a power plant. In cities, on the other hand, there are generally more people exposed to tailpipe emissions from ICE vehicles than to polluting emissions from power plants.

Given the poor road conditions in Bamako and Ouagadougou and the high wear and tear that vehicles face, the **end-of-life** impact also plays an important role in this analysis. Consideration was also given to the logistical and industrial difficulties in fully recycling the materials that comprise vehicles and their batteries.

The environmental impact caused by the end-of-life of vehicles and batteries is higher for electric vehicles than for ICE vehicles due to the batteries that require a more complicated recycling process. Consideration was given in this analysis to the fact that recycling of batteries is not done locally.

The environmental impact in this case increases with the size of the battery and therefore the vehicle. The impact is 88 percent higher for electric tricycles than for ICE tricycles. The end-of-life impact of electric scooters is 33 percent higher than for ICE scooters.

The end-of-life impact in Bamako and Ouagadougou are the same.

Electric bicycles have three times as much environmental impact than non-electric bicycles during the production phase, nine times as much impact during the use phase, and five times as much impact during the end-of-life phase. The impact in the transportation phase, however, is almost the same.

16 The tank to wheel phase is also indicated with the acronym TTW.

ENVIRONMENTAL IMPACTS BY COMPONENTS

Environmental impacts were analyzed according to six major components including climate change,[17] fossil fuel depletion, human toxicity, metal depletion, particulate matter, and photochemical oxidant formation.

The impacts on the components under consideration are shown in Figure 5.13 as a relative value to the worst- case scenario. All values are normalized in relation to the 100 percent designation represented by the vehicle with the greatest environmental impact for all the different components (that is to say, the ICE tricycle).

The data were divided into different chemical components such as photochemical oxidant formation potential (PFO) which includes alkanes, halogenated hydrocarbons, alcohols, ketones, esters, ethers, olefins, acetylene, aromatics, and aldehydes.

Human toxicity is calculated by compiling the releases that are toxic to humans in air, water, and soil.

Abiotic resource depletion includes the depletion of non-renewable resources such as fossil fuels and metals. In Figure 5.13, this indicator is separated to highlight fossil fuel depletion and metal depletion.

Motorized two- and three-wheelers all have a lower impact on these components than their ICE counterparts. Only the non-electric bicycle has a lower (and rather negligible) impact. E-bikes also have a low impact on all six components of climate change, fossil fuel depletion, human toxicity, metal depletion, particulate matter, and photochemical oxidant formation.

After comparing the same types of vehicles (e.g., electric scooters vs. ICE scooters), the following observations stand out:

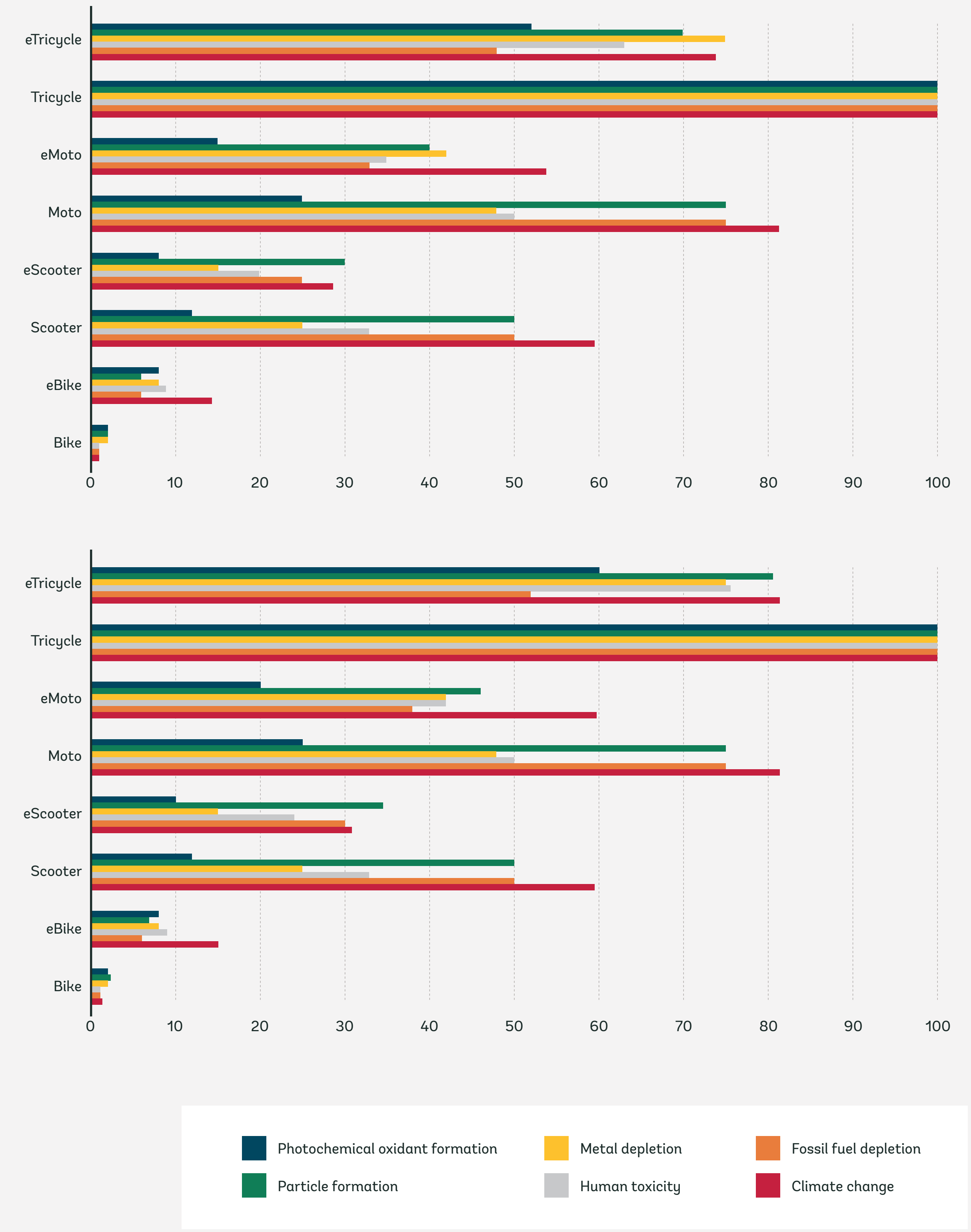
- The greater positive impact on climate change is achieved by switching from an ICE scooter to an electric scooter (resulting in a 52 percent reduction in Bamako and a 48 percent reduction in Ouagadougou).
- The greater positive impact on fossil fuel depletion is achieved by switching from an ICE motorcycle to an electric motorcycle (resulting in a 56 percent reduction in Bamako and a 49 percent reduction in Ouagadougou).
- The greater positive impact on human toxicity is achieved by switching from an ICE scooter to an electric scooter (resulting in a 39 percent reduction in Bamako and a 27 percent reduction in Ouagadougou).
- The greater positive impact on metal depletion is obtained by switching from an ICE scooter to an electric scooter (resulting in a 40 percent reduction in both Bamako and Ouagadougou). Although the batteries in electric vehicles are mainly composed of metals, the mechanical parts of electric motors are smaller than those of ice engines. This causes less metal depletion for electric vehicles, especially for smaller batteries such as those in electric scooters.
- The greater positive impact on particulate matter formation is obtained by switching from an ICE motorcycle to an electric motorcycle (resulting in a 47 percent reduction in Bamako and a 39 percent reduction in Ouagadougou).
- The greater positive impact on photochemical oxidant formation is achieved by switching from an ICE cycle to an electric cycle (resulting in a 48 percent reduction in Bamako and a 40 percent reduction in Ouagadougou).

The benefits of electric vehicles relative to their ICE counterparts are consistently higher in Bamako than in Ouagadougou. This is due to the energy mix for power generation in Bamako being more oriented to the use of renewable sources than Ouagadougou.

17 Climate change is defined as a sustained change in the statistical parameters of the Earth's global climate or its various regional climates, due to external influences and human activities.

Figure 5.13.

Relative impacts by component in Bamako (top) and Ouagadougou (bottom)



Source: Authors

SENSITIVITY ANALYSIS BY ENERGY MIX

A different energy mix for production of electricity can influence the equivalent CO_2 emissions of electric vehicles. A sensitivity analysis has been performed to estimate which benefits could be obtained by improving the energy mix. This is especially relevant for Ouagadougou where the electricity produced from renewable sources is currently just 17 percent of the total electricity production. In Bamako, renewable sources are currently used to produce 47 percent of the electricity.

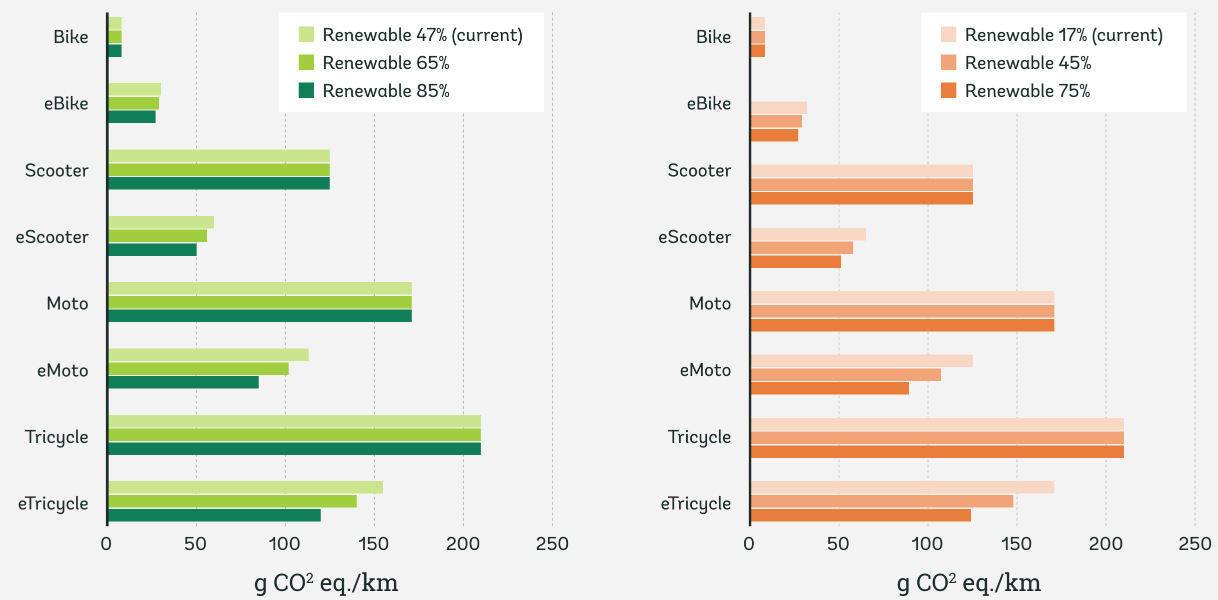
Figure 5.14 shows the changes in equivalent CO2 emissions when the percentage of renewable sources is increased. ICE vehicles in the figure are identified only with one bar since their emissions are not influenced by the energy mix. The analysis shows how the use of renewable sources would affect equivalent CO_2 emissions in Bamako and in Ouagadougou.

In Bamako, an increase in the use of renewable sources to 65 percent would lead to a reduction of equivalent CO_2 for electric two- and three-wheelers ranging from 5 percent for electric bicycles to 10 percent for electric motorcycles. An increase of 85 percent would lead to a reduction of equivalent CO_2 for electric two- and three-wheelers ranging from 12 percent for electric bicycles to 25 percent for electric motorcycles. It should be noted that reduction of equivalent CO2 for electric three-wheelers, in Bamako, is lower than that of electric motorcycles.

In Ouagadougou, an increase in the use of renewable sources to 45 percent of total production would lead to a reduction of equivalent CO_2 for electric two- and three-wheelers ranging from 7 percent for electric bicycles to 14 percent for electric motorcycles and electric tricycles. Increasing the use of renewable sources to 75 percent of electricity production would lead to a reduction of equivalent CO_2 emissions for electric two- and three-wheelers ranging from 15 percent for electric bicycles to 29 percent for electric motorcycles.

Figure 5.14

Equivalent CO_2 emissions by percentage of renewable sources in Bamako (left) and Ouagadougou (right)



Source: Authors

5.3.2. IMPACTS ON ENERGY CONSUMPTION

To calculate the impacts of two- and three-wheelers on energy consumption, the "fuel cycle" and the "vehicle cycle" are taken into consideration.

The "fuel cycle" concerns both the extraction, production, and transport (Well-to-Tank or WTT phase) and the use (Tank-to-Wheel or TTW phase) of petrol (in the case of ICE two- and three-wheelers) and electricity (in the case of electric two- and three-wheelers).

Fuel consumption during the WTT phase depends on the primary energy resource (e.g., coal, liquefied gasoline, and natural gas) required to produce the user end-product of gasoline or electricity, as well as the conversion efficiency of the primary energy resource, the proportion of fuel consumption in the various production processes, and the distance the primary energy is transported. This fuel consumption changes depending on the energy mix used to produce the energy product.

For the TTW phase, the energy requirements for two-wheel and three-wheel vehicles are shown in Figure 5.11.

Figure 5.15 shows the energy consumption during the life cycle phases; the "fuel cycle" is indicated by the term "energy" while the use phase during the "vehicle cycle" is indicated by the term "maintenance."

In both Bamako and Ouagadougou, the "fuel cycle" has the greatest impact on energy consumption. In the case of ICE vehicles, the WTT and TTW phases account for more than 90 percent of total energy consumption. In the case of motorized two- and three-wheelers, the impact of the WTT and TTW phases on energy consumption are less important (about 80 percent of the total).

In the case of non-electric bicycles, the production phase has the greatest impact on energy consumption. The total impact on energy consumption of non-electric bicycles is very small.

Electric two- and three-wheelers generally have a lower impact on energy consumption than ICE two- and three-wheelers. The greatest environmental gain is obtained by switching from an ICE scooter to an electric scooter, resulting in 41 percent and 42 percent less energy consumption in Ouagadougou and Bamako, respectively. Compared to the ICE tricycle, its electric counterpart reduces energy consumption by 5 percent in Ouagadougou and 10 percent in Bamako. The electric motorcycle reduces energy consumption by 19 percent in Ouagadougou and 23 percent in Bamako compared to its ICE counterpart.

Energy consumption (fossil and non-fossil) for all vehicles is lower in Bamako than in Ouagadougou due to the country's better energy mix in terms of use of renewable sources.

Since the "fuel cycle" has the greatest impact on energy consumption, a further analysis is presented in Figure 5.16 by separating the WTT and TTW phases of the "fuel cycle" and adding the phases of the "vehicle cycle" together.

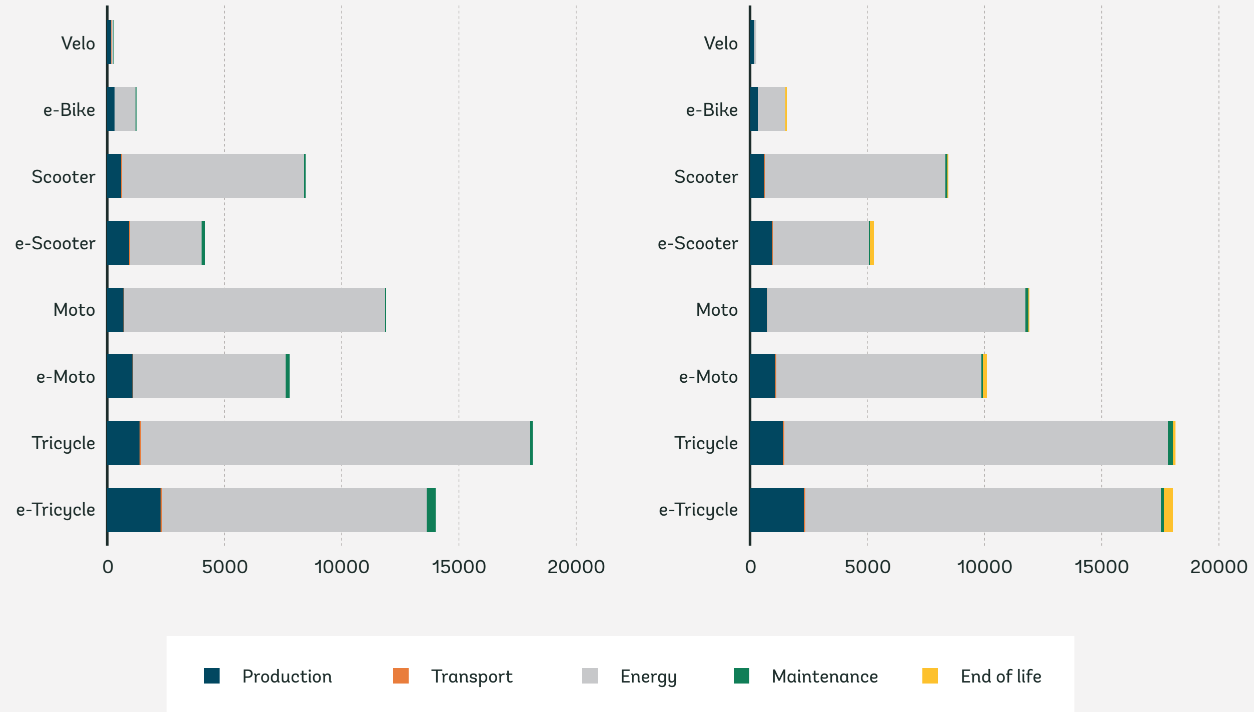
In the case of electrically powered two- and three-wheelers, the WTT phase has a greater impact on energy consumption compared to the TTW phase. In the case of ICE vehicles, the impact on energy consumption of the WTT and TTW phases is more balanced.

In both Ouagadougou and Bamako, the TTW phase of motorized electric two- and three-wheelers consumes less energy than their ICE counterparts.

During the WTT stage, the energy consumption of motorized electric two- and three-wheelers is not always better than that of ICE vehicles. In Ouagadougou, due to low use of renewable sources to produce electricity, electric motorcycle and electric tricycles consume more energy during the WTT phase than their ICE counterparts.

Figure 5.15.

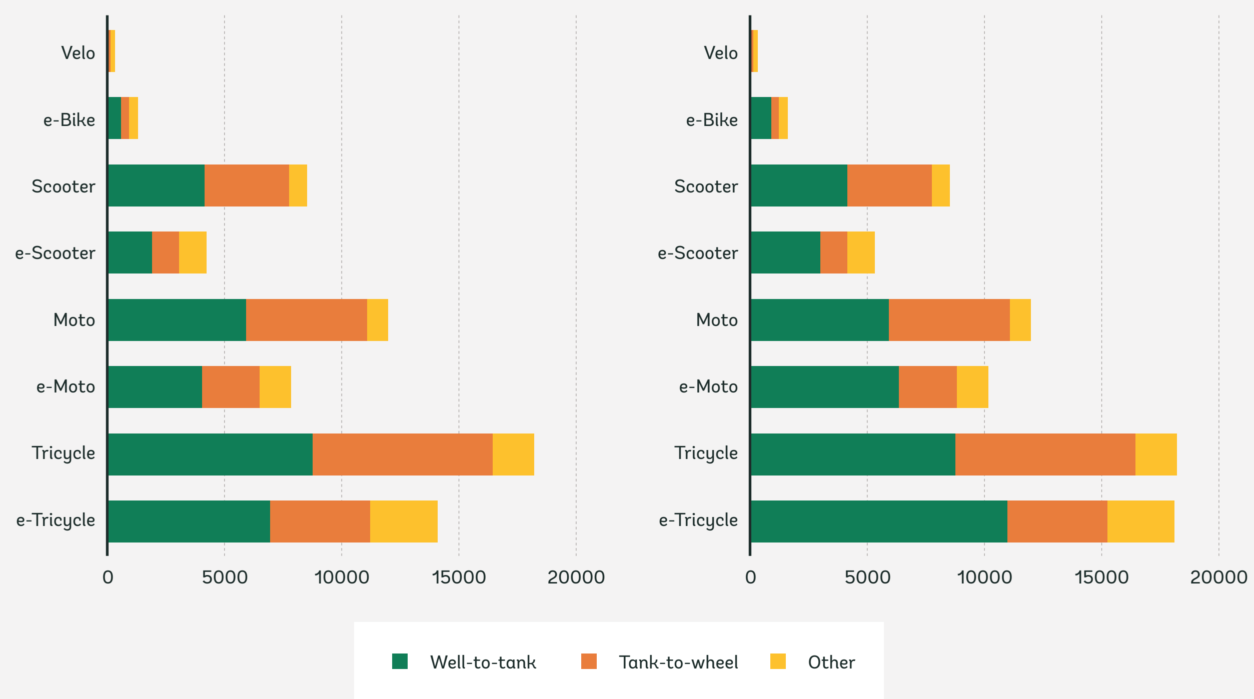
Energy consumption by life cycle phase in Bamako (left) and Ouagadougou (right)



Source: Authors

Figure 5.16.

Energy consumption in Bamako (left) and Ouagadougou (right)



Source: Authors

5.4. POTENTIAL ENERGY IMPACTS IN THE USE PHASE

Box 5.3: Key facts about energy impacts in the use phase

- Changing 5 percent of current two- and three-wheelers to electric models in Bamako and Ouagadougou would consume 1.3 percent (Mali) and 6.9 percent (Burkina Faso) of their respective country's electricity production.
- Changing 70 percent of current two- and three-wheelers to electric models in Bamako and Ouagadougou would consume 19.5 percent (Mali) and 82 percent (Burkina Faso) of their respective country's electricity production.
- A large increase in electricity production from renewable sources at the national level is needed to introduce a high number of electric vehicles.

5.4.1. SHORT-TERM SCENARIO

A calculation indicating the electricity consumption of electric two- and three-wheelers in the use phase (local consumption) according to a scenario with few vehicles in circulation is shown in Figure 5.17. For this calculation, 50 vehicles per type were analyzed with the assumption that they each travel 25 km per day. This scenario could correspond to a short-term pilot project.

The electricity consumption of the 200 electric vehicles in circulation was only about 114 MWh per year. This amounts to only about 0.06 percent of the annual electricity production in Mali and 0.07 percent of the annual electricity production in Burkina Faso.

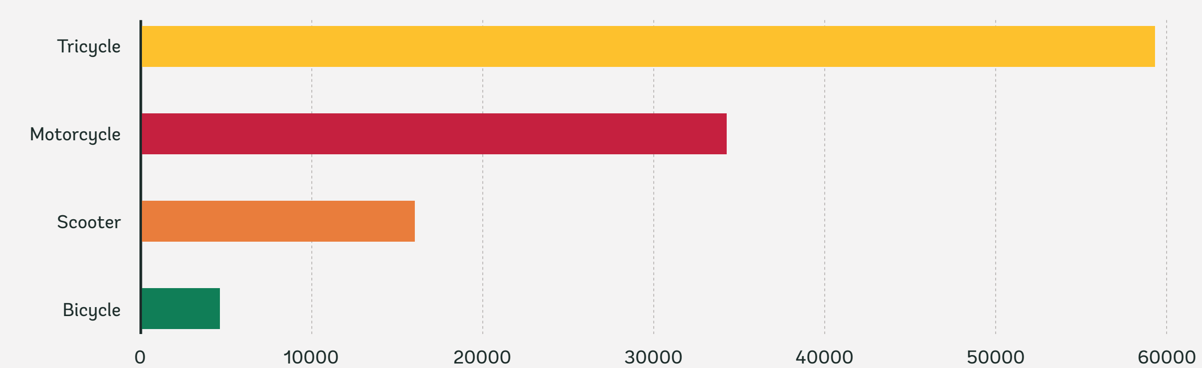
5.4.2. MEDIUM/LONG TERM SCENARIOS

In the medium/long term, the impact of electric vehicles in Ouagadougou and Bamako on energy consumption in the use phase may be related to several factors such as market penetration, driving styles, traffic conditions and vehicle parameters.

The objective of this analysis is to assess the energy requirement for scenarios in which several different types of electric two- and three-wheelers (e.g., bicycles, motorcycles, tricycles) are introduced into the current mobility system of the two cities.

Figure 5.17

Electricity consumption per year by vehicle type



Source: Authors

Two penetration scenarios are considered in the analysis for the medium/long term:

- *Slow penetration* (slow technological evolution and insufficient vehicle charging facilities). In this scenario, electric two- and three-wheelers would replace 5 percent of current two- and three-wheelers.
- *Fast penetration* (rapid technological development and sufficient vehicle charging facilities). In this scenario, electric two- and three-wheelers would replace 70 percent of current two- and three-wheelers.

The methodology used to calculate the number of bicycles, scooters, motorcycles, and tricycles used and the routes chosen are described in Annex 6.

The energy assessment also considers the influence of driving style. Three particular driving styles are considered in the analysis: normal, relaxed and stressed. These driving styles are analyzed based on the following factors: how the energy consumed by electric vehicles can change with average speed, maximum speed, and acceleration. It should be noted that the stressed driving style is considered as a kind of worst-case scenario, where the driving behavior is very erratic with high acceleration and maximum speed. The normal driving style was considered to have a medium value for acceleration and maximum speed. The relaxed scenario results in bringing the electric powertrain closer to its maximum efficiency for most operating conditions.

The resulting scenarios allow for the calculation of the energy consumed for each hour of a typical day in Ouagadougou (Figure 5.18) and Bamako (Figure 5.19). According to these scenarios, the daily energy consumption of electric two- and three-wheelers in the two cities would show the following results under the "normal" driving style:

Ouagadougou:

- Slow penetration: about 307 000 kWh/day (about 112 GWh/year)
- Fast penetration: about 3 655 000 kWh/day (environ 1 334 GWh/ year).

Bamako:

- Slow penetration: about 68 500 kWh/day (about 25 GWh/ year)
- Fast penetration: about 1 029 500 kWh/day (about 375 GWh/ year).

It is important to note that the scenarios under analysis are hypothetical and based on model-based vehicle type usage rates. This analysis is useful primarily to get a preliminary indication of the amount of electric power that would be required to operate a mobility system where the number of electric vehicles is quite high (e.g., the slow penetration scenario in Bamako would show about 6,400 electric vehicles in use).

Electric mobility in Bamako would absorb between 1.3 percent and 19.5 percent of Mali's total electricity production (in terms of total production in 2017), respectively, for the slow and fast penetration scenarios. In Ouagadougou, on the other hand, these slow and fast penetration scenarios would absorb between 6.9 percent and 82 percent of Burkina Faso's electricity production, respectively, in terms of total production in 2016.

Under these conditions, the fast penetration scenario in Ouagadougou would clearly be unsustainable without a large increase in national electricity production. The country's electricity production is increasing at a rate of 11 percent per year, which would allow the same amount of energy to be absorbed in the slow penetration scenario in about 2040.

The situation seems simpler in Bamako because there are fewer two- and three-wheeler trips. However, the impact on national power generation is still high in the fast penetration scenario although the country's power generation increases at a rate of 10 percent per year. For example, if we aim at a scenario that does not exceed 1 percent of the annual electricity production of the two countries, it would only be possible to use electric vehicles for

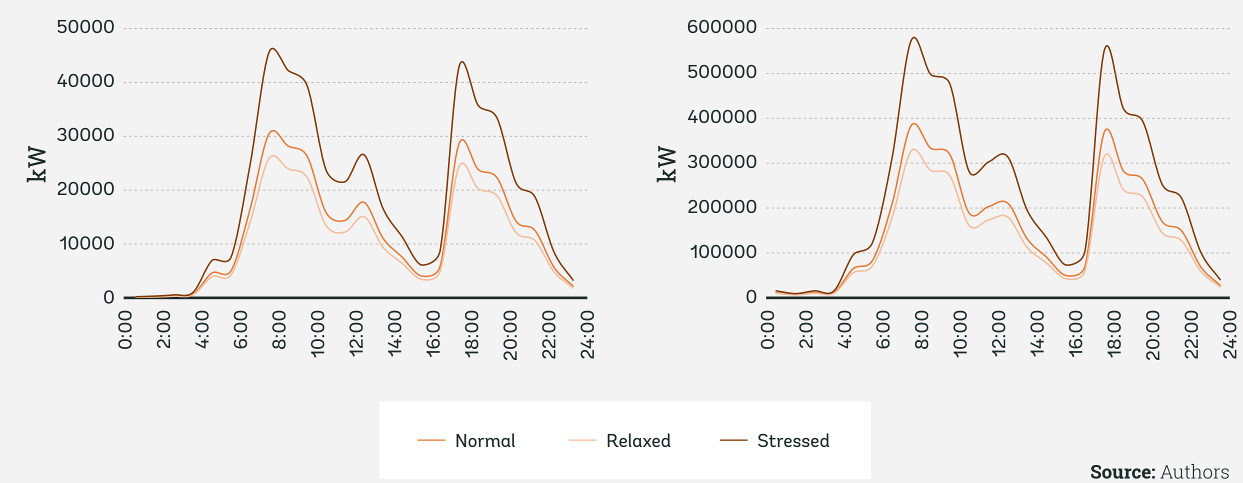
- 0.7 percent of two- and three-wheeled trips in Ouagadougou (about 4,200 trips per day);
- And 3.5 percent of two- and three-wheeled trips in Bamako (about 4,500 trips per day).

An important issue concerns the load impacts in the electricity grid that determine the stability of electricity provision; peak loads can cause power outages and blackouts, which are quite frequent in Bamako and Ouagadougou. Therefore, introducing a certain number of electric vehicles should be considered and managed attentively to avoid further deficits in electricity load caused by recharging of these vehicles. This means that recharging of electric vehicles should not be concentrated during specific periods of the day.

In this respect, the electric mobility market uptake should be accompanied by the monitoring of charging patterns by users and the estimation of the potential impact of peak periods on the electricity grid. Consequently, a revision/adaptation of the tariff regimes in both cities could incentivize an energy consumption "smoothing" by means of establishing suitable hourly rates. To this end, "smart meters" providing real-time data to the energy provider could be implemented within a general improvement program of the electricity grid.

Figure 5.18

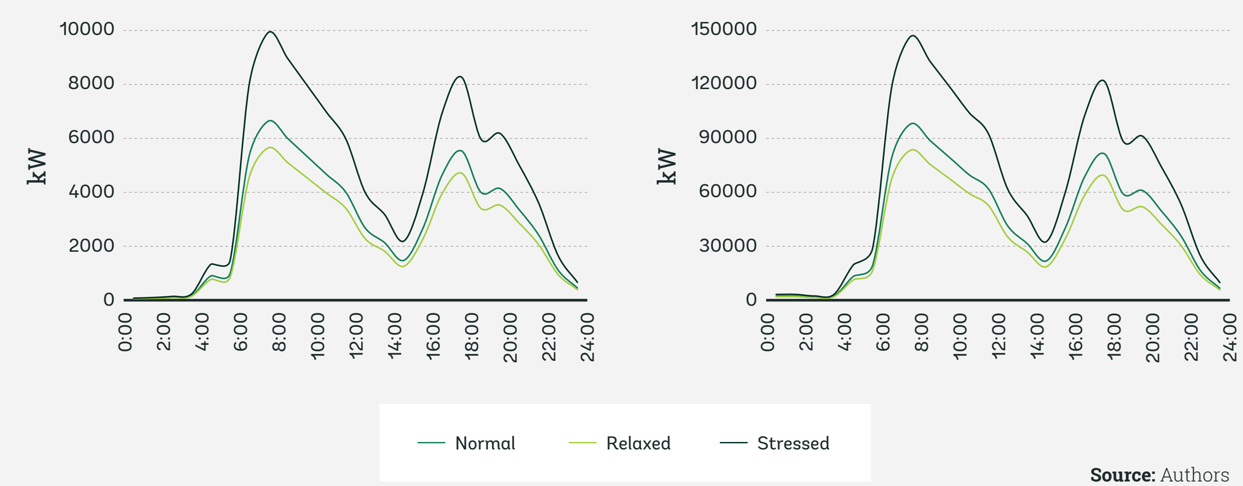
Energy consumption of two- and three-wheelers in Ouagadougou
Left: slow penetration; Right: fast penetration



Source: Authors

Figure 5.19

Energy consumption of two- and three-wheelers in Bamako
Left: slow penetration; Right: fast penetration



Source: Authors

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6. POTENTIALS FOR DEVELOPMENT

Box 6.1: Key Facts about key enablers for the development of electric mobility

Key enablers for the development of electric mobility include the following:

- The performance of electric vehicles is comparable to existing ICE vehicles.
- The total cost of ownership of an electric vehicle is often lower than that of an ICE vehicle.
- Incentives are needed to make the cost of purchasing an electric vehicle affordable.
- Investments are needed to ensure the availability of vehicle charging infrastructure.
- There are no significant institutional or regulatory barriers that would block the transition to electric mobility.

Analyses of the current mobility situation in Bamako and Ouagadougou, as well as estimates of the impacts of the electric transition of two- and three-wheelers, show a fairly large potential to initiate development of the electric mobility sector.

The potentials were assessed in relation to "key enablers" (KE) such as consumers starting to purchase electric vehicles to create niche markets and, in a more mature market phase, allow the market to scale up. For the time being, Bamako and Ouagadougou lack significant experience and knowledge of electric mobility, both among potential users and among policymakers and transport service providers.

The analysis is based on information provided by stakeholders during the consultations. This information reflects the knowledge and perceptions of different entities in the political and economic world (government and public institutions, vehicle dealers, service providers such as mototaxis, etc.) and civil society (see section 5.2).

KE1: PERFORMANCE COMPARABLE TO EXISTING ICE VEHICLES

This issue concerns the possibility of using electric vehicles to carry out routine trips and activities with the same degree of technical reliability, efficiency, and overall comfort. As far as the technical aspect is concerned, electric two- and three-wheelers should not have more technical failures than ICE vehicles. This issue is also related to the availability of spare parts and the general technical competence of dealers.

An important constraint could be related to the range mileage of electric vehicles and the possible "range anxiety" of users (i.e., the fear of not being able to cover distances with the charge provided by the vehicle's battery). This issue is strictly dependent on the possibility of easily and quickly recharging the vehicle.

Efficiency is determined by the ability to carry out a trip or activity while meeting the users' expectations. Key factors can be the overall travel time, influenced by the vehicle's performance in terms of speed as well as by the battery charging time, or by the loading capacity for freight transport.

Finally, user comfort concerns both physical considerations (e.g., driving comfort on rough roads) and the overall satisfaction of using/owning an electric vehicle, including aesthetic or social status considerations. Of course, the influence of these issues depends on the actual availability of suitable electric vehicle models in the local market.

The electric two-wheelers that dealers in Bamako and Ouagadougou might offer represent an appropriate alternative in purchasing decisions due to their similar technical characteristics to ICE vehicles and the relatively simple and mature technology achieved by this type of vehicle.

For three-wheelers, it is more difficult to find models that are fully comparable to ICE vehicles, although there seems to be a trade-off between vehicle load capacity and maximum vehicle speed.

In these circumstances, a key factor in both cities will be the willingness of consumers to accept this trade-off given that this type of vehicle is used mainly for freight transport.

KE2: TCO PARITY

As the TCO analysis has shown, electric vehicles are competitive with ICE models in Bamako and Ouagadougou, although competitiveness varies by vehicle type and depends on the specific total mileage (distance driven).

The most cost-effective type of electric vehicle (in terms of TCO per km) relative to its ICE counterpart is the three-wheeler for freight transport. Nevertheless, the profitability of such a change for vehicles with an annual mileage equal to or greater than 20,000 km per year (more than 55 km per day) is conditioned by the availability of an appropriate battery charging or exchange system that is acceptable to users in terms of availability (e.g., convenient times for charging at stations, parking lots, garages, etc.). This issue could be crucial for the deployment of commercial services in this sector.

Electric scooters are the second most cost-effective category for all assumed mileages, as they share the same considerations made for electric three-wheelers (availability of a charging or battery exchange system) with respect to freight vehicles with mileages above 21,000 km/year.

Three-wheeled electric vehicles for passenger transport are the third most cost-effective mode for all mileage in Ouagadougou and for total mileage of 10,000 km/year or more in Bamako. Nevertheless, this mode is only a marginally-used alternative in both cities.

Finally, electric motorcycles are profitable in Ouagadougou for mileage above 5,000 km per year, whereas a more "oscillating" pattern can be found in Bamako where electric motorcycles are slightly profitable for mileage ranges of 15,000-20,000 km and 33,000-55,000 km (e.g., mototaxi operations in Bamako are found in the latter range).

This difference between Ouagadougou and Bamako is explained by the relatively higher cost of electricity compared to gasoline, which undermines the potential gains to be made from using electric vehicles more efficiently than ICE vehicles. In Bamako, the average cost of electricity is US$0.237/kWh (CFAF 130/kWh) while the average cost of gasoline is US$0.143/kWh (CFAF 77/kWh). In Ouagadougou, the average cost of electricity is US$0.185/kWh (CFAF 100/kWh) while the average cost of gasoline is US$0.134/

Box 6.2: Tricycle ambulance in Bamako

A recent example which helps illustrate the market's propensity towards three-wheeled motorized vehicles is the purchase by a hospital in Bamako of tricycles adapted as ambulances (see image on the right). These vehicles were designed during the emergency phase of the COVID-19 pandemic and are an attempt to meet a large deficit in emergency services in Mali. While there may be some doubts about their ability to respond quickly to an emergency, they represent an interesting example and a clear indication of the market's (and users') propensity toward tricycles.

Source: Authors

kWh (CFAF 73/kWh). The relative TCO of electric vehicles in both countries could be improved by establishing hourly rates that avoid future grid overloads and making the electricity demand smoother over the day through lower tariffs in off peak periods.

In addition, cheaper electric bicycles could compete directly with ICE scooters (especially in the lower range of mileage) rather than being an alternative to non-electric bicycles. E-bikes could also be an alternative for public transport users, as other vehicles may be less affordable for transit users. E-bike travel may be cheaper than public transport (e.g., in Ouagadougou, a trip by public bus costs about US$0.5-0.9, whereas in the baseline scenario of the TCO analysis, a 25 km trip by e-bike would cost US$0.36).

Moreover, E-bike users would be less affected by heat problems compared to ICE bicycle users.

The results for both cities must also be interpreted considering the lack of any public incentives to encourage e-vehicle adoption. Encouraging electric transition is a key policy issue that must be addressed.

KE3: AFFORDABLE INITIAL COST AND EASE OF PURCHASE

Electric vehicles generally have higher purchase costs than ICE models. The challenge of affordability, reported by consultees as the most adverse factor in user decisions, is not offset by lower operating costs. An example cited by some stakeholders in Bamako concerns solar panels, which are rarely deployed because of their high purchase cost even if the user fees are limited.

Currently, this problem is not mitigated by any public incentives (e.g., a reduction in VAT) or by financial programs to avoid upfront costs (e.g., installment payments). An exception is the franchise system currently used by the Teliman mototaxi company, which allows motorcycle drivers to activate a lease to pay for the motorcycle in periodic installments.

A positive development is the potential for obtaining electric vehicles from dealerships. In fact, all the dealers consulted on the issue confirmed that it was easy to order electric vehicles through the usual supply chain, which also includes the availability of spare parts. In addition, the sale of electric bicycles appears to be an emerging trend among school-age youth in Ouagadougou.

Transport pollution in both cities is perceived by stakeholders as a significant problem. This issue represents an opportunity to communicate the importance of an "electric transition" in a way that would be well-received by users. However, this topic should be addressed carefully, especially in relation to vehicle costs. The consultations made it clear that environmental benefits and lower operating costs could take a back seat to the purchase costs.

KE4: AVAILABILITY OF FINANCING

The financial systems in both cities are not well developed and "cash" transactions are the common practice among customers except for officials at some institutions who may have access to financial loans. The presence of a developed financial ecosystem is a fundamental requirement to overcome the problem of upfront costs of electric vehicles, which are generally less affordable than ICE models for potential consumers. The development of an appropriate financial ecosystem would necessitate a general increase in knowledge of the technical characteristics of electric vehicles and greater experience in the field. In fact, these factors would allow financial institutions and operators to better focus on the market and identify specific risk profiles and business opportunities, thereby releasing more loans.

Of course, strengthening the financial ecosystem would also involve the emergence of new business models such as vehicle subscription/rental models, battery subscription/rental models, etc. Vehicle leasing could be particularly promising in Bamako and Ouagadougou, as it would also overcome the problems associated with the lack of experience with electric vehicles in terms of avoiding the "fear" of owning an electric vehicle due to negative perceptions related to limited range and technical failures.

KE5: AVAILABILITY OF CHARGING INFRASTRUCTURE/BATTERY SERVICES

The availability of an adequate charging network (charging stations and/or battery exchange services) is a fundamental condition which fosters the market adoption of electric vehicles bigger than two-wheelers. However, there is still no consensus for two-wheelers on whether a dedicated charging network is necessary. A charging network contributes to reducing the so-called "range anxiety" which impedes the adoption and more extensive use of electric vehicles. A widespread charging network would allow users to recharge the vehicle whenever they want, analogously to conventional vehicles.

No charging infrastructure exists in either city, with private locations being the only potential charging points. It does not appear to be a short-term constraint since most two-wheelers could easily be recharged in a few hours via a standard plug at home or at the office when used for limited distances. But the lack of a charging network could limit the penetration of electric three-wheelers and even two-wheelers on a large scale in the medium/long term, when mobility patterns could necessitate charging services different from plugging at home/office. In addition, limited household access to electricity and the frequent malfunctions of the electricity grid could be a problem. This is less of an issue in Ouagadougou where about 95 percent of households are connected to the electricity grid. In Bamako, the percentage of connected households is about 88 percent.

Consulted stakeholders are quite divided as to what type of infrastructure would be more appropriate in the two cities. Public institutions seem to be more oriented towards the development of public charging infrastructure (charging stations) that is easily accessible to private users. On the contrary, users and service providers are more likely to consider battery charging services (through dedicated workshops or at service stations). It is worth noting that, from a technical, regulatory, and economic point of view, a battery exchange service currently seems to be more feasible in Bamako and Ouagadougou than the installation of charging stations. This is especially true for two-wheelers whose lighter batteries would require faster swapping operations than three-wheelers. Nevertheless, a mixed approach with the added implementation of charging infrastructures could suitably serve the different mobility patterns, especially in the medium/long term. As shown by international practices, the deployment of a charging network in a less than mature market usually requires public subsidies to support initial investments and allow the network to expand.

The use of solar panel installations for battery recharging could also be a positive factor. This would further reduce the impact of electric vehicles on the environment and on energy consumption (see Life-cycle Assessment) through renewable energy sources. An energy cost benefit could also be envisioned.

Increased political support for electric vehicles would be a cross-cutting catalyst. To be successful, public policies would set clear scopes and targets, define comprehensive and sustainable intervention programs, and ensure their implementation. Electricity-oriented policies, including the definition of specific regulations, will need to be developed from scratch in Bamako and Ouagadougou.

KE6: ENERGY SUPPLY

To respond to the question of energy supply, we have analyzed the electricity requirements of both cities in relation to scenarios where several electric two- and three-wheelers of different types (e.g., bicycles, motorcycles, tricycles) are introduced to the current mobility system. The energy assessment also considered the influence of driving style under three conditions: normal, relaxed, stressed. Two penetration scenarios are analyzed here:

- Slow penetration of electric two- and three-wheelers (electric two- and three-wheelers would replace 5 percent of two- and three-wheelers currently being used).
- Fast penetration of electric two- and three-wheelers (electric two- and three-wheelers would replace 70 percent of two- and three-wheelers currently being used).

The impact on the grid depends on several factors, such as characteristics of existing and future energy production, market penetration of electric vehicles, driving styles, traffic conditions and vehicle parameters. Under the existing energy conditions, changing 5 percent of current two- and three-wheelers to electric models in Bamako and Ouagadougou would consume 1.3 percent and 6.9 percent of their respective country's electricity production. Changing 70 percent of current two- and three-wheelers to electric models in Bamako and Ouagadougou would consume 19.5 percent and 82 percent of their respective country's electricity production.

Overall, these results indicate that the transition should occur in a phased manner. Towards the medium term, the electrification of transport should be accompanied by a large increase in electricity production at the national level.

An important issue is the stability of electricity provision, which is impacted by peak loads that can cause frequent power outages and blackouts in Bamako and Ouagadougou. Consideration should be given to Introducing a certain number of electric vehicles that would be managed closely to avoid further deficits in electricity load caused by recharging of the vehicles. This means, for instance, that recharging of electric vehicles should not be concentrated during specific periods of the day. In this respect, energy tariff regimes suitably adapted to incentivize off-peak charging through efficient hourly rates could play a significant role.

KE7: POLICY ISSUES

Various policy and regulatory issues represent an opportunity to facilitate the development of electric mobility. Consultations with stakeholders did not reveal any institutional or regulatory barriers. The institutional officials all stated that the development of electric mobility on two- and three-wheelers would be supported through the revision of standards to include the existence of electric motors and other policies. Some changes in technical standards might be necessary (e.g., Burkina Faso may need to add a regulatory category for electric motors), but this would not be a significant obstacle.

It is important to note, however, that most institutions believe that electric transition is not a priority over public transport development and reduction of urban congestion. Stakeholders and road users are very sensitive to the reduction of travel time, especially in Bamako. Some stakeholders in Ouagadougou have considered the development of electric two-wheeler sharing services as a way of supporting public transport feeder lines. In contrast, this hypothesis was not considered to be of interest in Bamako.

Finally, there were some concerns about road safety related to the lack of noise from electric vehicles. Stakeholders have sometimes stressed this problem without pointing out the potential benefits on the quality of life such as less pollution and noise.

Environmental benefits of electric two- and three-wheelers are not currently anticipated by stakeholders and users, as demonstrated in the life cycle analysis.

SUMMARY OF STRENGTHS AND WEAKNESSES

Table 6.1 summarizes the strengths and weaknesses of each vehicle in terms of its potential for adoption and identifies potential cases for early use. As indicated by several stakeholders, particular attention should be paid to young people as a target group, as they are likely to be more open to an innovative experience than other, more conservative social groups.

Table 6.1.

Strengths and weaknesses for potential adoption of each type of electric vehicle

Vehicle type	Strengths	Weaknesses	Potential use
Electric bicycle	• Lowest TCO in both cities • More affordable purchase price than scooter • Less demanding charging operations • Models already in circulation in Ouagadougou	• Higher purchase cost than non-electric bicycles • Lack of financial incentives to reduce initial cost in both cities • Problems with road conditions	Private use for short distances (10 km per day - limited charging needs) in both cities by students/ workers
Electric scooter	• Technical performance comparable to that of ICE vehicles • Availability per order Competitive TCO in both cities	• Higher purchase cost than ICE models • Lack of financial incentives to reduce initial cost in both cities	Private use for short to medium distances (20-25 km per day - limited charging needs) in both cities by students and workers
Electric motorcycle	• Technical performance comparable to that of ICE vehicles • Availability per order Competitive TCO in both cities	• Higher purchase cost compared to ICE model • TCO differential in Bamako very sensitive to mileage • Lack of financial incentives to reduce initial cost in both cities • Lack of charging infrastructure in place in both cities	Mototaxi services in Bamako, managed by companies able to meet the initial costs, benefit from a lower TCO and set up of an appropriate recharging system (e.g., battery exchange)
Electric three-wheelers for passenger transport	• Technical performance comparable to that of ICE vehicles • Availability per order Competitive TCO in both cities	• Higher purchase cost than the ICE model • Lack of financial incentives to reduce initial cost in both cities • Lack of charging infrastructure in place in both cities	• Marginal mode of transport in both cities • No market segment identified
Electric three-wheelers for goods transport	• Availability per order Competitive TCO in both cities	• Limited technical comparability with ICE vehicles • Higher purchase cost than ICE vehicles • Lack of financial incentives to reduce initial cost in both cities. • Lack of charging infrastructure in place in both cities • Possible overloads limiting technical performance	Private use for short and medium distance freight transport (limited charging needs) in both cities

7.

INVESTMENT CONCEPTS

Based on the data and information collected and the analyses conducted during the first part of the study, investment concepts that could be implemented in the short term (i.e., within one to three years) were defined.

The selection of the investment concepts considered the following parameters:

- **Consistency with public transportation policies.** The investment concepts aim to demonstrate how to initiate a transition to electric mobility in Ouagadougou and Bamako. However, the concepts should also be aligned with current or planned future public policies.
- **Technical feasibility.** As these projects are expected to be implemented in the short term, it is important that they are technically feasible.
- **Suitability for the local context.** Investment concepts should be of interest to the local community, i.e., meet some of its travel needs. These concepts should therefore target specific groups of two- and three-wheeler users.
- **Positive impacts.** The selection of investment concepts should be based on options that have positive impacts on the environment (LCA), on the cost of ownership (TCO), on energy consumption, etc.
- **Reasonable costs.** Investment concepts should have relatively low implementation costs (whether public or private investment). The financial viability of the investment would be a secondary consideration in the first approach but would be analyzed in detail during the implementation of the concept.
- **Scalability and replicability.** The concepts should be relatively easy to scale up or expand and replicate in other Sahelian cities.

It is important to emphasize that the ultimate goal of the study is to promote the transition to electric mobility in order to reduce the environmental impacts (including greenhouse gas emissions, local air pollution, and dependence on fossil fuels) of transportation systems. Reducing congestion is not the primary objective of transitioning to electric mobility. For this reason, the choice of investment concepts has given priority to those offering the greatest environmental benefits.

Based on these considerations, the following chapters describe four investment concepts: one specific to Ouagadougou, one specific to Bamako, and two others that could be implemented in both cities (Figure 7.1). Examples of relevant pilot projects in Europe are described in Annex 7.

Figure 7.1.

Investment concepts

7.1. ELECTRIC MOTOTAXIS IN BAMAKO

7.1.1. RATIONALE

Mototaxi services in Bamako are becoming progressively more widespread. In recent years, more companies have been officially established and national institutions are in the process of registering these services to regulate them properly.

For instance, the mototaxi company Teliman employed 200 drivers based in Bamako in 2019. Considering the increased presence of other officially established and informal companies, around 1,000 motorcycles could be used for mototaxi services in Bamako.

Some mototaxi companies also use franchising arrangements that allow independent franchised drivers to benefit from different services (e.g., online application to manage the service, including payments, use of an official brand, call center services, staggered payment for the motorcycle, etc.). Drivers pay the company a periodic fee for these services and for the staggered purchase of the motorcycle.

The mototaxi services meet an intense demand for mobility in Bamako. A mototaxi driver travels about 120- 150 km per day. The service is generally considered profitable by drivers.

The total cost of ownership of an electric motorcycle in Bamako is quite similar to that of a gasoline motorcycle. The TCO of an electric motorcycle is estimated at US$0.053/km (CFAF 29/km) compared to US$0.051/km (CFAF 28/km) for a gasoline motorcycle. Considering a total distance travelled of 150 km per day, this translates into a cost of about US$7.6 (CFAF 4,200) per day with an electric motorcycle, compared to about US$8 (CFAF 4,350) per day with a gasoline-powered motorcycle.

However, most stakeholders consulted during the study emphasized that the price is the overriding factor in deciding which mode of transport to purchase. Therefore, users may not be interested in purchasing an electric motorcycle that is more expensive than its gasoline counterpart with a difference in purchase cost of about US$300, or CFAF 162,000.

Despite this challenge, some of the mototaxi companies consulted during the study are considering the possibility of converting a portion of their motorcycle fleet from gasoline to electric. Using a deductible staged purchase approach, drivers would accept the switch to an electric motor where the difference in purchase cost between an electric and a gasoline vehicle would be less noticeable.

From an energy and environmental impact perspective, the use of an electric motorcycle is more beneficial than its gasoline counterpart. The energy requirement would decrease by about 50 percent, while the equivalent CO_2 emissions would decrease by about 34 percent without changing the number of total km driven.

7.1.2. OBJECTIVES AND IMPLEMENTATION

The objective of this investment concept is to introduce several electric motorcycles for short-term use in mototaxi services. This concept should be realized in close collaboration with one or more official mototaxi companies already operational in Bamako.

A crucial aspect for the successful realization of this concept concerns the recharging of the vehicles' batteries. The current lack of infrastructure (e.g., charging stations) for electric mobility in Bamako is a problem. Unfortunately, the installation of public charging stations is not feasible in the short term for various reasons:

- High investment cost, either for public institutions or for private investors, that is difficult to justify in the short term (a charging station could have a cost for its installation of about US$6,000 - CFAF 3.2 million)
- Weakness of the Bamako city electricity network, especially in the outlying areas due to load shedding problems.
- Recharging times that are incompatible with mototaxi services (drivers would not accept staying parked for too long to recharge).

Alternatively, battery recharging should be performed through a battery exchange system which would involve the use of specific motorcycle models. For this purpose, "exchange points" should be established according to a new zoning of the city and the drivers' usual routes. In addition, the "exchange points" could be established in garages, service stations, or similar venues. For safety reasons, the battery exchange should be performed by mechanics trained for this activity. The operation of "exchange points" naturally depends on the availability of batteries. The mechanics could buy the batteries themselves or rent them from the mototaxi company and charge the drivers a fee for exchanging to a "full" battery (i.e., the mechanics would take care of recharging the depleted battery).

For the use of an electric mototaxi to be financially attractive to drivers, the cost of the exchange should be competitive with the cost of gasoline. In Bamako, the energy expenditure (i.e., the cost of gasoline) for a gasoline-powered mototaxi is about US$3.24 (CFAF 1,800) per day assuming a total mileage of 150 km per day. For this distance, a driver would need two full batteries per day; a fully charged battery has a range of about 80 km. The cost of recharging a 2.9 kW battery would be about US$0.7 (CFAF 390), based on current electricity prices. This would bring the electricity cost to about US$1.4 (CFAF 780) per day for two batteries. Therefore, the energy cost for a driver could be lower than the cost of gasoline considering the profit made by the garage for recharging and for the amortization of the purchase of the battery.

Beyond a means of managing battery recharging services, this investment concept would be carried out according to the same franchise formula currently in place for motorcycles. To ensure that the periodic amount paid by the drivers to the mototaxi company is not higher than the formula currently in place, it will be important to select electric motorcycles with a purchase price that is not too high compared to motorcycles that use gasoline (e.g., a difference in purchase cost of about US$300 or CFAF 162,000).

The investment concept could be initiated as a pilot project, with a limited number of electric two-wheelers being used. The final choice on the number of vehicles should be made by the stakeholders involved in the project. Considering the use of 20 electric motorcycles (thus 20 riders), for example, it would be necessary to calculate the availability of at least 50 to 60 batteries to be used for the exchanges.

The investment concept will necessitate accompanying public relations campaigns aimed at raising awareness of the importance of electric mobility among users of mototaxi services as well as sending positive messages to users of mototaxi services about the reliability of electric motorcycles. These awareness campaigns would be promoted by public institutions such as the National Directorate of Land, Maritime, and Inland Waterways of the Ministry of Transport (DNTTMF) and the Directorate of Traffic and Urban Transport Regulation of Bamako (DRCTU).

Although the investment concept would be viable without government subsidies, government incentives for the use of electric mototaxis could also help to accelerate the implementation of the pilot project. These incentives would also demonstrate a political commitment to the electric transition. Examples of these incentives could include the following:

- Subsidy for the purchase of electric motorcycles
- Subsidy for the purchase of batteries
- Tax exemption for electric mototaxi services
- Fixing electricity prices for electric mototaxi services (to avoid price fluctuations) during the pilot phase
- Subsidy for battery swapping services during the pilot phase.

It will also be important to train riders on how best to use electric vehicles (e.g., driving styles best suited to maximize battery life) and services for battery swapping and charging.

7.1.3. SCALABILITY AND REPLICABILITY OF THE CONCEPT

The investment concept should be easily scalable in Bamako. It would involve the gradual introduction of more electric motorcycles and expansion of the network of service providers involved (e.g., garages for battery exchanges).

The replicability of the concept in other cities will depend primarily on the presence of formal mototaxi services. The concept would be more easily replicable if these services were operated under the same franchise formula as in Bamako. Under this scenario, it will be necessary to establish similar conditions that allow drivers to spread the cost of purchasing the motorcycle.

7.1.4. FURTHER STUDY OR RESEARCH NEEDS

The implementation of this pilot project would require additional studies or research which could be the subject of a preliminary design project. This additional research and study would apply to the following:

- *Analysis of the user* ***demand*** *that could be intercepted by the electric mototaxi service.* This study should focus on identifying the segments of users that would use an electric mototaxi to identify possible areas of operation for this service. This analysis should be carried out by the mototaxi company that implements the service.
- *Further definition of the service* ***supply****, particularly in relation to the specific model of motorcycle to be used, and the location of battery exchange points (depending on demand and zoning).* This research could also investigate the possibility of developing a solar powered battery charging system. This topic could be analysed during the pilot project, in order to use real data on the use of electric motorcycles, their autonomy, the energy needs for battery charging, etc.
- *Identification of the* ***administrative and regulatory processes*** *necessary to put electric motorcycles on the road.* This process would first include vehicle approval and authorization to perform a battery exchange service.
- *Analysis of the introduction of* ***public incentives*** *for the development and use of electric mobility services.* This research should focus on identifying forms of incentives for mototaxi companies to make it easier for them to implement the pilot project. Incentives for users of mototaxis could also be explored to direct their preferences towards the use of electric motorcycles.

7.1.5. RESPONSIBLE ENTITY AND STAKEHOLDERS

This pilot project should be managed primarily by a mototaxi company (or companies) with the proper experience in this area. In addition to the lead management entity, several stakeholders would also be involved in this project. Their roles are described in Table 7.1.

Table 7.1.

Stakeholders and their roles - Bamako Investment Concept #1

Stakeholders	Roles
Mototaxi companies	**Responsible entity** Purchase of electric motorcycles Purchase of batteries for exchange Management of mototaxi services Monitoring of mototaxi activities Training of drivers and garages Coordination of implementation (e.g., identification of garages/service stations, agreements on prices for services, etc.)
Riders	Joining the pilot project Support for monitoring (periodic provision of information and data to the mototaxi company)
Garages / Service stations	Purchase or rental of batteries Recharging of depleted batteries Battery swapping Support for monitoring (periodic provision of information and data to the mototaxi company)
DNTTMF	Possible implementation of incentives Support for implementation (facilitation of administrative procedures) Awareness-raising activities on electric mobility
DRCTU	Support for implementation (facilitation of administrative procedures) Facilitation of implementation (support to the mototaxi company to establish agreements) Impact monitoring (environment, mobility, etc.) Awareness-raising activities on electric mobility

Source: Authors

7.1.6. MONITORING OF RESULTS

The investment concept will need to be validated in terms of usage, service reliability, mobility, and environmental impacts. Key Performance Indicators (KPIs) useful for monitoring results are shown in Table 7.2 which also identifies the stakeholders involved.

Table 7.2.

KPIs - Bamako Investment Concept #1

Sector	Stakeholders	KPI
Mototaxi activity	Mototaxi companies	Trips per rider on electric and non-electric vehicles Reservations for services on electric and non-electric vehicles Typical trips on electric and non-electric vehicles User interest in electric mobility
Vehicles	Riders	Commercial speed Battery life Battery changes per day Expenses related to battery swapping Duration of battery changes Driving styles Distances travelled Trips per day User interest in electric mobility Maintenance costs
Batteries	Garages/ service stations	Battery changes per day Electrical energy expenditure Duration of battery swapping
Environment	DRCTU	Estimated impacts on air pollutants Estimated noise impacts
Mobility and safety	DRCTU	Crashes involving electric and non-electric motorcycles Crashes caused by lack of noise

Source: Authors

7.1.7. DEVELOPMENT COSTS

An estimate of the costs required to implement this investment concept is summarized in Table 7.3 which includes the stakeholders involved. This estimate does not consider possible incentives from public institutions.

Table 7.3.

Development costs - Bamako investment concept #1

Elements	Stakeholders	N°	Cost (US$)	Cost (CFAF)
Electric motorcycles	Mototaxi company DNTTMF (eventual)	20	12,000	6,700,000
Batteries	Mototaxi company Garage/service station DNTTMF (eventual)	60	18,000	10,021,000
Electricity	Garage/service station DNTTMF (eventual)	60 / day	15,000/year	8,350,000/year
Insurance of electric motorcycles	Mototaxi company DNTTMF (eventual)	20	740/year	410,000/year
Total (for one year)	-	-	45,740	25,481,000

Source: Authors

7.1.8. POTENTIAL RISKS

Potential risks associated with the implementation of this investment concept and mitigation strategies are presented in Table 7.4.

Table 7.4.

Risk analysis and mitigation strategies - Bamako investment concept #1

Risks	Impacts	Mitigation strategies
Low user interest in electric vehicles (e.g., fear of unreliability).	Risk: Low Impact: Medium	Implement awareness and communication campaign before the pilot project begins. Ongoing communication about the effectiveness of electric mototaxi services and the positive environmental impacts.
Business model not adapted (e.g., unprofitable services for drivers and/or garages). The cost of changing batteries may be too high for drivers. For garages the income from battery changes might be too low.	Risk: Medium Impact: High	Detailed cost analysis in the detailed design phase of the pilot project. Institutional support from DNTTMF and DRCTU to identify prices, facilitate agreements between stakeholders, and set electricity price during the pilot phase. Possible revision of the business model.
Insufficient battery life for motorbike taxi services. The cost to drivers could increase due to a higher-than-expected number of battery changes.	Risk: Medium Impact: Medium	Training for drivers on the proper use of electric motorcycles. Training for garages on the best ways to recharge batteries. Control of use patterns and advice on use from the mototaxi company. Possible revision of the business model.
Short life span of electric motorcycles in case of poor local road conditions and inappropriate vehicle use.	Risk: Low Impact: Medium	Control of use patterns and advice on use from the mototaxi company.

Source: Authors

7.1.9. TIMELINE

The investment concept could be implemented according to the following preliminary timeline (Figure Figure 7.2).

Figure 7.2.

Development timeline - Bamako investment concept #1

Detailed design
Months 1 to 6

- Memoranda of Understanding between stakeholders
- Project design by stakeholders
- Agreement on business models
- Identification of potential funders

Implementation
Months 7 to 12

- Purchase of vehicles
- Purchase of batteries
- Training of stakeholders
- Awareness campaigns
- Launch of the service

Pilot project
Months 13 to 24

- Periodic data collection for monitoring
- Periodic reporting on activities
- Mid-term evaluation
- Final evaluation

7.2. ELECTRIC BICYCLES FOR STUDENTS AND EMPLOYEES IN OUAGADOUGOU

7.2.1. RATIONALE

ICE two-wheelers constitute the predominant mode of travel in the city of Ouagadougou. However, there is a significant amount of travel by bicycle and there has been a recent increase in the use of e-bikes, especially among the younger segments of the population. The current number of e-bikes could range between 100 to 200 vehicles.

E-bikes can be an effective substitute for ICE two-wheelers when used without passengers for distances that can be easily covered by the battery's range of about 50 km. Among motorized vehicle users, the current tendency not to use e-bikes is strongly influenced by the lack of knowledge about their technical characteristics and performance. In fact, many people do not know that the battery capacity of the e-bike would be able to cover the distances travelled daily.

At the same time, stakeholders who were consulted indicated that one of the disadvantages of the bicycle is its discomfort in hot weather. This inconvenience would not affect a user of a pedal-assist bicycle or even a fully electric bicycle which is equipped with a gas pedal preventing any need for physical effort expended in pedalling.

Considering the average speed of ICE two-wheelers in Ouagadougou (about 32 km/h)**[3]**, the average speed of an e-bike (25 km/h depending on the model) is quite competitive. Moreover, the reduced dimensions of an e-bike would also allow it to weave more easily through traffic and use the remaining space on the road. The possibility of having a reduced speed differential compared to motorized vehicles increases road safety conditions, especially in stop-and-go situations including stops at traffic lights. All these elements could encourage increased use of e-bikes.

While the characteristics of e-bikes are not fully comparable to those of ICE two-wheelers, the reduced total cost of ownership could prove to be a key element in closing the gap in user preference once it is understood by potential users. E-bikes could also be an effective alternative to ICE two-wheelers, especially considering that the average trip distance in Ouagadougou is about 12.5 km (25 km per day on average).

7.2.2. OBJECTIVES AND IMPLEMENTATION

The proposed investment concept consists of a pilot project to deploy 50 electric bicycles in Ouagadougou for each of the following target groups:

- Higher education students (secondary and/or university level)
- Public sector employees
- Administrative staff of the Joseph Ki-Zerbo University (Ouaga 1) for travel within the campus (most campus travel today is by motorcycle).

Students should be the main target group, as they are likely to use bicycles already and probably lack a driver's license or enough income to switch to ICE two-wheelers. Currently, students may be accompanied to school by their motorized parents or friends. Deployment of e-bikes among this target group would increase their propensity to use this type of environmentally friendly vehicle, while reducing their desire to switch to motorized vehicles. In addition, schools should allow charging of bicycle batteries during school hours, especially since schools are expected to have a more reliable electricity supply than the homes of private vehicle users.

Employees in the public sector (e.g., municipalities or ministries) might be another appropriate target group, as they should be able to recharge their batteries relatively easily and reliably at their place of work as opposed to their private homes.

It should be noted that because the battery could provide more than one round trip, vehicles would not need to be recharged every day at the same time. This would allow for better management of the electricity supply at the site.

Policymakers encouraging the implementation of electric mobility services may have a preference for the public sector over the private sector as an initial target group. Nonetheless, it is recommended that this pilot program focus on students first with later participation of public sector employees depending on funding availability and political will.

Administrative staff who travel around the Joseph Ki-Zerbo University campus could also be a target group, as their trips are made with private vehicles (ICE two-wheelers or cars) and the distances are relatively short (the shape of the campus corresponds to a 1 km square property as shown in Map 7.1).

Participants in the student and public sector employee pilot should be identified on a voluntary basis and should receive the vehicle free of charge from the sponsoring institutions or through an auction. To deploy an equitable service and avoid complaints about not being able to participate in the pilot, the vehicles should be loaned on a rotational basis or on a random basis. A rotational basis would be based on the number of potential users who could use the e-bike for a period of 3 or 6 months. A random basis could be used if the number of people wishing to participate is too high to ensure that all of them can use an e-bike during the pilot. Finally, the pilot should last at least one year.

The pilot could be implemented a little differently on the University campus. Here the e-bikes could be made available to staff without assignment on a so-called “free floating” basis. However, this implies that a bicycle management service

Map 7.1.

Campus of University Joseph Ki-Zerbo

would have to be organized by the university for recharging the bicycles and for daily repositioning of bicycle services in different areas of the campus.

The type of electric bicycle used for this pilot could be the same model as the one already circulating in Ouagadougou, due to the partial knowledge and acceptance of its existing users as well as its low price. The technical characteristics of this vehicle are shown in Table 7.5. The average purchase price on the Ouagadougou market is US$370 (CFAF 205,500) per bicycle, and maintenance costs (mainly for tires) per vehicle are estimated at about US$14 (CFAF 7,800) per year. No tax is currently levied on these purchases, and it is assumed that this policy will remain in the future.

It would also be possible to use another model of electric bicycle with a different frame and technical characteristics (as shown in Table 7.6) for this pilot, which would allow for greater comfort of use given the poor road conditions in the city. The purchase price of this model would be about US$600 (CFAF 333,000). Annual maintenance costs are expected to be similar to those of the other model.

The annual energy consumption for both models is expected to be about US$16 (CFAF 8,900), assuming an energy cost of US$0.17/kWh (CFAF 94/kWh), an average daily travel distance of 25 km, and an average energy consumption of 0.01 kWh/km. For services activated on the university campus, the average distance travelled per day would probably be lower.

Universities and schools should be able to deploy the service at no cost after receiving the e-bikes from the central government or municipality that will also be responsible for covering the vehicles’ operational costs.

Information and awareness about the technical capabilities of e-bikes are key factors in encouraging future use of this mode. Information and awareness campaigns should therefore be organized for target groups and other citizens with the aim of imparting technical knowledge about e-bikes and their capabilities as well as the anticipated environmental benefits.

Prior to the start of the pilot project, the target users should receive technical training to prepare them to use the vehicles and to react in case of malfunction.

Table 7.5.

Electric bicycle model 1

Model already used in Ouagadougou	
Make and model (example)	FY ON
Battery capacity	1,5 kWh
Voltage	48V
Recharge duration	4-6 h
Tires	14’’
Max speed	30 km/h
Autonomy	50 km

Table 7.6.

Electric bicycle model 2

Model not currently used in Ouagadougou	
Make and model (example)	I-BIKE CITY BIKE
Battery capacity	1,5 kWh
Voltage	48V
Recharge duration	4-6 h
Tires	26’’
Max speed	30 km/h
Autonomy	40 km

7.2.3. SCALABILITY AND REPLICABILITY OF THE CONCEPT

The project is easily scalable and replicable in the local context, including other schools, public institutions, and private companies involved in the pilot project. The number of vehicles can be increased without any difficulty, as there is sufficient supply on the international market. Increasing the number of vehicles in a single school / university / administration / company should not be a problem, as the electricity demand of the vehicles is low and not all vehicles need to be charged at the same time. The degree to which the number of vehicles can be increased would need to be assessed on a case-by-case basis, however.

Similarly, the replicability of the concept in other cities is straightforward but it will be useful to first verify the interest of users in cycling and presence of bicyclists.

A future challenge may be to replicate the concept in environments where bicycle mobility is not present or is decreasing as it is in Bamako. In these cases, it will be necessary to undertake awareness campaigns before initiating any project.

7.2.4. ADDITIONAL STUDIES OR RESEARCH NEEDS

The implementation of this pilot project would require additional studies or research with respect to the following:

- Analysis of the **demand** of users who could be involved as e-bike users. This study should focus on identifying potential users based on home-to-school or home-to-work distances and current means of transportation. This analysis would also identify schools, universities, and workplaces that could be involved in the project.
- Further definition of the service **supply**, particularly in relation to the specific model of bicycle to be used. This research could also investigate the possibility of developing a solar powered battery recharging system. This issue could be analyzed during the pilot project to use real data on the use of electric bicycles, their autonomy, energy needs for battery recharging, etc.

7.2.5. RESPONSIBLE ENTITY AND STAKEHOLDERS

The municipality of Ouagadougou should be responsible for this project, especially the provision of the vehicles and project management. Secondary schools and universities are the main stakeholders to be included in the pilot project. For the target group of public employees, the municipality of Ouagadougou and national ministries should be the main institutions to target. The stakeholders and their roles are described in Table 7.7.

Table 7.7.

Stakeholders and their roles - Investment concept Ouagadougou #1

Stakeholders	Roles
Municipality	**Responsible entity** Provision of vehicles (possibly provided by central government) Identification of potential users Management of the service Monitoring the service Impact monitoring (environment, mobility, etc.) Awareness raising and information Training in use
Ministries	Provision of vehicles Identification of potential users Management of the service Monitoring the service Impact monitoring (environment, mobility, etc.) Awareness and information Training for use
Secondary schools	Identification of potential users Management of the service Monitoring of the service Support for monitoring (periodic provision of information and data)
Universities	Identification of potential users Management of the service Monitoring of the service Support for monitoring (periodic provision of information and data)

7.2.6. MONITORING OF RESULTS

Project activities should be monitored through Key Performance Indicators (KPIs) to verify whether the mobility service is working effectively and whether the objectives of the investment are being met. The monitoring activities will therefore allow the identification of possible corrective measures. An example of monitoring indicators is presented in Table 7.8. However, the number of indicators should be limited and easily measurable in order to easily accomplish this task.

Table 7.8.

KPIs - Investment concept Ouagadougou #1

Sector	Stakeholders	KPI
Service	All	Number of users Number of trips Distances travelled User satisfaction (through questionnaires)
Vehicles	All	Commercial speed (as reported by users) Battery life (reported by users) Technical problems (reported by users) Number of vehicles charged per day Charging problems

7.2.7. DEVELOPMENT COSTS

Table 7.9 summarizes the investment costs for the two e-bike models under consideration and for scenarios of 50 to 100 vehicles deployed. The number of vehicles shown is considered appropriate for a preliminary experiment in electric mobility. However, this number could potentially be reduced depending on the financial resources available and the supply of electricity at the sites.

Table 7.9.

Development costs - Investment concept Ouagadougou #1

Elements	N° of vehicles	Cost (US$)	Cost (CFAF)
Scenario A			
Electric bicyclemodel 1	50	18,700	10,390,000
Electric bicyclemodel 2		30,000	16,700,000
Annual maintenance		710	393,000
Annual electricity consumption		800	441,000
Total (for one year)	-	50,210	27,924,000
Scenario B			
Electric bicyclemodel 1	100	37,400	20,775,000
Electric bicyclemodel 2		60,000	33,335,000
Annual maintenance		1,420	787,000
Annual electricity consumption		1,600	882,000
Total (for one year)	-	100,420	55,848,000

7.2.8. POTENTIAL RISKS

Potential risks associated with the implementation of this investment concept and mitigation strategies are presented in Table 7.10.

Table 7.10.

Risk analysis and mitigation strategies - Investment concept Ouagadougou #1

Risks	Impacts	Mitigation strategies
Low user interest in electric vehicles (e.g., fear of unreliability)	Risk: Low Impact: Medium	Identification of users on a voluntary basis or through an auction Implementation of an awareness and communication campaign before the pilot project begins Ongoing communication about the potential of e-bikes and the positive impacts
Prohibitively high service costs	Risk: Low Impact: High	Detailed cost analysis in the design phase of the pilot project Support from institutions (municipality, ministries) to identify prices, facilitate agreements between stakeholders, and set electricity prices during the pilot phase
Insufficient availability of energy for vehicle charging at the sites	Risk: Medium Impact: High	Detailed analysis of site capacity in the design phase of the pilot Management of recharging according to real needs (days and periods of recharging)
Insufficient battery life for services	Risk: Medium Impact: Medium	Training for users on the proper use of e-bikes Control of the use modes and advice on use Possible revision of the type of user
Low durability of e-bikes in relation to poor road conditions	Risk: Low Impact: Medium	Control of use patterns and advice on vehicle use.

7.2.9. TIMELINE

The following timeline should apply to the rollout of the investment concept (Figure 7.3).

Figure 7.3.

Development timeline – Investment concept Ouagadougou #1

Detailed design
Months 1 to 6

- Memoranda of Understanding between stakeholders
- Project design by stakeholders
- Agreement on forms of use
- Identification of potential funders

Implementation
Months 7 to 12

- Vehicle procurement
- Stakeholder training
- Awareness campaigns
- Launch of the service

Pilot project
Months 13 to 24

- Periodic data collection for monitoring
- Periodic reporting on activities
- Mid-term evaluation
- Final evaluation

7.3. ELECTRIC SCOOTERS FOR MAIL AND NEWSPAPER DELIVERY SERVICES IN BAMAKO AND OUAGADOUGOU

7.3.1. RATIONALE

Delivery services in both Bamako and Ouagadougou use motorcycles to deliver letters, parcels, and newspapers (Figure 7.4 and Figure 7.5).

In Bamako, the Malian postal service has had a low volume of activity in recent years. However, a trial program to revitalize the service began in March 2021 with a donation of 20 motorcycles. About 50 motorcycles could bed use currently for postal service in Bamako.

In contrast, the distribution of the national daily newspaper is very active. Every morning, newspapers are delivered by motorcycle to almost all administrative centers in Bamako. This service represents a significant volume of activity. Approximately 30 motorcycles are used for this service, covering an average distance of 25 km per day.

In Burkina Faso, "La Poste" uses ICE two-wheelers for the collection, processing, dispatch, and distribution of urgent items. The service operates through door-to-door pickup and

delivery on a call-by-call basis or automatically according to contractual terms. Once the mail is delivered, an acknowledgement of receipt and a message is sent to the correspondents. About 50 motorcycles could be used for these services.

Ouagadougou, motorcycles are also used for "courier" services by public and private companies. Almost all companies have liaison officers for the distribution of mail of various kinds. An estimated 100 motorcycles could be used for these services.

Delivery services have potential for the development of electric mobility in both cities, as an electric delivery service could help demonstrate the benefits of electric vehicles.

The cost of ownership of a gasoline-powered motorcycle in Ouagadougou is US$0.045/km (CFAF 25/km), while an electric scooter has a TCO of US$0.033/km (CFAF 18/km). Considering a distance travelled of 80 km per day (the maximum distance according to the range of an electric scooter), this translates into a cost of about US$2.6 (CFAF 1,500) per day with an electric scooter compared to about US$3.6 (CFAF 2,000) per day with a gasoline powered motorcycle.

In Bamako, a gasoline scooter has a TCO of US$0.047/km (CFAF 26/km), while an electric scooter has a TCO of US$0.040/km (CFAF 22/km). Considering an average distance travelled of 80 km per day, this translates into a TCO of about US$3.2 (CFAF 1,800) per day with an electric scooter compared to about US$3.8 (CFAF 2,100) per day with a gasoline scooter.

The relative benefit of lower greenhouse gas emissions due to the use of electric scooters would be quite significant in both Bamako and Ouagadougou. An electric scooter produces between 60 and 65 gCO2eq/passenger-km in Bamako and Ouagadougou, respectively. In contrast, a gasoline-powered motorcycle in Ouagadougou produces 171 gCO2eq/passenger-km and a gasoline-powered scooter in Bamako produces 125 gCO2eq/passenger-km. Therefore, use of electric scooters in Bamako could reduce the equivalent CO2 emissions per km by more than 50 percent, while the potential for CO2 emissions reduction in Ouagadougou would be 62 percent.

DID NOT FIND THESE.

Figure 7.4.

Two-wheelers for mail services in Ouagadougou

Figure 7.5.

Two-wheelers mail services à Bamako

7.3.2. OBJECTIVES AND IMPLEMENTATION

The objective of this investment concept is to introduce, in the short term, several electric scooters to be used for mail and newspaper delivery services. This concept would necessarily have to be implemented in close collaboration with the public or private company in charge of delivery.

This same concept could be implemented in both Bamako and Ouagadougou, involving the following target groups:

- Bamako:
  - Postal workers of the Mali Post Office.
  - Distribution agents of the national daily newspaper (L'Essor).
- Ouagadougou:
  - Postal workers of the Burkina Faso Post Office.
  - Liaison officers from the municipality or other public institution, if applicable.

The pilot projects in Bamako and Ouagadougou can be implemented independently of each other.

The investment concept foresees the deployment in each city of 20 electric scooters that should be used for daily mail or newspaper delivery activities. Each electric scooter should be provided to a single letter carrier for a fixed period (e.g., 6 months) to collect sufficient information about driving habits and possible problems with the electric vehicle.

The electric scooters should be used only for delivery services and not for the mailmen's commute, for example. The objective of this pilot project is to test the use of "light" electric vehicles on targeted and fixed routes. In addition, this method of use allows the batteries of the scooters to be recharged during non-working hours. Recharging would take place at the headquarters of the companies involved, which are assumed to have a more reliable electricity supply than private homes.

The type of vehicle to be used for this pilot could have the characteristics shown in Table 7.11. The model allows battery charging through the electrical grid using a normal electrical outlet. This model of scooter does not necessarily need specific charging stations and does not allow "battery swapping."

The purchase of the electric scooters could be performed by the company itself, the central government, or the municipality. Operational costs (charging, maintenance, etc.) should be covered by the company that receives and uses the vehicles.

The investment concept will necessarily have to be accompanied by awareness campaigns (conducted by public institutions) aiming to foster greater understanding of the benefits of electric mobility as well as to convey positive messages about the reliability of electric scooters. These communication should also include the benefits obtained by future pilot projects on mail or newspaper delivery.

To guarantee an optimal life span of the scooters and batteries, it will also be important to train the distribution agents on how to use the vehicles, the most suitable driving style,[18] as well as how to manage performance and possible malfunctions.

Table 7.11.

Electric scooter

Electric scooter model	
Motor	2000 W
Voltage	72 V
Recharge duration	6-8 h
Tires	16’’
Max speed	50 km/h
Autonomy	80 km

7.3.3. SCALABILITY AND REPLICABILITY OF THE CONCEPT

The investment concept should be quite easily scalable within the same environment in Bamako and/or Ouagadougou. This would involve the gradual introduction of more electric scooters and increasing the number of distribution agents associated with the program.

The same concept could also be replicated in other fleets of ICE two-wheelers for public or private companies (e.g., private delivery agents, the municipal police fleet, etc.) in Bamako and/or Ouagadougou. The replicability of the concept in other cities could be achieved if similar delivery services or fleets of two-wheelers are available. Electric scooters could also replace gasoline-powered four-wheelers, which would result in higher environmental and traffic benefits.

18 The most suitable driving style should be as close to “relaxed” as possible, so that the electric powertrain will have its maximum efficiency under most operating conditions (see Life Cycle Assessment).

7.3.4. ADDITIONAL STUDY OR RESEARCH NEEDS

The implementation of this pilot project would require further study or research with respect to the following issues:

- *More precise definition of the service* ***supply****, particularly in relation to the specific model of scooter to be used.* This research could also study the possibility of developing a solar powered battery recharging system. This topic could be analyzed during the pilot project to use real data on the use of electric scooters, their autonomy, the energy needs for battery recharging, etc.
- *Identification of the* ***administrative and regulatory processes*** *required to put the electric scooters on the road (e.g., first vehicle approval).*

7.3.5. RESPONSIBLE ENTITY AND STAKEHOLDERS

This pilot project should be handled mainly by the company that performs the delivery, which already has experience in managing these services. The stakeholders involved in this project and their roles are described in Table 7.12.

Table 7.12.

Stakeholders and their roles – Investment concept Bamako #2 / Ouagadougou #2

Stakeholders	Roles
Delivering company	Responsible entity Purchase of electric scooter Management and coordination of the service Identification of delivery agents Monitoring the activities of the delivery agents
Ministries	Purchase of electric scooters Support for the implementation (facilitation of administrative procedures) Awareness activities on electric mobility Training of distribution agents
Municipalities	Support for implementation (facilitation of administrative procedures) Impact monitoring (environment, mobility, etc.) Awareness raising activities on electric mobility Training of distribution agents

7.3.6. MONITORING OF RESULTS

The investment concept will need to be verified in terms of usage, service reliability, mobility, and environmental impacts. Key Performance Indicators (KPIs) useful for monitoring purposes are shown in Table 7.13, which also indicates the stakeholders involved.

Table 7.13.

KPIs – Investment concept Bamako #2 / Ouagadougou #2

Sector	Stakeholders	KPI
Scooter use	Post	Trips by distribution agents on electric and non-electric scooters Typical trips on electric and non-electric scooters Duration of battery recharges Driving styles Electrical energy expenditure Maintenance expense
Vehicles	Postmen	Commercial speed // Battery life Distance travelled // Trips per day
Environment	Municipalities	Estimated impacts on air pollutants // Estimated impacts on noise
Mobility and safety	Municipalities	Crashes involving electric scooters // Crashes caused by lack of noise

7.3.7. DEVELOPMENT COSTS

An estimate of the costs required to implement this investment concept is summarized in Table 7.14 which also includes the stakeholders involved.

Table 7.14.

Development costs – Investment concept Bamako #2 / Ouagadougou #2

Elements	Stakeholders	N°	Cost (US$)	Cost (CFAF)
Electric scooters	Delivery company Ministries (eventually)	20	12,500	6,930,000
Electricity (battery recharging)	Delivery company	20/day	3,500/year	1,950,000/year
Annual maintenance	Delivery company	-	1,000/year	555,000 / year
Total (for one year)	-	-	17,000	9,435,000

7.3.8. POTENTIAL RISKS

Potential risks associated with the implementation of this investment concept and mitigation strategies are presented in Table 7.15.

Table 7.15.

Risk analysis and mitigation strategies – Investment concept Bamako #2 / Ouagadougou #2

Risks	Impacts	Mitigation strategies
Low interest factor in electric vehicles (e.g., fear of unreliability)	Risk: Low Impact: Medium	Implement awareness and communication campaign before the pilot project begins Initial training on the use of electric scooters Ongoing communication about the effectiveness of electric scooter delivery services and the positive impacts
Insufficient battery life for postal services	Risk: Medium Impact: Medium	Training for letter carriers on the proper use of electric scooters Training on the best ways to recharge batteries Control of the use of the scooters and advice on their use from the company Possible revision of the distances to be covere
Low durability of electric scooters in relation to local road conditions and frequent use	Risk: Low Impact: Medium	Control of usage patterns and advice on usage from the company
Insufficient availability of energy for vehicle charging at the sites	Risk: Medium Impact: High	Detailed analysis of site capacity in the design phase of the pilot project Management of recharging services according to actual needs (days and periods of recharging)

7.3.9. TIMELINE

The investment concept could be implemented according to the following preliminary timeline (Figure 7.6).

Figure 7.6.

Development timeline – Investment concept Bamako #2 / Ouagadougou #2

Detailed design
Months 1 to 6

- Memoranda of Understanding between stakeholders
- Project design by stakeholders
- Agreement on forms of use
- Identification of potential funders

Implementation
Months 7 to 12

- Vehicle procurement
- Stakeholder training
- Awareness campaigns
- Launch of the service

Pilot project
Months 13 to 24

- Periodic data collection for monitoring
- Periodic reporting on activities
- Mid-term evaluation
- Final evaluation

7.4. ELECTRIC SCOOTERS FOR EMPLOYEES IN BAMAKO AND OUAGADOUGOU

7.4.1. RATIONALE

Electric scooters are a competitive means of transport compared to ICE vehicles, as they have a lower total cost of ownership (TCO) over their technical life in Bamako and Ouagadougou.[19]

The difference is illustrated in Bamako where an electric scooter has a TCO equal to US$0.040/km (CFAF 22/km), while a gasoline scooter has a TCO equal to US$0.047/km (CFAF 26/km). In Ouagadougou, the situation is somewhat more advantageous thanks to the lower cost of electricity; the TCO of the electric scooter and the ICE scooter are US$0.033/km (CFAF 18/km) and US$0.042/km (CFAF 23/km), respectively.

The difference is even more significant for ICE motorcycles, as the TCO of motorcycles is equal to US$0.051/km (CFAF 28/km) in Bamako and US$0.045/km (CFAF 25/km) in Ouagadougou.

These economic benefits are accompanied by net environmental gains. Indeed, an electric scooter has an emission of 60 and 65 gCO_2eq/passenger-km in Bamako and Ouagadougou, respectively. In contrast, a gasoline-powered motorcycle produces 171 gCO_2eq/passenger-km and a gasoline-powered scooter produces 125 gCO2eq/passenger-km in both cities.

In addition to these decarbonization benefits, it is worth mentioning that the switch to electric vehicles would avoid the local emission of several pollutants dangerous to human health such as particulate matter (PM), hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx), and other emissions resulting from the release of burnt and unburnt lubricating oils.

The mileage provided by the battery of an electric scooter is about 80-90 km. Although variable depending on specific driving conditions, this travel range is compatible with a large proportion of daily trips made in cities (averaging 10-13 km per trip) and would allow several round trips without the need to recharge. Electric scooters could therefore be considered a competitive alternative to both mopeds and motorcycles, provided that effective information and communication are provided to users.

7.4.2. OBJECTIVES AND IMPLEMENTATION

The deployment of electric scooters among public sector employees for their daily "home-to-work" trips could replace a portion of the trips made by ICE vehicles without any difficulty. A rough estimate shows that more than 1,000 motorcycles used daily for "home-to-work" trips by public sector employees could be replaced by electric vehicles.

Given the limited accessibility to electricity at home as well as an unstable electricity supply due to weaknesses in the electricity grid, an initial development of electric scooters could concern people commuting from their homes to their offices. The fact that public sector employees have been working "full time" for several years and therefore do not go home for lunch should also be considered. Most employees make one round trip per day (about 25 km per day).

Offices could be the primary location for charging electric scooters, as they generally have better access to the electrical grid than private homes. In addition, recharging during working hours would avoid wasting time waiting for the recharge to be completed. Finally, public sector employees are more likely to include people who travel at mileages compatible with the range of the electric scooter battery.

19 According to the TCO analysis carried out in this study and its baseline scenario.

The investment concept could be implemented by deploying 20 electric scooters among public sector employees who could be selected on a voluntary basis or through an auction that takes into account their usual travel patterns and applies a rotation mechanism. In fact, each person could receive the electric scooter for a period of 3-6 months to allow for equitable access to the service, as well as testing of the mobility habits of different users, their driving behavior, and their experience.

The pilot project should have a duration of at least 12 months. The recommendation to deploy the pilot in the public sector is strictly based on an immediate and clear identification of the target groups and a rather easy management/control of the potential users. Nevertheless, there is no concern about possibly involving private sector employees in the future.

The electric scooters should be given to the users free of charge, as the main objective of the pilot project is to allow them to experiment with electric vehicles and to pave the way for their use as an alternative to traditional means of transportation. In this regard, the local government or municipality should cover the purchase and operational costs of the vehicles.

An example of an electric scooter model is shown in Table 7.16 in which the technical characteristics of the vehicle are summarized.

The average purchase cost is equal to US$700 (CFAF 386,000), for a total investment of US$14,000 (CFAF 7,716,000) to deploy 20 electric scooters.

In terms of annual operational costs for a pilot project in Bamako, the energy consumption of a single vehicle is estimated to be US$110 (CFAF 60,630) assuming 25 km per day travelled, while insurance and taxes amount to US$42 (CFAF 23,150) and maintenance amounts to US$22 (CFAF 12,125). The resulting operational cost for the entire fleet of 20 electric scooters would therefore be US$3,480/year (CFAF 1,918,000/year). These estimates assume that taxes and insurance would be the same as for ICE vehicles.

In Ouagadougou, the annual operational costs of the pilot project are estimated as follows: US$79 (CFAF 43,540) in energy consumption for each vehicle (assuming 25 km travelled per day), US$40 (CFAF 22,050) in taxes, and US$22 (CFAF 12,125) in maintenance. The overall operational cost of the fleet of 20 electric scooters would be US$2,820/year (CFAF 1,554,000/year). As for Bamako, it is assumed that taxes would be the same as for ICE vehicles (currently insurance is not mandatory).

Disseminating information and building awareness of the technical characteristics and capabilities, as well as the cost of ownership of electric scooters, are key variables in introducing these modes of transportation to citizens. In fact, one of the main barriers to the adoption of electric vehicles in the market is insufficient knowledge of their potential and cost-effectiveness which leads to biased perceptions and unjustified doubts and fears.

Therefore, information and awareness campaigns should be organized for target groups and other citizens with the aim of imparting technical knowledge about electric scooters and their capabilities, as well as the anticipated environmental benefits.

Prior to the start of the pilot, the target users should receive technical training to prepare them to use the vehicles properly, manage their performance, and respond to malfunctions.

Table 7.16.

Example of electric scooter

Electric scooter	
Make and model	KAINING KN-JIAYUE
Motor	1 500 W
Voltage	72 V
Recharge duration	6-8 h
Tires	16’’
Max speed	45 km/h
Autonomy	90 km

7.4.3. SCALABILITY AND REPLICABILITY OF THE CONCEPT

The pilot project can be scaled up and extended locally to accommodate more participants from both the public and private sectors.

The increase in the number of vehicles delivered to a single institution should not create challenges in terms of recharging. Attention should be paid, however, to the management of recharging periods to avoid any problems related to weaknesses in the energy supply.

With respect to the costs of purchasing and operating electric scooters, the availability of public resources should be assessed. If necessary, additional resources could be provided by sponsors. Designing new incentives for users could also be considered.

The replicability and scalability of the investment concept to other cities is possible if they have similar mobility patterns (i.e., short- and medium-distance commuting, less than 25 km per day).

7.4.4. ADDITIONAL STUDY OR RESEARCH NEEDS

The implementation of this pilot project would require additional studies or research with respect to the following issues:

- *Analysis of the **demand** of users who could be involved as users of electric scooters.* This study should primarily identify potential users based on commuting distances and current means of transportation. This analysis would also identify the workplaces that could be involved in the project.
- *Further definition of the service **supply**, particularly in relation to the specific model of scooter to be used.* This research could also study the possibility of developing a system of battery recharging by solar energy. This issue could be analyzed during the pilot project in order to use real data on the use of electric scooters, on their autonomy, on the energy needs for battery recharging, etc.
- *Identification of the **administrative and regulatory processes** required to put the electric scooters on the road.*

7.4.5. RESPONSIBLE ENTITY AND STAKEHOLDERS

The responsible entity for this pilot project should be the municipalities of Bamako and/or Ouagadougou, which have the capability to provide the vehicles and management the project. The municipalities of Bamako and Ouagadougou and the national ministries are the main target groups for the investment concept, according to the roles described in Table 7.17.

Table 7.17.

Stakeholders and their roles – Investment concept Bamako #3 / Ouagadougou #3

Stakeholders	Municipalities	Ministries
Roles	**Responsible entity** Supply of electric scooters (possibly provided by the central government) Identification of potential users Management of the service Monitoring the service Monitoring of impacts (environment, mobility, etc.) Information, awareness, training of users	Purchase and provision of vehicles Identification of potential users Management of the service Monitoring the service Impact monitoring (environment, mobility, etc.) Information, awareness, training of users

7.4.6. MONITORING OF RESULTS

The activities of the pilot project should be monitored through Key Performance Indicators (KPIs) in order to verify whether the mobility service is working effectively and the objectives of the investment are being met. The monitoring activities will therefore allow for the identification of possible corrective measures. An example of monitoring indicators is presented in Table 7.18. The number of indicators should be limited and measurable, in order to accomplish this task more easily.

Table 7.18.

KPIs – Investment concept Bamako #3 / Ouagadougou #3

Sector	Stakeholders	KPI
Service	All	Number of users Number of trips Km travelled User satisfaction (compiled through questionnaires)
Vehicles	All	Commercial speed according to users Battery life reported by users Technical problems reported by users Number of vehicles charged per day Charging problems

7.4.7. DEVELOPMENT COSTS

Table 7.19 summarizes the costs of the investment concepts in Bamako and Ouagadougou. The differences in costs between the two cities are explained by different energy costs, taxation levels, and regulatory frameworks. The proposed number of vehicles may be reconsidered depending on the availability of public funding and the actual power supply conditions of the selected sites.

Table 7.19.

Development costs – Investment concept Bamako #3 / Ouagadougou #3

Elements	N° of vehicles	Cost (US$)	Cost (CFAF)
Bamako			
Purchase of electric scooters	20	14,000	7,716,000
Annual electricity consumption	20	2,200	1,212,600
Insurance and taxes	20	840	463,000
Annual maintenance	20	440	242,500
Total (for one year)	-	17,480	9,634,100
Ouagadougou			
Purchase of electric scooters	20	14,000	7,716,000
Annual electricity consumption	20	1,580	870,800
Insurance and taxes	20	800	441,000
Annual maintenance	20	440	242,500
Total (for one year)	-	16,780	9,270,300

7.4.8. POTENTIAL RISKS

Potential risks associated with the implementation of this investment concept and mitigation strategies are presented in Table 7.20.

Table 7.20.

Risk analysis and mitigation strategies – Investment concept Bamako #3 / Ouagadougou #3

Risks	Impacts	Mitigation strategies
Low user interest in electric vehicles (e.g., fear of unreliability).	Risk: Low Impact: Medium	Identification of users on a voluntary basis or through an auction Implementation of an awareness and communication campaign before the pilot project begins Ongoing communication about the potential of electric scooters and their positive impacts
Prohibitively high service costs	Risk: Low Impact: High	Detailed cost analysis in the design phase of the pilot project Support from institutions (municipalities, ministries) to identify prices, facilitate agreements between stakeholders, and set electricity prices during the pilot phase
Insufficient availability of energy for vehicle charging at the sites	Risk: Medium Impact: High	Detailed analysis of site capacity in the design phase of the pilot Management of recharging according to real needs (days and periods of recharging)
Insufficient battery life for services	Risk: Medium Impact: Medium	Training of users on the proper use of electric scooters Control of the modes of use and advice on the use Possible revision of the type of user
Low durability of electric scooters in relation to local road conditions and use	Risk: Low Impact: Medium	Control of use patterns and advice on use

7.4.9. TIMELINE

The following timeline should apply to the deployment of the investment concept (Figure 7.7).

Figure 7.7.

Development timeline - Investment concept Bamako #3 / Ouagadougou #3

Detailed design
Months 1 to 6

- Memoranda of Understanding between stakeholders
- Project design by stakeholders
- Agreement on forms of use
- Identification of potential funders

Implementation
Months 7 to 12

- Vehicle procurement
- Stakeholder training
- Awareness campaigns
- Launch of the service

Pilot project
Months 13 to 24

- Periodic data collection for monitoring
- Periodic reporting on activities
- Mid-term evaluation
- Final evaluation

R7. REFERENCES

[3] OPTIS (2020) «Ouagadougou Public Transport Implementation Study. Rapport d'Activité 1»

8.

RECOMMENDATIONS FOR THE DEVELOPMENT OF ELECTRIC MOBILITY

The development of electric mobility would be facilitated by the definition of a national strategic plan for electric mobility by the governments of Burkina Faso and Mali that would provide a framework for the transition process, the objectives, the strategies to be put in place, the key actors, and the necessary resources. The plan should consider a set of medium- and long-term strategic recommendations for decision- makers, especially for the promotion of electric two- and three-wheelers.

Strategic recommendations can be formulated based on the analyses carried out during the study, the consultations with stakeholders, and the international experiences of participants in the electric mobility sector.

As shown in Figure 8.1, the recommendations touch on several areas that can all contribute to changing the paradigm of two- and three-wheeled mobility to reduce carbon emissions, air pollution and dependence on fossil fuels in the long term.

The recommendations are described in Table 8.1 according to a set of categories and a priority level for their implementation.

Figure 8.1.

Areas contributing to electric mobility

Table 8.1.

Recommendations for the development of electric mobility on two- and three-wheelers

Priority	Recommendations
Skills and knowledge	
High	The governments of Burkina Faso and Mali should improve specific **knowledge** of electric mobility (particularly on electric two- and three-wheelers) and related **skills** at the level of the **ministries** to better focus on the potential of the electric transition and consequently to design **public policies** to support the transition. The same applies to local governments. In this respect, ministries in charge of public transport policies should organize **capacity building activities** for technicians and decision-makers with the support of multilateral and international organizations. This will enable effective management of policies and interventions.
High	National and local policies should be put in place to **raise citizens' awareness of the environmental and health costs of conventional mobility.** In fact, citizens of both Ouagadougou and Bamako do not seem to have a clear understanding of the causes of mobility-related pollution, and show limited awareness of the real consequences of their mobility-related behavior. **Raising awareness of environmental and health issues** should be a prerequisite for the dissemination and promotion of electric mobility on two- and three-wheelers. Indeed, the analyses conducted in Ouagadougou and Bamako have shown that the transition to electric mobility also requires a cultural change that should be supported by public authorities.
High	Public authorities in Burkina Faso and Mali should be active in **communicating and disseminating information on the technical characteristics of electric two- and three- wheelers.** This will address the current knowledge gap which prevents citizens from viewing electric vehicles as an alternative to the ICE vehicles currently in use. This activity should also include **training sessions** for users and service providers (e.g., garages, mototaxi companies, etc.) regarding the correct management of technical problems. In particular, the communication should make use of the information from this study regarding the ownership costs, environmental and energy benefits, etc. of using electric two- and three- wheelers instead of internal combustion engines. In particular, the municipalities of Bamako and Ouagadougou should take advantage of the analyses carried out in the two cities to develop targeted communication campaigns.
High	The national and local governments of both countries should implement **pilot projects** to allow users to gain direct experience with electric vehicles and go beyond the phase of mere "perception" of their benefits and characteristics. These pilot projects should first focus on electric two-wheelers (motorbikes and scooters) in both Ouagadougou and Bamako, due to the higher potential for the vehicles' use in those cities and avoidance of large investments in charging infrastructure. The pilot projects should focus on the investment concepts described in the study for the cities of Ouagadougou and Bamako.
High	End-of-life management, especially of batteries, should be built into the structure of the different scenarios as a critical way of minimizing negative environmental impacts in the medium/long term.
Medium	The establishment of a local (public) **system of periodic assessment of transport pollution** is an important activity to support effective mobility policies. In both Ouagadougou and Bamako, detailed data on noise pollution, air pollution and greenhouse gas emissions are currently not available. This hinders the potential for evaluating the effectiveness of sustainable mobility solutions.

Priority	Recommendations
Economic and financial aspects	
Medium	The governments of Burkina Faso and Mali should consider **the introduction of public subsidies** to reduce the purchase cost differential of electric two- and three-wheelers compared to their internal combustion engine counterparts. Cost of ownership analyses and consultations with stakeholders in Ouagadougou and Bamako have shown that this is a relevant issue in both cities. A higher purchase cost of electric two- and three-wheelers compared to the ICE equivalents currently in use could limit the attractiveness of electric vehicles and slow down the transition. Similarly, **policies that support the development of a financial ecosystem** that allows for the payment of vehicles in installments should be encouraged. Vehicles are currently paid in cash at the time of purchase in both Ouagadougou and Bamako. The possibility of making staggered purchases would be a benefit to customers. The **reduction or elimination of import taxes** on electric two- and three-wheelers should also be considered, as they have a significant influence on the selling price on local markets. Currently, no specific tax provisions are in place for electric vehicles. The possibility of setting a differentiated regime favoring electric vehicles would contribute to reducing or even eliminating the upfront cost differential with ICE vehicles. This would be particularly useful in demonstrating national government preference for electric mobility. At the same time, an easing of custom procedures should be considered to make the electric vehicle supply more responsive to demand and increase the chance that the electric market will meet users' expectations. In order to further increase their convenience, users of electric two- and three-wheelers in both countries could be **exempted from paying possession fees** related to different aspects of vehicle ownerships, like registration, technical inspections, etc. These fees could at least be reduced in comparison to MCI two- and three-wheelers. Such a policy could be implemented as a short-term measure to expedite the market uptake of electric vehicles. Nevertheless, considering that the reduction on tax revenues (including the fuel tax) might lead to imbalances in government finances and eventually an underfunding of the transport sector, it is recommended that a medium- to long-term assessment of the "fine balance" of tax policy be implemented. **Disincentives** against the use of polluting modes of transport could also be identified (e.g., restriction of access to certain areas of the city).
Public policies	
High	The interrelation of public policies of the sectors involved in electric mobility should be developed to ensure consistency. Any electric mobility policies on two- and three-wheelers developed by the governments of Burkina Faso and Mali should be strictly coordinated with energy policies in order to ensure harmony and avoid an unsustainable impact on national electricity production. This is especially necessary in the case of the fast electric two- and three-wheeler penetration scenarios envisioned for the two cities, which require significant improvements to the electricity grid and an increase in domestic electricity production from renewable sources. These improvements should also aim to increase access to electricity for the citizens of Ouagadougou and Bamako so that electric two- and three-wheelers can be recharged without too many problems. The implementation of this recommendation should be managed by a government entity designated as the "leader" (e.g., the ministry in charge of public transport policies).
High	From a normative point of view, electric mobility of two- and three-wheelers would require **a revision of transport standards**. Indeed, current legislation in Burkina Faso and Mali does not include electric vehicles in the codification of transport modes. This is a relatively simple change that concerns the inclusion of new types of vehicles. However, this revision of the standards is necessary to ensure that electric two- and three-wheelers can be registered and can circulate freely throughout these cities.

Priority	Recommendations
Medium	The development of electric two- and three-wheelers should be **coordinated with local public transport development plans** to increase the overall efficiency of the transport system. In Ouagadougou, where public transport development is receiving particular attention (e.g., investments for BRT corridors), the sharing of electric two- and three-wheelers is seen as a potential opportunity to complement the transport system (e.g., as support for BRT feeder lines). As the development of public transport in Ouagadougou and Bamako progresses, electric mobility of two- and three-wheelers should gradually be oriented towards integration services as opposed to competing with public transport.
Low	Local mobility management should envision disincentives to the use of conventional vehicles in both cities, including **restrictions on circulation** in specific areas (e.g., central areas).
Medium	Identifying public policies for the **management of electric mobility products**, especially for battery recycling, should be carefully considered to ensure that a lack of management does not cause environmental problems. Currently, the recycling systems in Bamako and Ouagadougou are not able to cope with the high demand for battery recycling. Policy guidelines should aim to adapt local systems to demand while encouraging the establishment of specialized structures and companies.
Low	Public industrial policies should be considered to **encourage the opening of factories on national territory** (possibly by international electric vehicle manufacturers), thus linking the transition to electric mobility to positive effects on employment and economic development. Factories could, for example, focus on the production of electric two- and three-wheelers, batteries, recharging infrastructure, recycling services, etc. As indicated in the life cycle analysis, all of these areas would reduce the environmental impacts caused by the transport phase of the vehicles from the production sites to the places of use.
Low	Electric two- and three-wheelers are normally slower than their ICE counterparts. **Public policies to limit the speed of ICE two- and three-wheelers** could be used to limit the differences between the vehicle types and could also contribute to a reduction in traffic accidents.
Energy sector	
High	The governments of Burkina Faso and Mali should **improve the national energy mix**, aiming mainly at increasing electricity production from renewable sources in order to increase the environmental benefits of electric two- and three-wheelers. Indeed, life cycle analyses of two- and three-wheelers in Bamako and Ouagadougou have clearly shown that the presence of a better energy mix would further increase the capacity of electric two- and three-wheelers to reduce air pollution and greenhouse gas emissions. The improvement of national energy mixes should focus on the development of **solar power generation.**
Medium	In order to avoid overloading of the electricity grid, the electrical transition should be accompanied by a **monitoring of charging patterns** to estimate the impact of current and newly constituted peak periods. This activity should be the basis of assessing an eventual revision/adaptation of the current hourly tariff regimes with the objective of setting **efficient hourly rates** to incentivize off peak charging.

Priority	Recommendations
Infrastructures	
Medium	The **development of a charging infrastructure network (charging stations and/or battery exchange services)** should be designed and implemented in both Ouagadougou and Bamako in the medium term. Neither the infrastructure nor the services for electric mobility exist currently in either city. While certain two-wheelers used for limited distances can be easily recharged via standard plug at home or at the office, the penetration of electric two- and three- wheelers on a large scale in the medium/long term would be limited as greater charging needs arise. The use of electric two- and three-wheelers can start on a small scale by using battery exchange services or simply by charging the vehicles through a building's electricity network. This is not sustainable in the medium/long term, however, until a widespread charging infrastructure network and/or battery exchange services is implemented. The development of a charging infrastructure network would require an increase in electricity production as well as the improvement of the electricity network in both cities (e.g., to avoid load shedding problems) and the development of network management systems (e.g., to avoid electricity consumption peaks concentrated at specific times of the day).

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A.

ANNEXES

ANNEX 1
INTERNATIONAL PRACTICES

The current global market for motorized two-wheelers is dominated by two regions (Asia and Africa) that account for 95 percent of global sales. Scooters and motorcycles up to 250cc are particularly dominant, accounting for 90 percent of the global market.

Asia accounts for 82 percent of the world market for motorized two-wheelers, while Europe and North America account for 3 percent and 1 percent, respectively. The remaining 14 percent is accounted for by other regions, including Africa.

In 2019, more than 300 million electric motorized two-wheelers were registered and used in China. During the same year, nearly 152,000 units of electric motorcycles and scooters were sold in India. The European market for electric scooters and motorcycles grew in 2020; sales on the continent (28 countries including the UK) reached 75,000 units, an increase of 22.6 percent over 2019.

In some parts of the world, particularly South Asia, small three-wheel motorized cabs are an important part of the urban transportation system for carrying passengers. In addition to South Asia, three-wheel cabs are also common in Indonesia, Thailand, coastal Kenya, Ethiopia, and increasingly in Tanzania, Egypt, Gambia, Cambodia, Laos, the Philippines, Cuba, Guatemala, and Peru. Three-wheeled cabs go by a variety of names in different countries, including auto-rickshaws, tuk-tuks, trishaws, autos, rickshaws, autoricks, bajajs, ricks, tricycles, mototaxis, Kata Katani and baby taxis.

In recent years, the Asia-Pacific region has emerged as the largest market for electric three-wheelers. In fact, when all other vehicle segments experienced slow growth in demand compared to the previous year, sales of electric three-wheelers increased by about 21 percent during 2018-2019.

According to IEA, electric two/three-wheelers will continue to represent the lion's share of the total electric vehicle fleet worldwide. Indeed, this vehicle category is well-suited to completely transition from internal combustion engines to electric drives thanks to the combination of relatively short trip distances, low energy requirements per kilometre (km) driven, small battery size and ease of charging without the need for dedicated charging infrastructure. The future electric two- and three-wheeler fleet will be concentrated in China, India and the ten countries of ASEAN.

China is a leader in the adoption of electric technology with a series of far-reaching policies [40]. The stock of electric two/three-wheelers in China is now approaching 300 million vehicles. In 2020, 60 percent of the two and three-wheelers sold in China were electric, and it is expected this value will reach 85 percent by 2030. In the same year 2020, most of the electric mobility GHG savings (50 Mt CO2-eq) were achieved thanks to electric two and three-wheelers in China**[97]**.

The process began with small-scale projects and has developed into more articulated policies, including full or partial bans on gasoline-powered motorcycles in some major cities, subsidies, and setting electric vehicle quotas for vehicle manufacturers. Although the first electric two-wheelers in China were introduced in the 1980s, and Shanghai was the first city to ban ICE two-wheelers in the early 1990s, the actual emergence of electric two-wheelers in China started in the late 1990s. The exponential growth of two-wheelers was driven by several factors [96]:

- Technological improvements of batteries in the 1990s made electric two-wheelers reach similar technical performance as the ICE counterparts. At this time, the progress led to ranges of autonomy of 50/60 km that could more easily compete with ICE vehicles.
- As technology developed, the cost of electric two-wheelers decreased as income increased. On the other hand, the price of oil increased in the same period. With time, electric two-wheelers became more economically competitive.
- The central government developed policies to incentivize the development of electric two-wheelers including the development of national electric two-wheelers standards (1999) and the Road Transportation Safety Law (2004). The National Standard defined the performance limit for electric two-wheelers. Industry standards are being applied to achieve harmonization, specifically for electric two-wheelers and batteries. These standards allowed the use of any two-wheelers with functional pedals. This actually incentivized the development of electric scooters (even with limited pedal functionality), as the technical performance was just partly the same as the ICE scooters. The Road Transport Safety Law classified electric two-wheelers as non-motorized transport, which allowed their use without driving license or registration, and the ability to circulate in bike lanes.
- Policies were also developed at local level. Issues around energy and air pollution became a great concern as cities grew quickly and the impact of local air pollution affected public health. In the late 1990s, cities such as Guangzhou and Shijiazhuang, and many other large and mid-size cities started banning ICE two-wheelers. This removed the competition from ICE two-wheelers.

However, not all Chinese cities took this attitude towards electric two-wheelers. Beijing, for instance, banned electric-two wheelers for several years in favor of other modes of transport. Guangzhou banned electric two- wheelers in 2006 due to safety concerns. Other cities have banned them as well. The recycling of batteries has also created concerns about their use.

Another interesting transportation sector revolution in Chinese cities in the 2010s was the fight for the dominance of the bike-sharing market. The over-supply of bikes and the dump of non-maintained bikes in cities created concerns about the role of these shared modes. Some of the survivors of the bike-sharing war (that occurred initially with non-electric bikes) have not transformed into electric two-wheeler providers like Hellobike that started offering shared electric-bicycles in 2017. Some companies offered battery swap systems instead, rather than the plug-in-and-wait for charging to be completed.

India has announced an ambitious plan for a rapid transition to electric vehicles**[43][45][46][48]**. Motorized road transport in India has two major characteristics. First, it is dominated by two-wheelers, the preferred mode of personal transportation both in urban and rural areas. Second, there is a strong and increasing presence of three-wheelers, which serve as commercial vehicles for passenger and goods transport. Two-wheelers represent 20 percent of CO_2 emissions and 30 percent of particulate emissions in India. Three-wheelers cater to the mobility needs of those not using private transport and not being served by the existing mass transit system. Three-wheelers are also popular for goods transport for short distances. It has been estimated that two-wheelers and three-wheelers together constitute 83 percent of all vehicles in India. Electrification of two- and three-wheelers is recognized as a low hanging fruit for clean mobility in India, based on the market readiness, cost competitiveness, ease of charging, and emission reduction potential**[44]**.

The Indian government has put forward a series of measures under its FAME (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles) scheme to strengthen the Indian electric vehicle industry. The first phase of this scheme (FAME 1) was launched in April 2015 and ran for four years. Demand incentives, which were available as a direct subsidy on the retail price of eligible vehicles to consumers, were the most significant component of FAME 1. The first phase was designed to encourage all vehicle segments, including two- and three-wheelers, four-wheelers, light commercial vehicles, and buses. In addition, it covered hybrid and electric technologies such as mild hybrid, strong hybrid, plug-in hybrid, and battery electric vehicles.

Under FAME 1, 88 models of electric two-wheelers were eligible for a subsidy. Until September 2018, around 90 percent of the beneficiaries under FAME 1 were lead-acid powered electric scooters. From October 2018, subsidies for lead-acid battery vehicles were discontinued, but incentives for lithium-ion battery vehicles remained.

The sales of electric two-wheelers in India rose from 54 800 units in 2018 to 126 000 units in 2019. India had an estimated fleet size of 0.6 million electric two-wheelers in fiscal year2018-19. In addition, India is now home to approximately 1.5 million battery-powered electric three-wheelers (e-rickshaws). The e-rickshaws transport about 60 million people per day**[61]**. During the last few years, e-rickshaws have been introduced in several Indian cities and are allowed to operate on roads under certain conditions.

The government approved FAME 2 with a budget of approximately INR 100 billion (US$1.3 billion) for a three- year period from April 2019. FAME 2 focuses on vehicles used for public or shared transportation (buses, rickshaws, and taxis) and private two-wheelers. 23 percent of the budget for demand incentives is allocated to electric two-wheelers while 23 percent is allocated to electric three-wheelers. Regarding two-wheelers, FAME 2 encompasses strict speed, range, and energy efficiency requirements. Given that only advanced battery chemistries (excluding lead-acid) with incentives based on battery size are eligible under FAME 2, there was an immediate negative impact resulting in a 94 percent drop on the sales of electric two-wheelers in 2019. Most electric two-wheelers sold in India have lead-acid batteries and are low-speed and therefore not eligible for incentives under the FAME 2 scheme. To provide some compensation, however, the federal budget for 2019-20 announced an income tax exemption of INR 150 000 (US$2 000) on loans for EV purchases. It is premature to measure the effects on personal EV sales from this tax measure [61].

Nevertheless, the penetration of electric two-wheelers could reach 25-35 percent and electric three-wheelers 65-75 percent of their respective market share by 2030. Widespread market adoption of electric vehicles requires the creation of an appropriate ecosystem resulting from successful collaboration between OEMs and central and state governments. Under an innovative business model, two-wheelers, three-wheelers, and non- air-conditioned city buses manufactured by automakers in India could be sold without batteries, which is expected to result in a price drop of about 70 percent. Batteries can be rented at a predetermined cost and exchanged with recharged batteries at stations. The rapid shift to electric two- and three-wheelers in India is linked to public sector involvement through major state and central government reforms.

India's current EV policy framework is a mix of incentive-based policies accompanied by regulatory reforms, and public-private partnerships to encourage EV adoption, expand charging infrastructure and support domestic EV and supply equipment manufacturing capacity and battery manufacturing [61].

Several states are providing financial incentives, duty waivers, exemptions from permit fees, streamlined registration processes and supporting infrastructure to encourage electric vehicle uptake and charging station deployment. While specific policy approaches vary by local context, states such as Andhra Pradesh, Delhi, Gujarat, Karnataka, Maharashtra, Tamil Nadu, Telangana, and West Bengal have developed state level roadmaps and policy guides to aid policy consistency. In some Indian states, registration tax and VAT are being reduced or exempted. The state of Tamil Nadu has reduced VAT for two-wheelers and promoted the use of bicycle lanes. Delhi offers a 15 percent purchase discount, VAT exemption, and a 50 percent reduction in road taxes for electric vehicles. Other states have reduced various taxes. The Government of the National Capital Territory of Delhi established an Air Ambiance Fund in 2008, which is funded by a tax on the sale of diesel fuel. This tax is still in place and part of the revenue is used to provide cash subsidies to consumers for the purchase of electric vehicles.

Identified as a "smart city" by the national government, Jabalpur, India is committed to fostering the country's economic development and providing affordable access to citizens by reducing carbon emissions. To that end, Jabalpur's transportation officials have initiated the adoption of zero-emission tuk-tuks and created a network of solar-powered charging stations. In a pilot project in Jabalpur, local authorities plan to set up nine solar- powered charging stations to be used by about 400 electric tuk-tuk owners in the city. The charging stations can produce 50 kW of electricity and can power up to four tuk-tuks simultaneously. It takes seven to eight hours to fully recharge the battery, allowing the tuk-tuks to travel 100 to 150 kilometres. The station's solar panels are also connected to the state's electrical grid to power the additional energy generated by net metering. In 2017, Jabalpur was scheduled to operate 400 licensed tuk-tuks. The city's goal is to convert 5,000 gasoline-powered tuk-tuks operating in the city to a cleaner, greener mode of propulsion, which could eliminate 46 tons of CO_2 per day. Charging the batteries at a solar station is also 30 percent cheaper than grid-connected electricity.

In **Nepal**, the capital city, **Kathmandu,** switched from diesel three-wheelers to electric three-wheelers (**Safa Tempo**) in the late 1990s and early 2000s, illustrating an interesting example of electric development. The factors that led to this change include the following:

- A growing concern about pollution from older diesel vehicles
- Government policies that removed import taxes and annual fees for electric vehicles
- The use of cheaper off-peak electricity for charging
- A ban on diesel-powered three-wheelers.

Although this project was not motivated by climate change considerations, the reduction in greenhouse gases was significant, as Nepal's electricity supply is primarily hydroelectric.

However, the Safa Tempos had significant technical flaws, including batteries that had to be replaced almost every two years. This represented a 25 percent higher operating cost than traditional buses (Vikrams). The batteries had to be replaced after only one year for high-speed vehicles. In addition to technological weaknesses, the development of electric vehicles has been hampered by insufficient government policy to allow owners of banned traditional buses to import gasoline-powered microbuses at a reduced rate. In addition, the Federation of National Transport Entrepreneurs of Nepal, which controls transport routes throughout Nepal (of which microbus owners are influential members), has refused to grant Safa Tempos owners permits to operate certain routes. This led substantially to the end of Safa Tempos' operations in late 2000.

Nevertheless, the Nepalese government inaugurated a campaign in 2018 to transition to electric vehicles as part of its commitment to the Paris climate agreement. The Kathmandu experience demonstrated the importance of building favorable local conditions for electric vehicles.

Activities to promote electric mobility are also promoted by international organizations. For example, the **United Nations Environment Programme** (UNEP) is supporting public policies, regulations, and pilot projects to promote electric two- and three-wheelers in eight countries in Africa and Asia: **Ethiopia, Morocco, Kenya, Rwanda, Uganda, the Philippines, Thailand,** and **Vietnam [49]**. The activities are expected to trigger a transition to electric two- and three-wheelers, which will then be replicated in other countries as a first step towards a general shift from fossil fuel-based mobility to electric mobility. In particular, sales of ICE two- and three-wheelers up to 250 cc are planned to be phased out. The reason is that electric scooters and motorcycles are already a competitive alternative worldwide, while recharging infrastructures are becoming less problematic due to their relatively simple implementation from the technical point of view).

The following is a sampling of some of the more prominent activities that UNEP has promoted in Asian and African countries:

The **Philippines** is one of the first countries to pilot electric jeepneys and three-wheelers in Southeast Asia since 2008. As of 2020, about 4,300 electric three-wheelers have been registered. The Ministry of Energy has delivered 3,000 electric tricycles to 33 local government units and four national government agencies with support from the Asian Development Bank. In addition, the Land Transport Bureau and the Product Standards Bureau are pursuing the development of regulations for two- and three-wheelers. UNEP's pilot project also supports electric freight vehicles in urban areas. UNEP also aims to further support demonstration projects and establish a charging network in Pasig City.

In **Thailand**, UNEP is supporting the development of standards and regulations on two- and three-wheelers, while also deploying a demonstration project to support electric motorcycle deliveries. In addition, the Energy Conservation Fund has approved a US$3.4 million grant to encourage tuk-tuk owners to switch from liquefied petroleum gas (LPG) to electricity.

In **Vietnam**, 1.35 million electric two-wheelers have been registered (June 2020 data). UNEP is supporting the development of standards and regulations as well as demonstration projects on electric two-wheelers for personal use and for urban freight transport. Private investment is also important. VinFast, for example, has a new 11 million m2 factory in Haiphong where it builds electric scooters, electric buses, and electric cars. The company began offering electric motorcycles in late 2018 and sold 50,000 in 2019, with a target of 112,000 in sales in 2020.

Electric scooters have failed to penetrate the market due to user preconceptions of inferior performance compared to ICE scooters. Namely, these preconceptions include lower speeds, reduced range, and less attractive comfort and styling [38]. Perceptions need to be replaced by actual experience to reduce the information gap with ICE vehicles, whose performance is well known. Fiscal policy (e.g., purchase tax) is considered a very effective measure to promote electric vehicles.

In addition to the activities deployed by UNEP, it is worth mentioning that a joint venture was created in Marrakech, Morocco between the local industrial operator Imperium Holding and Allianz SE to make the country the most important African platform for sustainable mobility. Currently, EMOB is deploying a large set of two- and three-wheel electric vehicles manufactured by Yadea, a French company specializing in electric motors and a subsidiary of the Chinese company Norinco. An initial order for 1,200 units has been submitted to the manufacturer.

In **Rwanda**, the company Ampersand is similarly testing the use of electric motorcycles used by mototaxi companies operating in the capital of Kigali [37]. Ampersand has installed electric motors on gasoline-powered motorcycles. The motorcycles are imported in parts from several suppliers and assembled in Rwanda. The battery packs are designed and built by Ampersand itself. The network of exchange stations also operates on a proprietary software platform.

The current generation of motorcycles has a top speed of 80 km/h, the same as the 125cc ICE motorcycles used in Rwanda. The current range is 65 km per charge under real conditions (i.e., in the hilly urban landscape of Kigali) with a mototaxi carrying passengers.

Recharging a battery pack usually takes a little over an hour. The battery swap model is based on a network of low-cost swap stations. Drivers pay according to the amount of energy they use, just as they would if they were buying fuel. All payments are cashless, using cell phone payment systems that are widespread in Africa.

The pricing model was designed to match the way most drivers currently pay for their motorcycles and fuel, but with lower prices. In Rwanda, this means that motorcycles are paid off over 18 months on a lease-to-own basis. Riders end up paying about US$37 per week for the motorcycle. The real savings come from battery swaps, which cost at least 25 percent less than buying fuel. Ampersand also offers a service package for US$5.25 per week for maintenance, nearly half of what riders normally pay. This package includes roadside assistance and a loaner motorcycle if the repair takes longer than 45 minutes.

The motorcycle is priced similarly to its gasoline-powered counterparts. Overall, riders save about US$500 per year. The company's website states that it has increased customer revenue by 50 percent per day and reduced CO2 emissions by 45 tons.

Uganda has over 600,00 motorcycles and that number is growing. The challenge is to make them sustainable, both in terms of driver income and air pollution.

Electric motorcycles with solar charging and PayGo are the solutions implemented by Zembo (Zero Emission Motorcycle Boda), Uganda. Solar PayGo is a solution that has revolutionized access to energy for domestic use. Zembo is translating this model to mobility by replacing gasoline-powered motorcycles with electric ones and selling them through PayGo. Zembo offers electric motorcycles to mototaxi drivers and charges the batteries at its solar stations. Fuel is replaced by lithium batteries, and Zembo distributes the lithium batteries throughout the country. In addition, purchase prices are similar to those of gasoline-powered motorcycles.

In **Côte d'Ivoire**, the development of three-wheeled solar cabs in the city of **Jacqueville** (40 km from Abidjan) is replacing the dominance of traditional cabs, "taxi-brousse" and "woro-woro" (private artisanal cabs) [39][47]. The vehicles are 2.7 meters long and 2 meters high, and are covered with solar panels with six 12-volt batteries providing a range of about 140 km. A private entrepreneur privately developed this new means of transport with the support of the municipal government which was eager for the city to become a model of an environmentally friendly city and to reduce the consumption of fossil fuels. According to illustrations provided by the local government, between 500 and 1,000 people use this means of transport every day.

Among two-wheeled vehicles, an important role can also be played by bicycles which could provide an efficient and affordable sustainable mobility solution for the population. An interesting example is in **Namibia**, where SunCycles (a company founded in 2014) is deploying **solar-powered electric bicycles.** Solar-powered electric bikes can provide access to markets as well as health and education services while representing an affordable, locally produced transportation system. The operating cost per km of a solar electric bicycle is about one-tenth the price per km of a taxi. In addition, the battery can be used to power basic electrical equipment such as lighting and communications in off-grid areas.

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ANNEX 2
EXAMPLES OF TWO- AND THREE-WHEELERS IN OUAGADOUGOU AND BAMAKO

Table 2A.1.

Examples of two- and three-wheelers in Ouagadougou and Bamako

BICYCLES

Presence:	Bamako / Ouagadougou
Muscular pedalling	(i.e., non-electric)
Autonomy:	Not Applicable
Recharge time:	Not Applicable
Weight:	14 kg
Maximum speed:	20 km/h
Battery capacity:	Not Applicable
Purchase price:	US$200 (CFAF 109,000)
Maintenance cost:	US$15 (CFAF 8,250)
Battery recharge cost:	Not Applicable
Age / average life:	3-5 years
Usual use:	freight transport

Presence:	Ouagadougou
Electric	(Pedal assisted; unassisted pedalling also possible)
Autonomy:	50 km
Recharge time:	6 h
Weight:	20 kg
Maximum speed:	25 km/h
Battery capacity:	1.5 kWh
Purchase price:	US$365 (CFAF 150,000)
Maintenance cost:	US$15 (CFAF 8,250)
Battery recharge cost:	US$0.26 (CFAF 145)
Age / average life:	3-5 years
Usual use:	private travel

SCOOTERS / MOTORCYCLES

Presence:	Ouagadougou
Gasoline / Power:	110-250 cc
Dry weight:	90-110 kg
Loading capacity:	150 kg
Maximum speed:	80-100 km/h
Fuel tank capacity:	4-5 liters
Fuel consumption:	1.8 liters / 100 km
Purchase price:	US$475 / 1,100 (CFAF 260,000/ 600,000)
Maintenance cost:	US$30 (CFAF 16,500)
Cost per tank:	US$5.7 (CFAF 3,105)
Average age/duration:	5-8 years
Usual use:	Private travel

Presence:	Bamako
Gasoline / Power:	110-250 cc
Dry weight:	90-110 kg
Loading capacity:	150 kg
Maximum speed:	90 km/h
Fuel tank capacity:	5.5 liters
Fuel consumption:	1.8 liters / 100 km
Purchase price:	US$545 / 730 (CFAF 300,000/400,000)
Maintenance cost:	US$30 (CFAF 16,500)
Cost per tank:	US$6.7 (CFAF 3,650)
Average age/duration:	5-8 years
Usual use:	Private travel, Transport of people and goods

TRICYCLES

Presence:	Ouagadougou
Gasoil/Power: 150 cc	(i.e., non-electric)
Dry weight:	530 kg
Loading capacity:	2 000 kg
Maximum speed:	130 km/h
Fuel tank capacity:	12 liters
Fuel consumption:	2,5 - 5,0 liters / 100 km
Purchase price:	US$1,320 (CFAF 725,000)
Maintenance cost:	US$90 (CFAF49,500)
Cost to fill up:	US$13.70 (CFAF 7,460)
Age/average life:	5-8 years
Typical use:	Transport of goods

Presence:	Bamako
Gasoil/Power: 150 cc	150 cc
Dry weight:	530 kg
Loading capacity:	2 000 kg
Maximum speed:	80 km/h
Fuel tank capacity:	18 liters
Fuel consumption:	2,5 - 5,0 liters / 100 km
Purchase price:	US$2,150 (CFAF 1,180,000)
Maintenance cost:	US$90 (CFAF 49,500)
Cost to fill up:	US$22 (CFAF 11,980)
Age/average life:	5-8 years
Typical use:	Transport of people and goods

ANNEX 3
DETAILS OF TOTAL COST OF OWNERSHIP ANALYSIS

The main characteristics of the two- and three-wheelers analyzed and the assumptions of the analysis are shown in Table 3A.1.

Table 3A.1.

Two- and three-wheeler characteristics and assumptions for TCO in Bamako and Ouagadougou

Vehicle type	Acronym	Average purchase price (US$)	Average consumption	Battery autonomy
e-bicycle 250W	e-Bike	500	0.01 kWh/km	50 km
scooter 50cc (gasoline)	C-2W (Mobi)	540	0.013 L/km	
e-scooter 2000W	E-2W (Mobi)	980	0.035 kWh/km	57 km
motorcycle 110cc (gasoline)	C-2W (Moto)	630	0.018 L/km	
e- motorcycle 2900W	E-2W (Moto)	1,100	0.075 kWh/km	67 km
tricycle 150cc (gasoline - passenger transport)	C-3Wtuk-tuk	2,000	0.028 L/km	
e-tricycle 3000W (passenger transport)	E-3Wtuk-tuk	3,000	0.13 kWh/km	69 km
tricycle 125-200cc (gasoline - freight)	C-3W cargo	2,100	0.080 L/km	
tricycle 125-200cc (diesel - freight)	C-3W cargo G	3,600	0.056 L/km	
tricycle e-tricycle 1500W (freight)	E-3W cargo	2,520	0.086 L/km	60 km
Assumptions				
Vehicle lifetime	5 years			
	Bamako		Ouagadougou	
Energy cost	US$0.24/kWh (CFAF130/kWh)		US$0.17/kWh (CFAF 92/kWh)	
Gasoline cost	US$1.20/L (CFAF 650/L)		US$1.14/L (CFAF 620/L)	
Diesel cost	US$1.10/L (CFAF 600/L)		US$1.00/L (CFAF 540/L)	
Depreciation	90 percent for ICE vehicles and 100 percent for electric vehicles			
Maintenance cost	**Electric vehicles (3 percent of purchase value)** **ICE vehicles (18 percent of purchase value)**			

Figure 3A.1 shows the TCO per km in the baseline scenario in Bamako and Ouagadougou. The breakdowns of TCO by cost category (in percent) in Bamako and Ouagadougou are shown in Figure 3A.2 and Figure 3A.3.

Figure 3A.1.

TCO per km in Bamako (left) and Ouagadougou (right) - baseline scenario

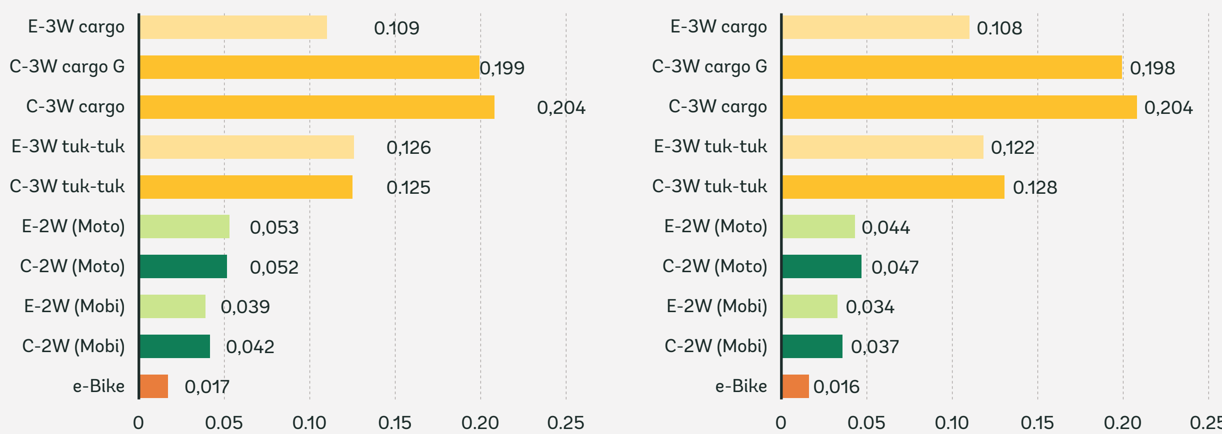


Figure 3A.2.

Percentage of TCOs by category in Bamako - baseline scenario

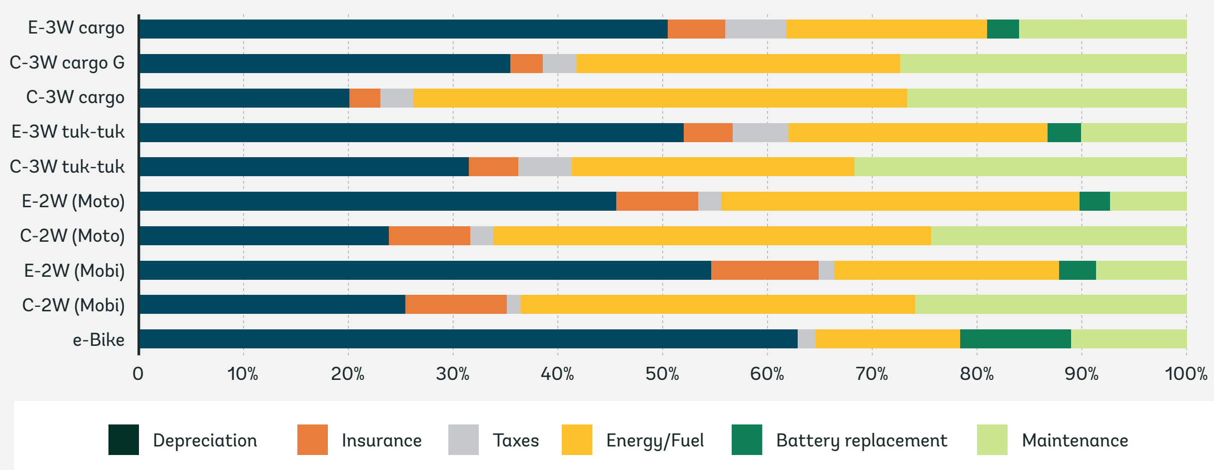
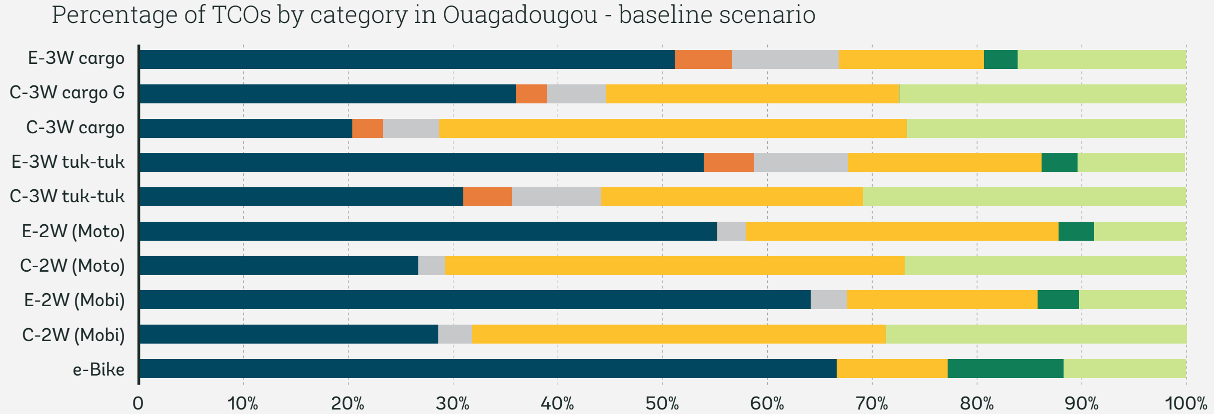


Figure 3A.3.

Percentage of TCOs by category in Ouagadougou - baseline scenario



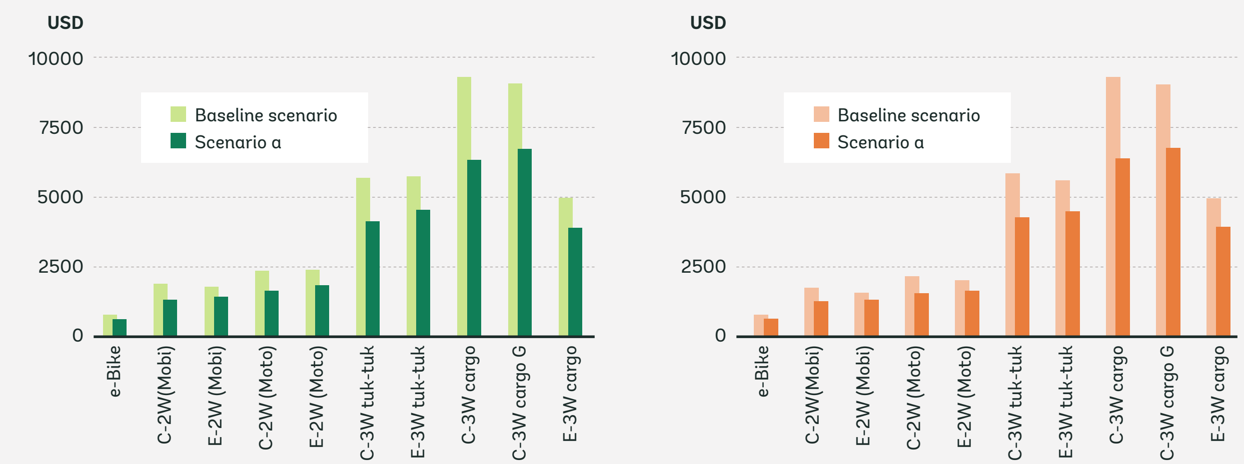
Next, the results of the TCO sensitivity analyses are described in detail.

SCENARIO A (3-YEAR LIFE SPAN)

The results show that the reduction in the number of years of use penalizes electric vehicles in both cities except for the three-wheeled cargo vehicle (Figure 3A.4). Electric vehicles had a lower cost than ICE vehicles in the baseline scenario. In this scenario, almost all of them have a higher cost than their thermal counterparts. The only exception is the electric tricycle for freight transport. This is related to the higher impact of the purchase cost over the period of use and together with the lower impact of the economic benefits in terms of energy consumption.

Figure 3A.4.

TCO in Bamako (left) and Ouagadougou (right) - Scenario a

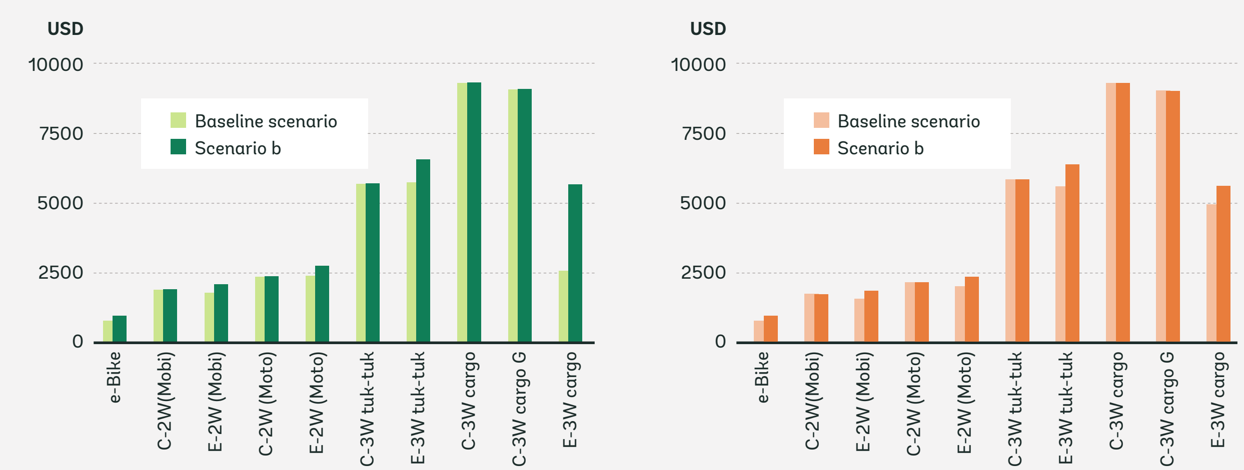


SCENARIO B (PURCHASE PRICE +25 PERCENT)

This scenario shows similar results to the previous one, confirming the importance of vehicle purchase costs (Figure 3A.5).

Figure 3A.5.

TCO in Bamako (left) and Ouagadougou (right) - Scenario b

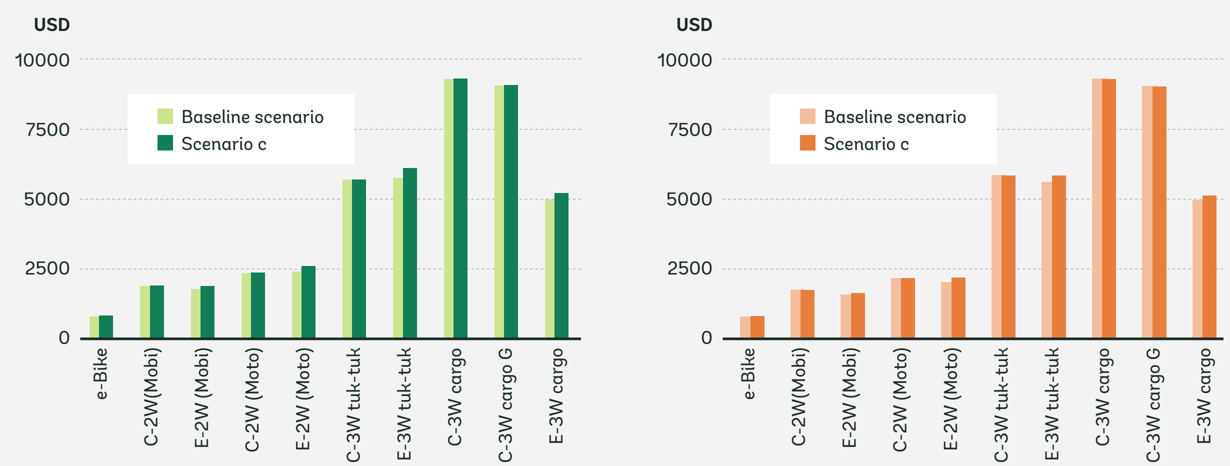


SCENARIO C (ENERGY CONSUMPTION PER KM +25 PERCENT)

The results of this scenario in both cities show that there is no significant change in the TCO of electric scooters, which continue to be cheaper than ICE models. The same is true for electric three-wheelers for freight transport. In Ouagadougou, the TCO of electric motorcycles and three-wheelers for passenger transport, compared to the baseline scenario, is similar to that of ICE vehicles (Figure 3A.6).

Figure 3A.6.

TCO in Bamako (left) and Ouagadougou (right) - Scenario c

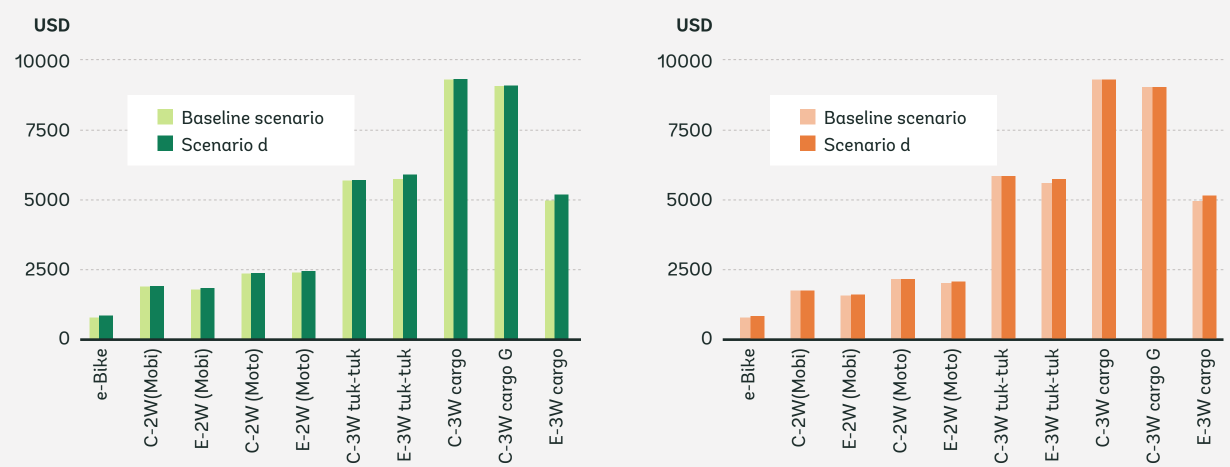


SCENARIO D (MAINTENANCE COSTS +25 PERCENT)

The change in maintenance costs envisaged in this scenario does not significantly change the TCO of electric vehicles in the two cities compared to the baseline scenario (Figure 3A.7).

Figure 3A.7.

TCO in Bamako (left) and Ouagadougou (right) - Scenario d

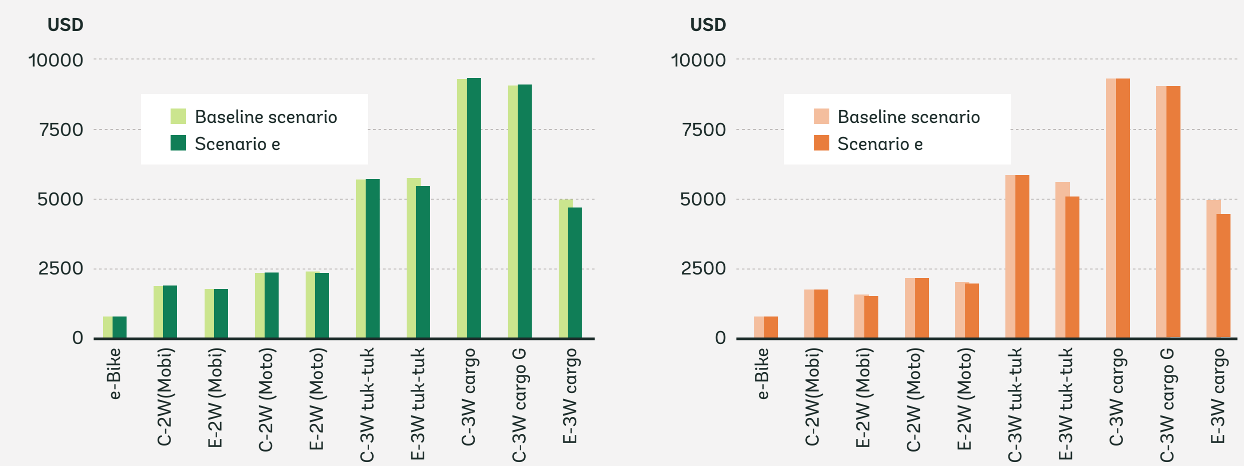


SCENARIO E (ELIMINATION OF TAXES)

The elimination of taxes for electric vehicles in Bamako makes electric motorcycles and electric tuk-tuk slightly cheaper than ICE models, while in Bamako no change in the relative convenience is observed (Figure 3A.8).

Figure 3A.8.

TCO in Bamako (left) and Ouagadougou (right) - Scenario e



SENSITIVITY IN RELATION WITH TRAVELLED DISTANCES

The TCO was also analyzed for both cities in relation to different annual mileage scenarios, compared to the baseline scenario of 9,125 km per year (25 km per day) while assuming a lifetime of five years. With increasing annual mileage, the TCO decreases and electric scooters and three-wheelers for freight transport become progressively more attractive than ICE vehicles. For other vehicles, there are differences between the two cities regarding TCO.

Figure 3A.9 illustrates how a positive differential means that the TCO of the electric vehicle is lower than that of the ICE vehicle. In Bamako, the chart shows for electric motorcycles, cost parity with ICE motorcycles is achieved at around 11,000 km driven per year, although the differential is still negative at 25,000-30,000 km because of the need for an additional battery. It should be noted that the mileages that require an additional battery are indicated in the figure by a circle. From this mileage, ICE motorcycles have an additional cost between 1.6 percent and 3.1 percent, up to 50,000 km, when another additional battery is required. Beyond this distance, the differential is practically zero.

Three-wheel electric vehicles for passenger transport are more economical than ICE vehicles for distances between 14,000 and 25,000 km, while for longer distances they are negatively affected by the cost of additional batteries.

For other vehicle types, ICE types have higher costs for almost all mileages. The differentials range from 6 percent to 20 percent for scooters, from 38 percent to 63 percent for gasoline-powered three-wheelers, and from 42 percent to 50 percent for diesel-powered three-wheelers.

Figure 3A.10 shows that electric motorcycles, except for those with mileage below 6,000 km, cost between 6 percent and 19 percent less than ICE vehicles in Ouagadougou. For other vehicles, ICE types have higher costs for all mileages, with a differential ranging from 10 percent to 40 percent for scooters, from 1 percent to 16 percent for three-wheelers for passenger transport, from 38 percent to 71 percent for three-wheelers for freight transport using gasoline, and from 41 percent to 59 percent for three-wheelers for freight transport using diesel.

The results show that, with a few exceptions for motorcycles and three-wheelers for passenger transport for specific annual mileages, the electric transition could be profitable for all vehicles used for both for private and professional purposes.

It should be noted that the analysis does not consider the specific operational challenges associated with setting up and operating the future charging model (i.e., charging at stations or other locations, swapping batteries). Although the findings do not influence the TCO, they could influence the actual feasibility of the electric transition as well as the decisions of users.

The TCO analysis does not consider the operational costs of running a potential battery swapping service that might be incurred by commercial operators (e.g., mototaxi companies). However, these findings will not have a significant influence on the overall outcomes of the analysis. Similarly, no incentives were considered in the analysis (e.g., tax reductions related to electric mobility).

Figure 3A.9.

TCO differential between ICE and electric vehicles in Bamako

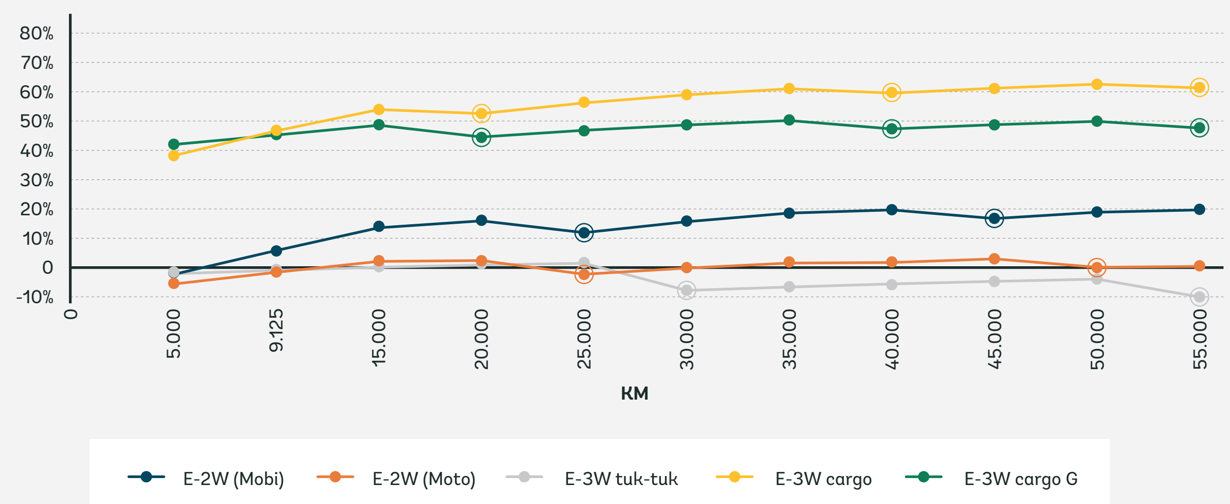
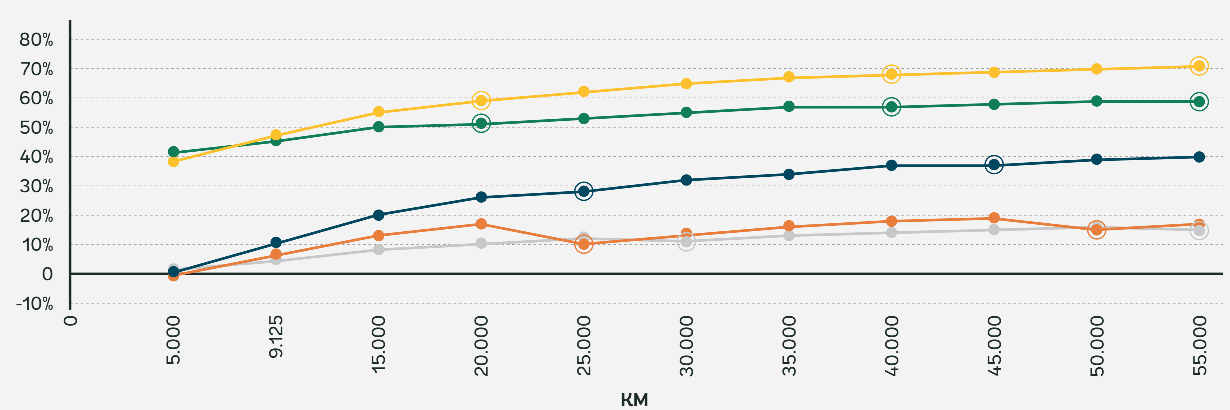


Figure 3A.10.

TCO differential between ICE and electric vehicles in Ouagadougou



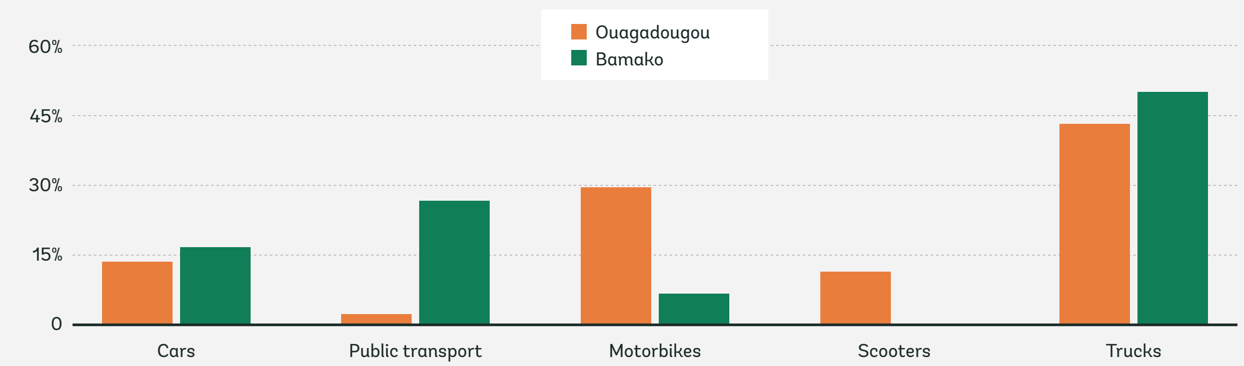
ANNEX 4
USERS' OPINIONS ON ELECTRIC MOBILITY

PERCEPTION OF THE MOST POLLUTING VEHICLES IN TOWN

In both Bamako and Ouagadougou, trucks are perceived by respondents as the most polluting mode of transport (Figure 4A.1). Although the share of trucks in the traffic of both cities is not high (e.g., about 1 percent in Ouagadougou), users consider them to be the most environmentally damaging. On the other hand, fewer people consider motorized two-wheelers (which account for the largest share of traffic) to be the most polluting; about 41 percent of people in Ouagadougou and about 7 percent of people in Bamako hold this view. This perception does not seem to be much different among the following sample categories of people in the analysis: age, gender, education, means of transport used, average daily distances travelled.

Figure 4A.1.

Perception of more polluting modes of transport



PERCEPTION OF ELECTRIC VEHICLE BATTERIES

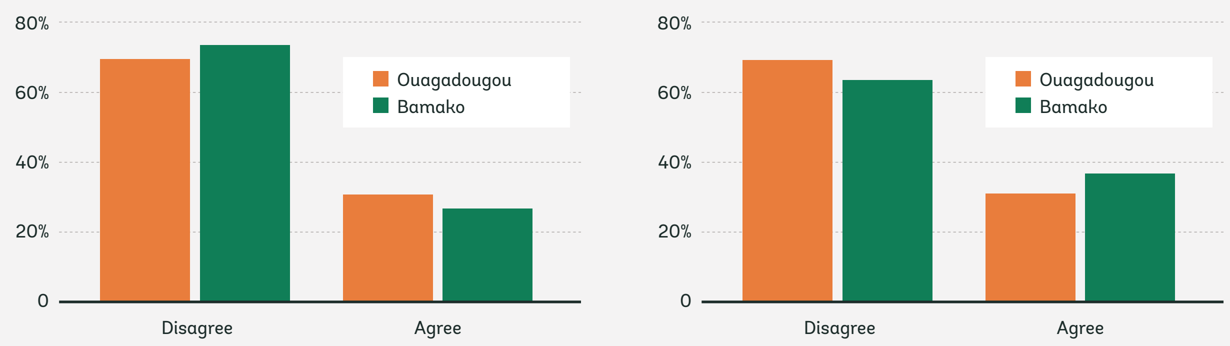
Most respondents do not think it would be easy to recharge the battery of a two- or three-wheeler in Bamako or Ouagadougou (Figure 4A.2 - left). Only 27 percent of people in Bamako and 31 percent of people in Ouagadougou find it easy to recharge batteries in their cities. This perception is very different among the various sample categories of people except for men who seem to largely disagree on this issue.

A significant part of respondents also believe that the battery capacity itself is not sufficient to cover the daily distance travelled (Figure 4A.2 - right). In Ouagadougou, this is the perception of about 31 percent of people which is the same percentage for ease of charging. In Bamako, slightly more people think that the duration would be sufficient (about 37 percent).

These responses highlight the problem of the future charging infrastructure's ability to meet demand as well as the prevailing issue of "autonomy anxiety." If the first issue is a challenge for the government and local administrations in terms of adequate investments in the electrical grid and for the implementation of charging stations, the second issue needs to be addressed through effective communication, especially for users whose daily distances could already be easily covered with the autonomy of an electric vehicle.

Figure 4A.2.

Perceived ease of battery charging (left) and battery life (right)



BUYING AND MAINTAINING AN ELECTRIC VEHICLE AND THE DIFFERENTIAL WITH AN ICE VEHICLE

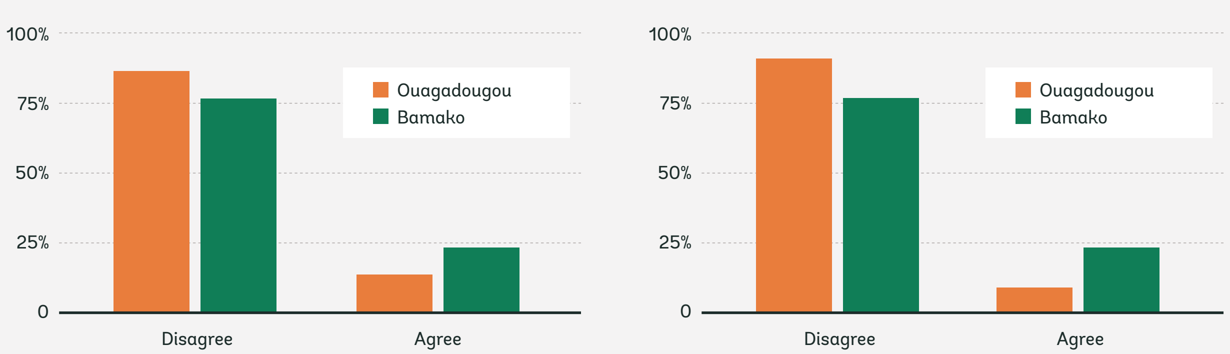
The possibility of purchasing and maintaining two- and three-wheelers is not perceived as an easy task in either city (Figure 4A.3 - left). In Bamako, about 77 percent of respondents perceive a difficulty; in Ouagadougou this perception is shared by about 86 percent of respondents. This question involves the problem of the availability of vehicles at retailers as well as the availability of specialized workshops and spare parts for vehicles. This may reflect the current lack of vehicles circulating in cities; however, some retailers who were consulted stated that there would be no difficulty in providing electric vehicles and technical assistance on a similar level to what is currently offered for ICE vehicles.

A similar percentage of respondents (67 percent in Bamako and 91 percent in Ouagadougou) disagreed with the similarity of purchase and maintenance costs between electric and ICE two- and three-wheelers, indicating a strong perception of electric vehicles as a more expensive alternative (Figure 4A.3 - right). It is interesting to note that this perception is not consistent with the results of the TCO analysis.

Indeed, several consulted stakeholders indicated that users are much more sensitive to the cost of purchasing a vehicle (i.e., the amount they must spend immediately) than to the costs over time of operating (e.g., fuel) and maintaining the vehicle. According to stakeholders, most people would not buy an electric vehicle at a higher cost than its ICE counterpart. The respondents to the questionnaires seem to confirm these perceptions.

Figure 4A.3.

Perceived ease of purchase (left) and similarity of purchase cost (right)



VEHICLES FOR INTRODUCING ELECTRIC MOBILITY AND POTENTIAL PROBLEMS TO ADDRESS

About 73 percent of respondents indicated that motorcycles were the best mode of transport to introduce electric mobility in Bamako. Similarly, about 69 percent of respondents held the same view in Ouagadougou (Figure 4A.4). This is probably due to the strong presence of motorized two-wheelers in both cities, which are perceived as a necessity for daily travel. Indeed, this same view was shared by almost all the stakeholders consulted.

It is interesting to note that in Bamako, motorcycles are viewed as the appropriate vehicles to introduce electric mobility even by people who currently use bicycles. This may indicate a lack of available information about the characteristics of e-bikes, or it may indicate a desire to change modes of transport. The latter view would be consistent with the relative reduction in bicycle use in recent years.

Figure 4A.5 shows the range of opinions of respondents on the modes of transport that should be used to introduce electric mobility.

Figure 4A.4.

Opinions on the mode of transport to introduce electric mobility

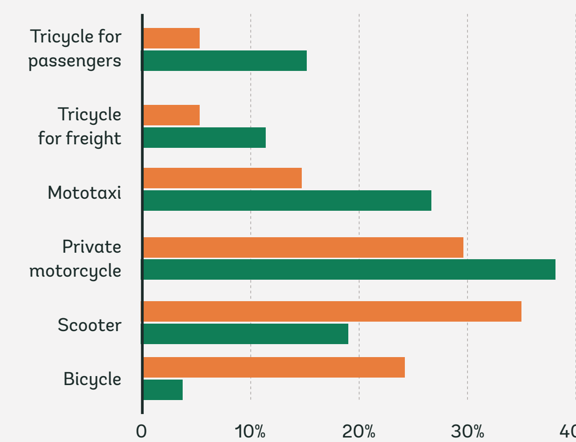
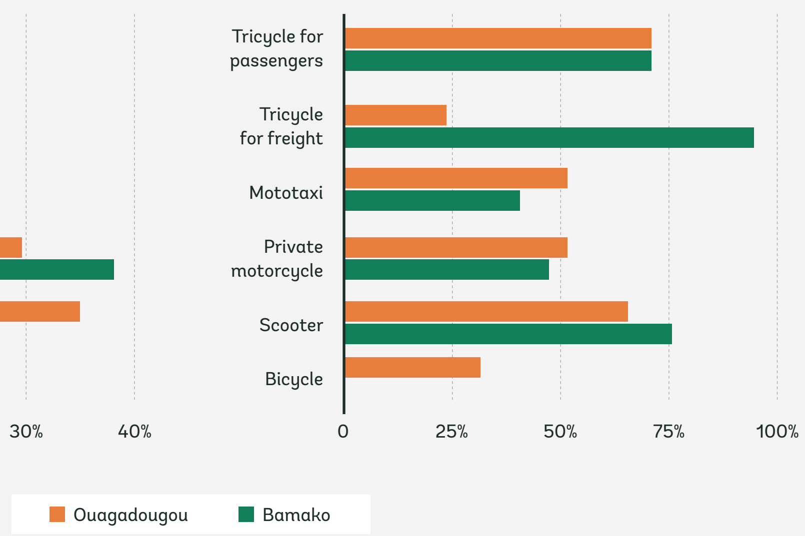


Figure 4A.5.

Ease of use of an electric vehicle by mode of transport



PERCEPTION OF POTENTIAL PROBLEMS WITH ELECTRIC TWO- AND THREE-WHEELERS

Most respondents from both Bamako and Ouagadougou believe that the use of electric two- and three-wheelers would not pose any problems (Figure 4A.6). This perception appears to be somewhat stronger in Bamako than in Ouagadougou. This perception was confirmed by most of the stakeholders who were consulted for this report.

Greater concern seems to exist among those whose daily travel distances are greater than 30 km (perceived ease of use is just over 40 percent) (Figure 4A.7 - left). There is less concern about battery life when distances are less than 5 km.

It appears that women in both Bamako and Ouagadougou find it easier to use an electric vehicle than men. This could be related to differences in driving behavior and other characteristics of women and men. For example, most trips made by women are less than 20 km (more than 80 km), while most trips for men are much longer (Figure 4A.8).

Figure 4A.6.

Ease of use of an electric vehicle

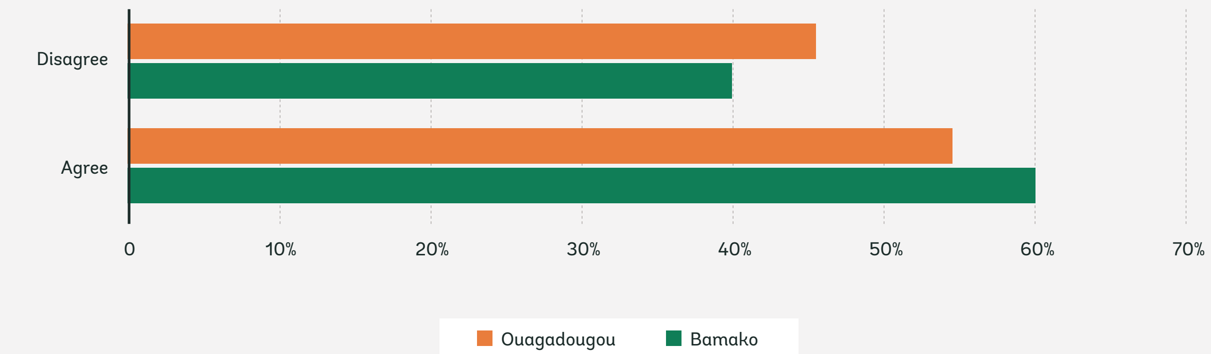


Figure 4A.7.

Ease of use of an electric vehicle by distance travelled (left) and gender (right)

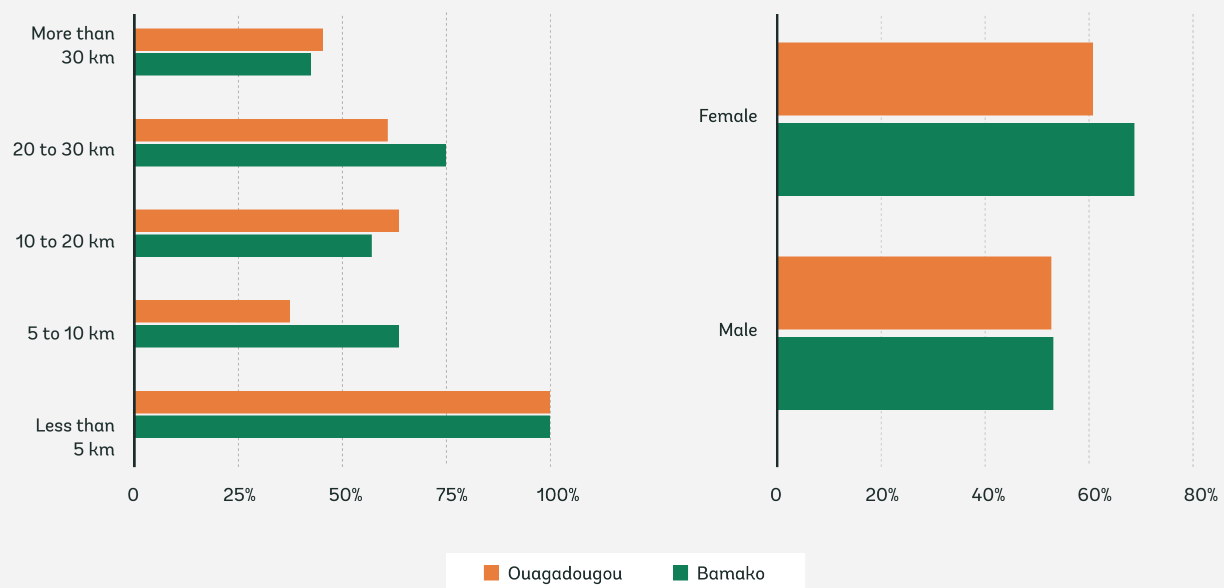
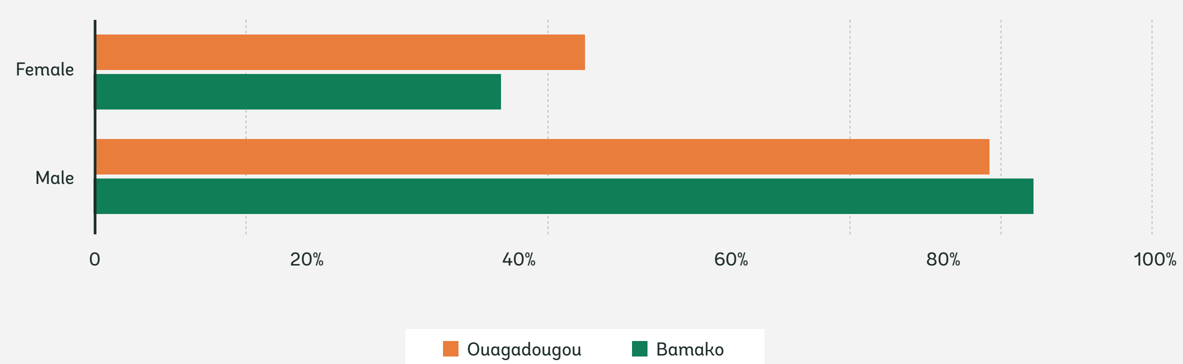


Figure 4A.8.

Average distance travelled under 20 km by gender



ANNEX 5
MAIN ASSUMPTIONS FOR THE LIFE CYCLE ASSESSMENT

Below are the main assumptions used to perform the life cycle analysis.

For electric bicycles, the on-board battery has the following characteristics: Lithium 36 V, 15 Ah (~500 Wh) with 800 charge cycles. Considering that one charge allows travel of up to 45 km, the calculated lifetime of an electric bicycle is 36,000 km with 12 Wh/km.

The efficiency of charging and discharging the Lithium battery is constant over the life of the battery. This is a "conservative" assumption, and there are two reasons for reduced efficiency over the life of the battery that would have a greater impact on the environment: the charging and discharging processes become less efficient, and the stored energy and power output are decreasing.

The main characteristics of electric bicycles are shown in Table 5A.1.

Table 5A.1.

Main characteristics of electric bicycles

Elements	Bicycles
Controller	0.4 kg
Charger	0.5 kg
Electric motor	250 W / 2.7 kg
Li-ion battery	2.6 kg
Total weight	~23 kg
Lifetime	15m000 km
Energy consumption (average)	0.01 kWh/km
Maintenance required	Tires every 4,000 km // Li-ion battery after 3 years (depending on use)

For electric scooters, the typical battery size is 2 kWh, while the typical battery size electric motorcycles is 3 kWh. The main characteristics of electric scooters and motorcycles are shown in Table 5A.2.

Table 5A.2.

Main characteristics of electric scooters and electric motorcycles

Elements	Scooters	Motorcycles
Controller	1.5 kg	1.5 kg
Charger	2.0 kg	2.0 kg
Electric motor	2,200 W / 7.0 kg	2,900 W / 8.5 kg
Li-ion battery	9 kg pour 2 kWh	17 kg pour 3 kWh
Total weight	~70 kg	~80 kg
Lifetime	50,000 km	70,000 km
Energy consumption (average)	0.035 kWh/km	0.075 kWh/km
Maintenance required	Tires every 10,000 km Li-ion battery after 4 years (depending on use)	Tires every 15,000 km Li-ion battery after 4 years (depending on use)

For motorized three-wheelers, the main characteristics of electric tricycles are shown in Table 5A.3.

The LCA requires the identification of the vehicle's component parts, as described below.

Table 5A.3.

Main characteristics of electric tricycles

Elements	Tricycles
Controller	2.5 kg
Charger	4.0 kg
Electric motor	8,000 W / 25 kg
Li-ion battery	45 kg pour 6 kWh
Total weight	~170 kg
Lifetime	70,000 km
Energy consumption (average)	0.13 kWh/km
Maintenance required	Tires every 15,000 km // Li-ion battery after 5 years (depending on use)

THE ELECTRIC POWER TRAIN

Understanding the subsystems that are part of the two- and three-wheelers is the basis for a reliable life cycle analysis.

Figure 5A.1 shows the main components of the electric bicycle drive train. Note the presence of the battery (the main energy source), the controller (the DC-AC converter), and the electric motor, which can be installed in the hub (as shown in the photo) or in the pedalboard. Figure 5A.2 shows a block diagram for two-wheel and three-wheel electric vehicles. This diagram is also valid for heavier vehicles such as scooters and motorcycles. The DC-AC converter consists of MOSFET devices and the corresponding diodes. Capacitors are placed on the DC bus between the inverter and the battery. The traction motor is powered by the inverter and is coupled to the wheel. The coupling devices can be very different depending on the vehicle, ranging from a simple chain for electric vehicles to a CVT with a belt for electric scooters, to a gearbox and chain for motorcycles.

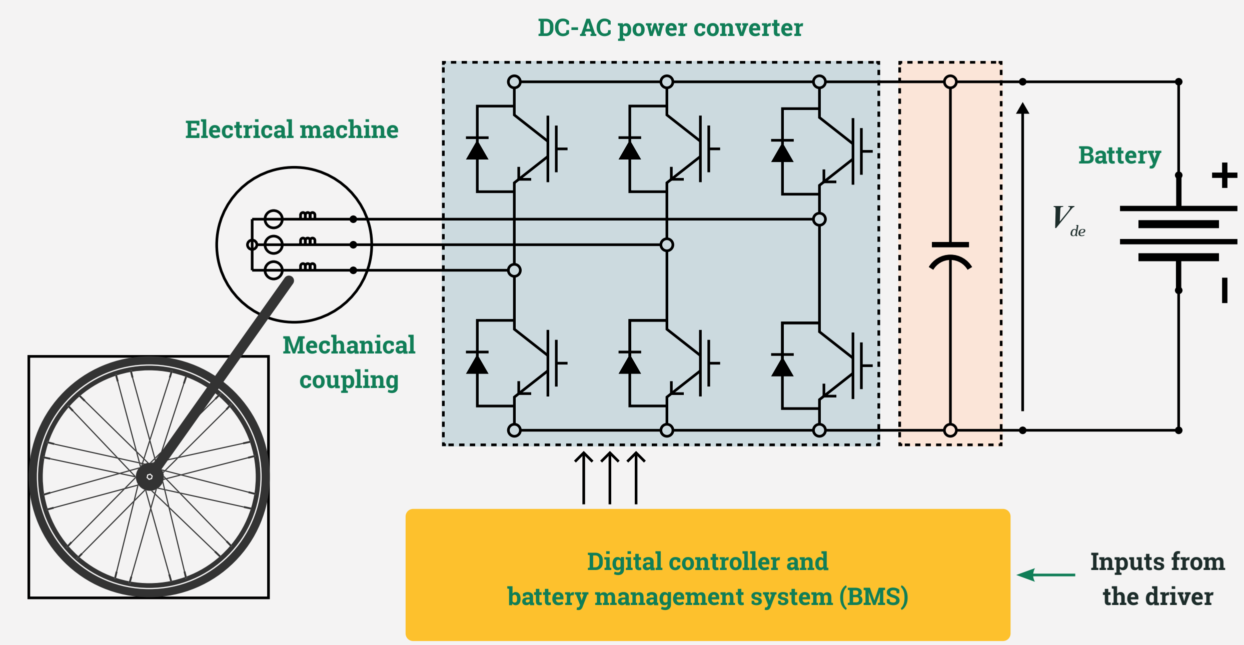
Batteries nowadays are mainly powered by Lithium where each type has its own specific characteristics, due to the different chemical composition of the Lithium element and the reactants. For light vehicles, the Li-Ion battery is the most used, and it has been considered in the LCA. In fact, a lithium battery has a best-in-class combination of total weight and capacity. Lithium-ion batteries have the advantage of possessing the highest specific capacity and energy density of all existing types. Lithium-ion batteries also do not have the "memory" effect, which occurs when the charging phase is performed on a non-discharged battery. In addition, lithium-ion batteries for electric bicycles must be designed to fit the specifications of a battery management system (BMS). This circuit must be set appropriately to control the amount of current needed by the motor and to limit over-discharge of the battery, which could significantly reduce its life. The BMS is also important for balancing the cell charge between the different cells in the battery to maintain battery life over time. Because of the inherent instability of lithium, electric vehicle manufacturers are now replacing the common Lithium-ion battery with a more stable LiFePO4 (lithium iron phosphate) battery, also known as an LFP battery. This is the safest type of lithium battery available today. It is designed to be small and lightweight and has a high energy density. It can also last for thousands of cycles when used and maintained properly.

Figure 5A.1.

Detailed diagram of the electric drive train

Figure 5A.2.

Schematic diagram of the powertrain for two- and three-wheelers



Recommendations for increasing the life of the battery are listed below:

- **Tip 1** - Try not to discharge the battery below 20 percent. A deep discharge makes the battery too difficult to use and reduces its capacity in the future. A lithium battery starts to oxidize, which has a negative effect on its capacity as well as its life span. If the power is turned off (e.g., in winter), it is recommended to fully charge the battery at least once every 90 days.
- **Tip 2** - Do not charge the battery immediately after driving. The battery must cool down before charging. If you start charging a heated battery, it will not be able to cool down at all and will degrade much faster.
- **Tip 3** - Don't fully charge the battery if you do not need to. When you charge the battery to more than 80 percent of its capacity (about 40V for electric bicycle batteries), the internal resistance of the battery increases, the battery heats up more and this accelerates the degradation process considerably.
- **Tip 4** - Avoid extreme temperatures. High temperatures and freezing temperatures affect performance and shorten the life of the battery. Never store the battery outside where it will be exposed to temperatures below 0ºC. Similarly, it is recommended that the battery not be stored at temperatures above 30ºC. Also, avoid prolonged parking in direct sunlight.

Figure 5A.3 shows the properties of lithium, which is the basis of the batteries currently used thanks to its relatively high energy density. Lithium is a light metal, non-toxic and very abundant on the planet (more than copper). In its metallic form, it is very reactive, which means that lithium-based energy storage systems (such as the BMS mentioned above) require additional circuitry to ensure their safety.

Figure 5A.4 shows the detailed composition and corresponding percentages of elements in the cell of a lithium battery. As the figure shows, lithium represents the lowest percentage of material in the cell's composition. 40 percent of the cell is made up of metals such as aluminium and copper, 20 percent is made up of electrolytes and the rest is comprised of positive and negative electrodes, only one of which is lithium-based.

Another important element of the electrified powertrain is the electric motor that converts electrical energy into mechanical energy. The motor is manufactured with an external rotor for installation in the wheel hub. Due to the compactness and weight constraints of these machines, their application is based on permanent magnet synchronous topologies. This results in an average material composition of the system (as summarized in Figure 5A.5) that is about half steel, followed by aluminium and copper. Rare-core magnets account for about 5 percent of the composition and the presence of plastic is very low. As a result, the electric motor is almost 100 percent recyclable.

Figure 5A.3.

Properties of lithium

Lithium properties

- Lightest metal
- Highest electrochemical potential
- Not toxic (used as medicine)
- Not scarce (e.g. more abundant than Cu, 0.17 ppm in sea water)
- Highly reactive in metallic form (burns)

Production

- Mainly won from salt lakes in the Andes (Chile, Bolivia) or in China (Tibet)
- Mainly solar energy used for production
- Refined to Lithium carbonate (Li2CO3) near the saline

Figure 5A.4.

Average composition of a Lithium-based battery.

- Only ~ 1% of a Li-Ion cell is Li
- ~40% of a cell is Al (~23%) and Cu (~13%)
- ~40% is the active electrode material (cathode $LiMn_2O_4$ ~24%, anode graphite ~16%)
- ~20% is the electrolyte (Lithium salt)

Figure 5A.5.

Electric motor composition

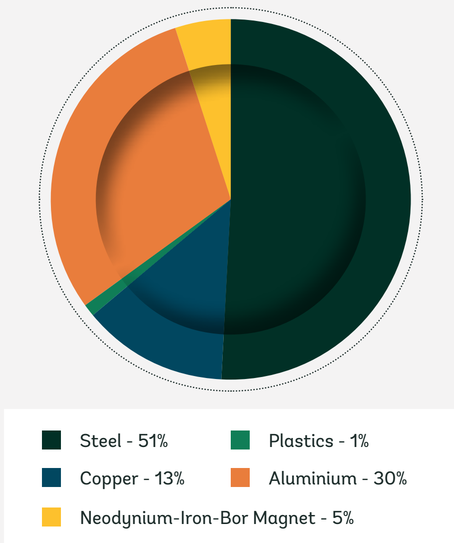
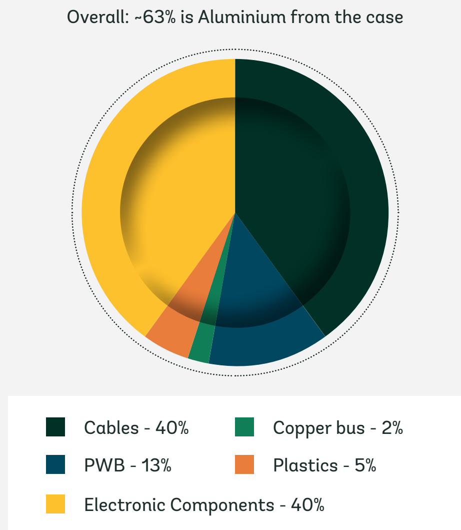


Figure 5A.6.

Material composition of the controller (Without case) PWB: Printed Wiring Board.



The final component of the electric drive is the control panel, also called the "controller." As shown in Figure 5A.6, it is based on an electronic circuit board where the components and one or more microcontrollers are placed. This is the actual electronic part that is manufactured in a corresponding technological process. As you can see, the electronic components and wiring are the main elements, followed by the Printed Wiring Board (PWB). Plastic only represents about 5 percent of the control panel.

The battery has a significant overall impact on various environmental indicators such as extraction of copper, lithium and other metals, and production. Recycling systems for batteries as well as for electronic components such as inverters and traction motors will be important to environmental sustainability. The second area of consideration for global impact is powertrain electronics. Recycling locally or in another country is strongly recommended for batteries, as they are composed mainly of metals and plastics. Rare earths such as neodymium (Nd) or samarium (Sm) will also be present in permanent magnets that are part of a synchronous electric machine that forms the basis of the traction motor. Metals and resins must also be taken into account in the recycling chain.

CALCULATION METHODS

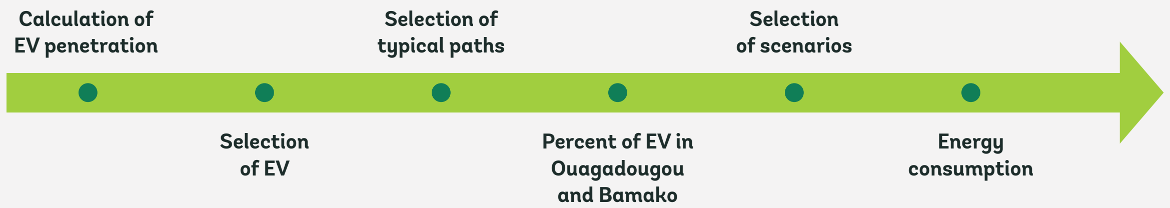
The LCA has been conducted using two overlapping methodologies. From the software perspective, the bibliographic analysis of previously achieved LCA investigations has supported the use of the open LCA20 tool. For the open LCA software, the "Ecoinvent"[20] and "European Platform on Life Cycle Assessment (ELCD)"[21] databases were used. These databases include datasets for a range of products covering various sectors such as metals, chemicals, plastic, etc.

20 https://www.ecoinvent.org/

21 https://eplca.jrc.ec.europa.eu/index.html

Figure 6A.1.

Methodological scheme for energy consumption analysis



ANNEX 6
MAIN ASSUMPTIONS FOR THE LIFE CYCLE ASSESSMENT

The methodology used to estimate energy consumption is based on international literature **[32]**. The block diagram of the implemented algorithm is shown in Figure 6A.1. Electric Vehicle (EV) penetration methodology is developed to analyze consumer choice of vehicle technologies based on a series of attributes and to predict the market share of each technology.

In (1), the probability P(j|k) that a consumer chooses vehicle technology j from the set of technologies k was derived as a function of the utility of the technology by assuming that the unobservable part of the utility is random and subject to an independent and identical Gumbel distribution [33].

$$P(j\,|k) = \frac{e^{-V_j}}{\sum_{j=1}^{n} e^{-V'_j}} \qquad (1)$$

In (2), nis the number of vehicle technology types in set k and Vj is the consumer utility (or generalized cost) of vehicle technology j, which is a weighted sum of the product between the attribute weight βj and the observable attribute functions f(xi,j).

$$V_j = \sum_{i=1}^{n} \beta_i \cdot f(x_{i,j}) \qquad (2)$$

A discrete choice model was adopted to analyze the factors affecting the penetration of electric vehicles. According to this model, two scenarios were evaluated: 1) slow penetration and 2) fast penetration.

The slow penetration scenario describes a future with slow technological development and insufficient charging facilities, while the fast penetration scenario describes a future with rapid technological development and sufficient charging facilities.

In addition, although battery capacity can reduce and increase impedance during cycling [34], the influence of battery performance was limited by maintaining the same state of charge (SOC) at 80 percent at the beginning of each starting trip.

In the slow penetration scenario, the total number of electric vehicles under consideration on the road in Ouagadougou and Bamako is 29,050 and 6,400, respectively. In the fast penetration scenario, the number of electric vehicles on the road is equal to 406,700 in Ouagadougou and 89,600 in Bamako.

Next, the set of two- and three-wheelers was selected based on the following attributes:

- Purchase price
- Fuel economy
- Autonomy
- Performances
- Maintenance cost
- Fuel price
- Refueling / loading convenience.

The types of vehicles and their characteristics considered for this analysis are described in Annex 4.

Table 6A.1.

Main characteristics of electric tricycles

City	Total EVs	e-Bikes	e-Motos/Scooters	e-Tricycles
Slow penetration scenario				
Ouagadougou	29,050	10,263	12,297	6,489
Bamako	6,400	2,795	2,283	1,323
Fast penetration scenario				
Ouagadougou	406,700	143,701	172,170	90,830
Bamako	89,600	39,125	31,957	18,517

Based on the algorithm, the number of electric vehicles in Ouagadougou and Bamako in the slow and fast penetration scenarios is presented in Table 6A.1.

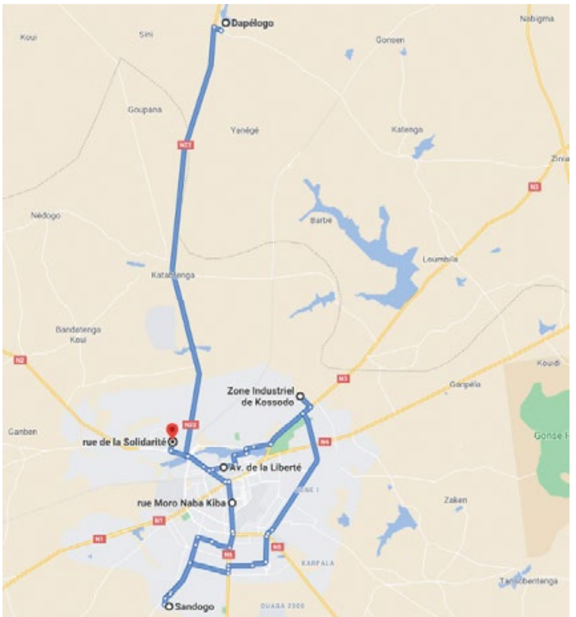
Note that these values are based on statistical models. They are useful for calculating what might happen in terms of energy consumption in hypothetical scenarios. They are not intended to be an accurate reflection of reality.

In order to be representative of average daily driving behavior, different routes in Ouagadougou and Bamako were selected, as shown in Map 6A.1 and Map 6A.2. The three trips selected in Ouagadougou include the following:

- **Route 1:** The first route starts at the Kossodo Industrial Zone and ends at Sandogo; the distance is about 20 km.
- **Route 2:** The second route starts at Moro NabaKiba Street and ends at Solidarity Street, Cité Azimmo Tampouy; the distance is about 8 km.
- **Route 3:** The third route starts in Dapélogo and ends in Av. de la Liberté, Dapoya; the distance is about 35 km.

Map 6A.1.

Examples of daily trips in Ouagadougou



Map 6A.2.

Examples of daily trips in Bamako

Those selected in Bamako include the following:

- **Route 1:** The first one starts from Ave De La Liberté and ends at Senou; the distance is about 20 km.
- **Route 2:** The second one starts at Djikoroni and ends at Avenue Manoir Diagne; the distance is about 8 km.
- **Route 3:** The third route starts at Rue Pasteur and ends at Diago; the distance is about 35 km.

The number of vehicles per type and per trip (distance) is shown in Table 6A.2 and Table 6A.3.

Different scenarios were simulated to obtain the energy consumed for each hour of the day. The number of electric vehicles driving on the three routes was also estimated for each hour of the day.

The proposed energy assessment considers the influence of driving style. Three different driving conditions were considered: normal, relaxed, stressed. These driving styles are considered because the energy consumed by electric vehicles can change depending on their average speed, maximum speed, and acceleration. Considering all these factors and the energy used by individual electric vehicles per km (kWh/km), the energy consumption by time period was estimated for Ouagadougou and Bamako.

Figure 6A.2 and Figure 6A.3 show the energy consumption of two- and three-wheel electric vehicles for different trips using a normal driving style in Ouagadougou and Bamako for slow and fast penetrations. These results represent the energy consumed during the trips. The batteries of the electric vehicles are charged at a time that is different from the time scale shown in the figures.

Table 6A.2.

Number of EVs circulating for different routes in the slow penetration scenario

City	Trip	e-Bikes	e-Motos/Scooters	e-Tricycles
Ouagadougou	1	3,592	4,304	2,271
	2	2,567	3,074	1,621
	3	4,105	4,919	2,596
Bamako	1	978	800	434
	2	699	517	331
	3	1,119	912	528

Table 6A.3.

Number of EVs circulating for different routes in the fast penetration scenario

City	Trip	e-Bikes	e-Motos/Scooters	e-Tricycles
Ouagadougou	1	50,295	60,258	31,789
	2	35,925	43,042	22,708
	3	57,480	68,869	36,332
Bamako	1	13,693	11,184	6,480
	2	9,781	7,989	4,630
	3	15,651	12,784	7,407

Figure 6A.2.

Energy consumption of two- and three-wheeled electric vehicles for different trips under normal driving conditions in Ouagadougou: (left) slow penetration scenario; (right) fast penetration scenario

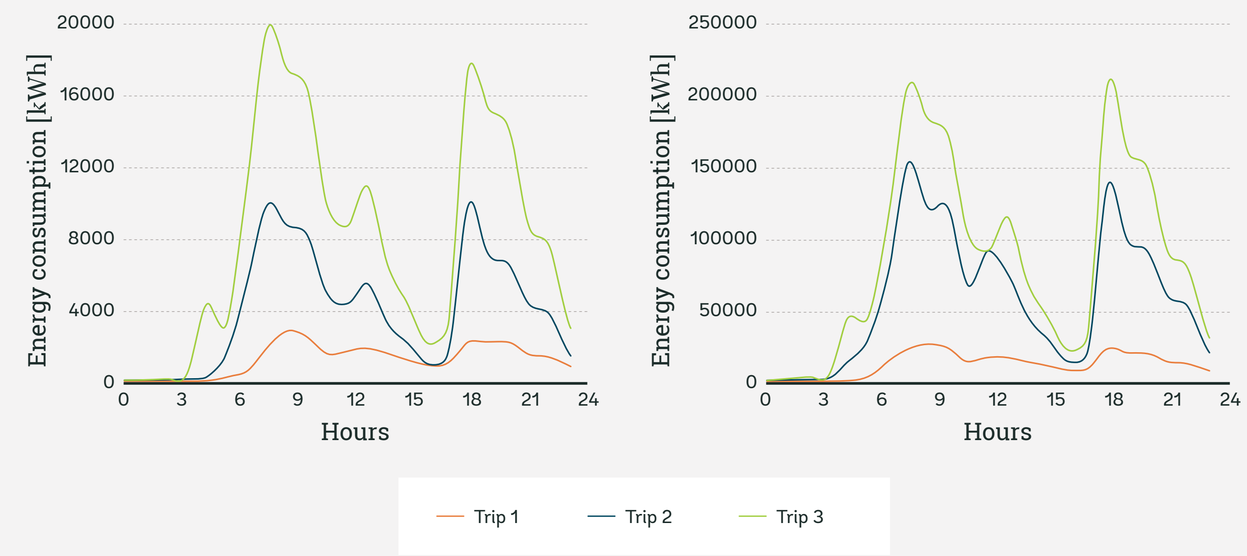


Figure 6A.3.

Energy consumption of two- and three-wheeled electric vehicles for different trips under normal driving conditions in Bamako: (left) slow penetration scenario; (right) fast penetration scenario

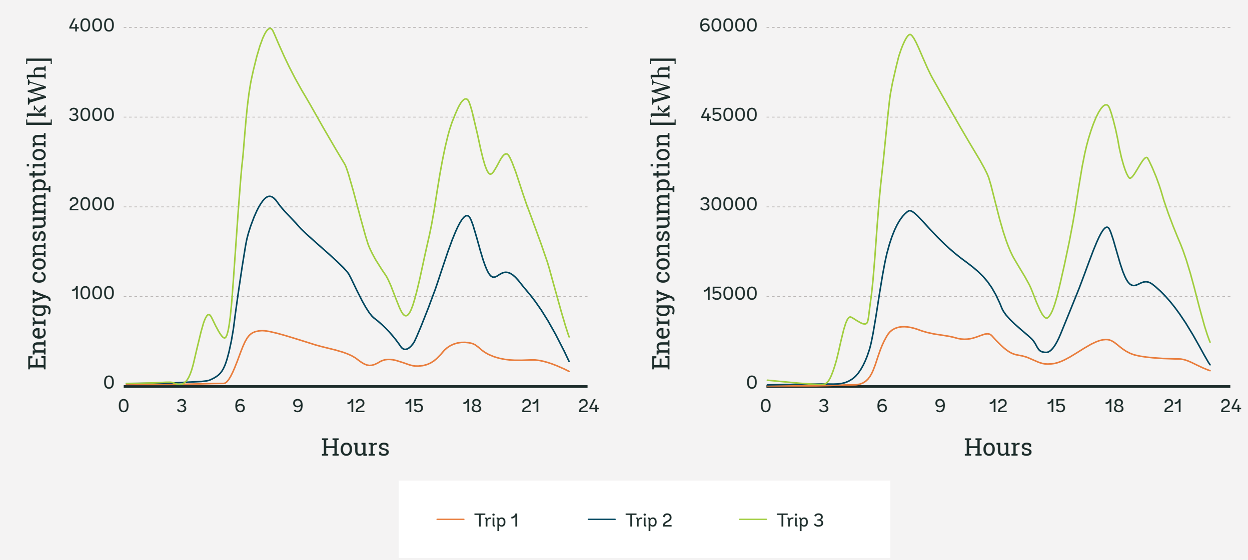


Figure 6A.4 and Figure 6A.5 show the energy consumption of electric two- and three-wheelers during trips according to driving styles in Ouagadougou for the slow and fast penetration scenarios.

Figure 6A.6 and Figure 6A.7 show the energy consumption of electric two- and three-wheelers as a function of driving styles in Bamako for the slow and fast penetration scenarios, respectively.

Figure 6A.4.

Energy consumption of two- and three-wheeled electric vehicles for different driving styles in a slow penetration scenario in Ouagadougou: (top) route 1; (middle) route 2; (bottom) route 3

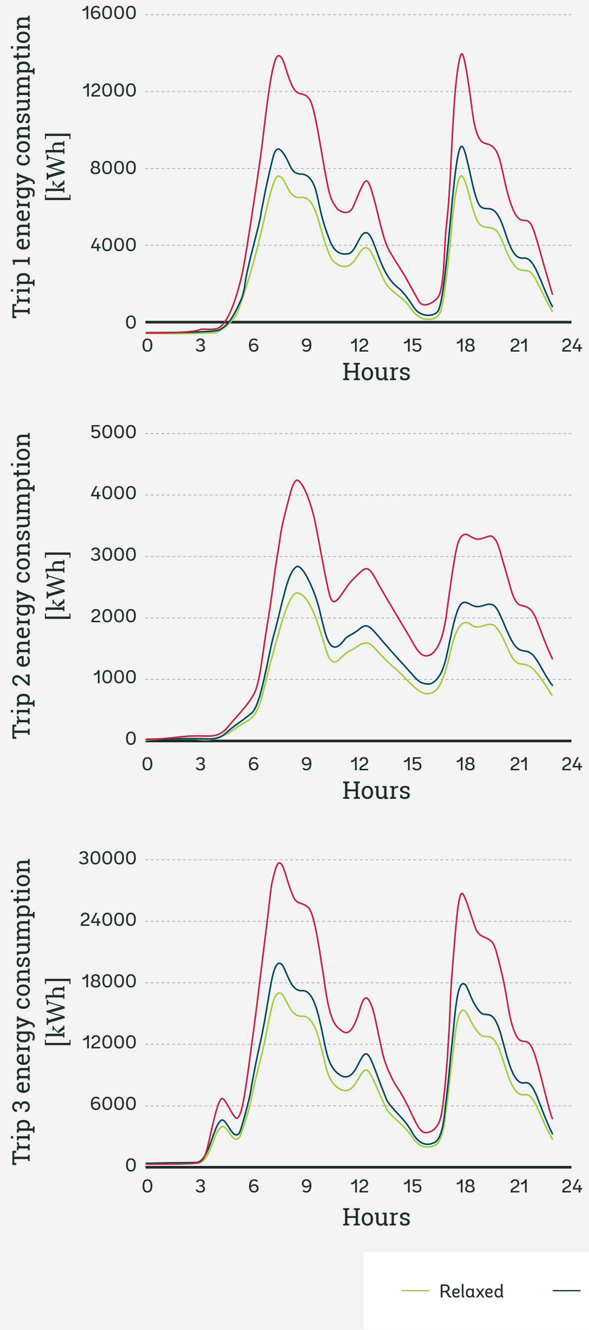


Figure 6A.5.

Energy consumption of two- and three-wheeled electric vehicles for different driving styles in a fast penetration scenario in Ouagadougou: (top) route 1; (middle) route 2; (bottom) route 3

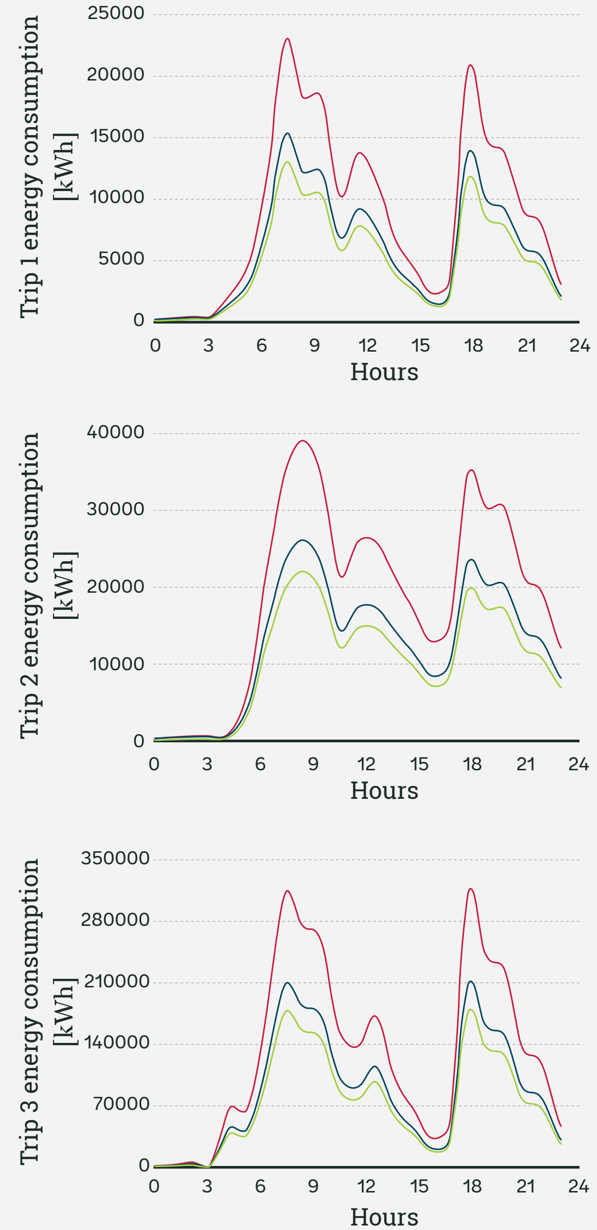


Figure 6A.6.

Energy consumption of two- and three-wheeled electric vehicles for different driving styles in a slow penetration scenario in Bamako: (top) route 1; (middle) route 2; (bottom) route 3

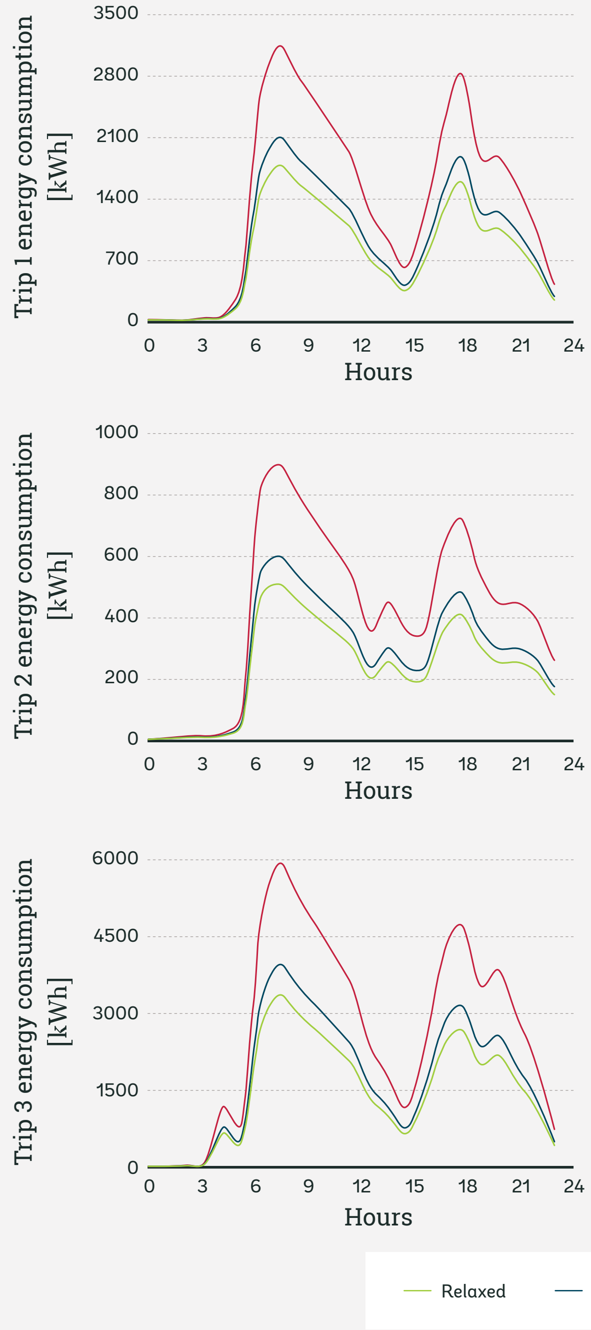


Figure 6A.7.

Energy consumption of two- and three-wheeled electric vehicles for different driving styles in a fast penetration scenario in Bamako: (top) route 1; (middle) route 2; (bottom) route 3

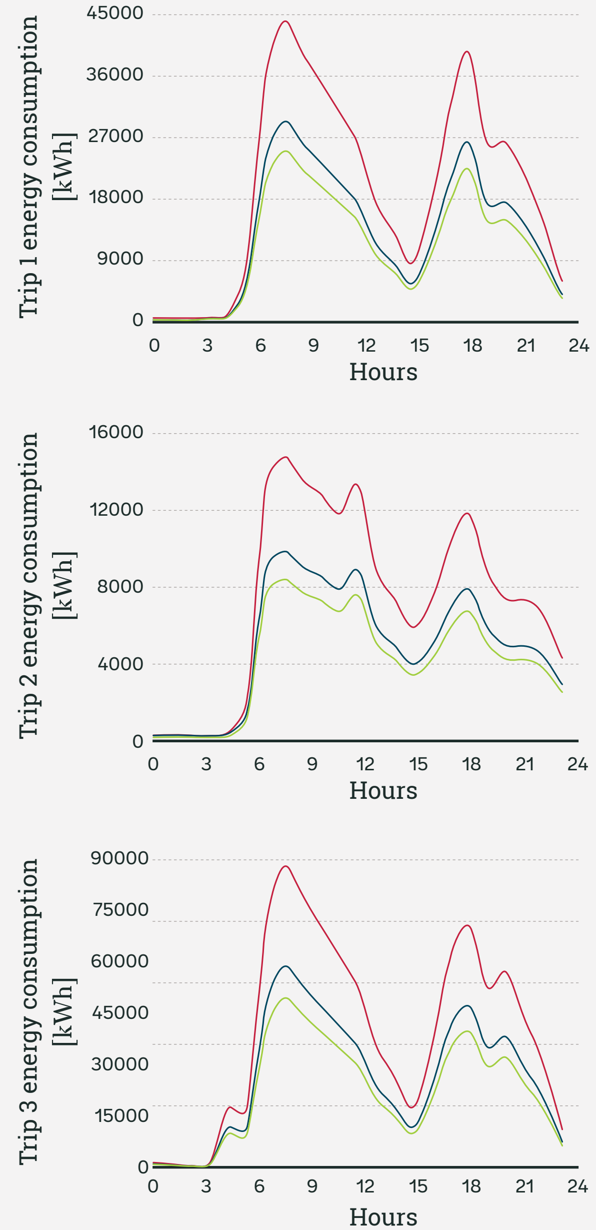


Figure 6A.8 and Figure 6A.9 show the total energy consumption as a function of daily time periods in the slow and fast penetration scenarios in Ouagadougou and Bamako. The peak energy consumption occurs in the morning and evening, since the percentage of electric vehicles is higher than at other times of the day. In addition, since the number of two- and three-wheelers is higher in Ouagadougou than in Bamako, the peak energy distribution in Ouagadougou is higher than in Bamako.

Figure 6A8.

Total energy consumption of two- and three-wheel electric vehicles in Ouagadougou: (top) slow penetration; (bottom) fast penetration

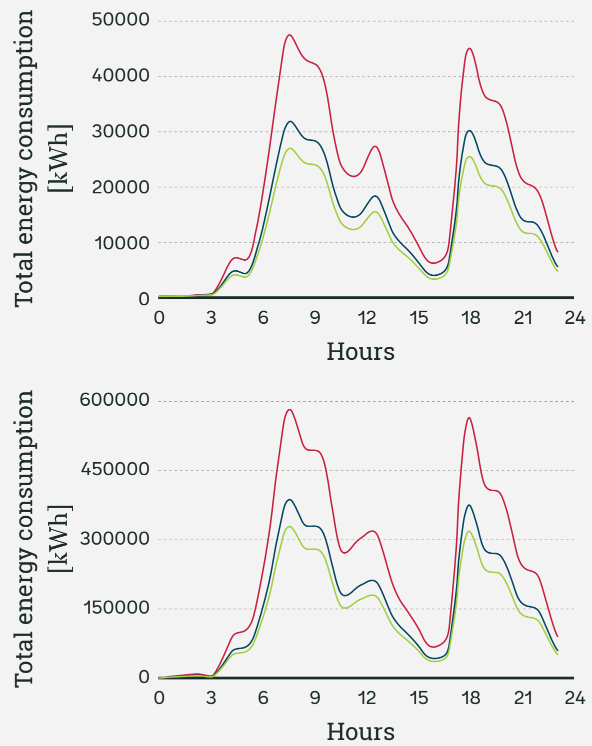
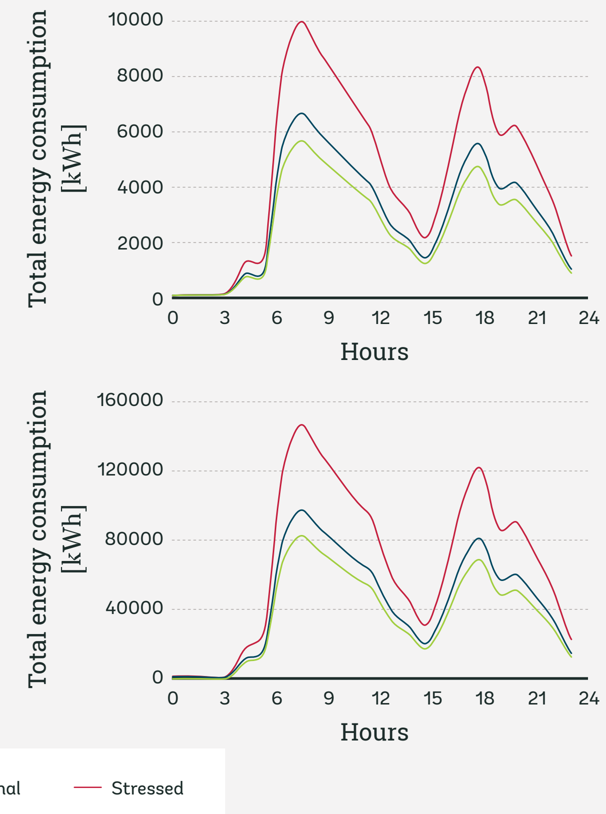


Figure 6A.9.

Total energy consumption of two- and three-wheel electric vehicles in Bamako: (top) slow penetration; (bottom) fast penetration



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ANNEX 7
EXAMPLES OF PILOT PROJECTS IN EUROPE

THE ELVITEN PROJECT

The project focused on the demonstration of electric mobility services in six European cities. One of the Elviten pilot projects was carried out in Rome with the following characteristics:

- Responsible entity of the pilot project: Municipality of Rome (with support from UNeed.IT for the implementation, management, and monitoring of the pilot project).
- Use of 60 L1e-A electric bicycles (also called "motorized bicycles").[22]
  - » Brand: Radpower
  - » Model: RadRhino 5
  - » 250W geared motor
  - » Up to 70 km per charge
  - » 672 Wh Lithium-Ion battery
  - » Load capacity: 125 kg
  - » Maximum speed: 25 km/h
  - » Equipped with throttle
  - » Purchase price: US$2,000 (CFAF 1,092,000)
- Electric bicycles loaned to officials of the Municipality of Rome and the Rome Municipal Police (one bicycle for each official for 18 months)
- Electric bicycles used for commuting and for travel during working hours (e.g., travel of Municipal Police officers)
- Duration of the pilot project: 12 months
- Batteries recharged in the workplace
- Pilot project carried out in a specific area of the city of Rome (called "EUR").

The bicycles were equipped with a "GPS box," allowing the collection of data on distances travelled, times of use, average speeds, and to monitor in real time the use of each bicycle.

This type of e-bike, according to Italian regulations, is considered a moped and therefore needs to be registered and insured (at least for civil liability). In Italy, this type of e-bike cannot be used on bicycle lanes and must be used while wearing a helmet.

During the pilot project period, an average of 56 people used their e-bike every day. On average, the e-bikes were used for trips (one way) of about 6 km. Approximately 156,000 km were travelled on these e-bikes during the pilot project (i.e., approximately 32,000 trips in one year).

Almost all the e-bike users rode the e-bike fairly consistently, and many of them stated that they would purchase the bike at the end of the project.

22 It is a two-wheeled vehicle with a power output of 1,000 watts or less, and a maximum speed not exceeding 25 km/h

Figure 7A.1.

L1e-A electric bicycle

THE LIFE SCPROJET

The *Life for Silver Coast* project aims to reduce polluting emissions caused by intense mobility in the Italian coastal area through the promotion of mobility patterns. The objective is to allow residents and tourists to access individual or public electric transport services, depending on personal needs and the destination to be reached.

The project is testing an integrated mobility network in three coastal towns (Isola del Giglio, Monte Argentario, Orbetello) combining public transport and private sharing services. In particular, the project develops the following:

- A sharing system operating with electric bikes and electric cars
- New links, operated by electric boats, connecting Orbetello to the nearby beaches
- Electric boats suitable for sea operation for tourist connections in the coastal area of Argentario and Giglio
- An electric shuttle bus between the Orbetello train station and the town center
- An integrated mobility platform that allows users to travel on all services using a single ticketing system.

The pilot began in July 2020, with bike (15) and electric scooter (10) sharing services. It is expected that the remaining electric mobility services will be rolled out starting in June 2021, including the following:

- 80 pedal-assist electric bicycles (ICONE brand) used in a "point-to-point" sharing model (bicycles are recharged by bicycle parking facilities located in different areas of the three cities):
  - » Maximum speed: 25 km/h.
  - » Autonomy: 30-40 km.

Figure 7A.2.

Electric bicycle

Source: Brand's website

Figure 7A.3.

Scooter

Source: Brand's website

Figure 7A.4.

Electric car

Source: Brand's website

- 20 electric scooters (Askoll brand) used according to a "free floating" sharing model and recharged through battery swapping
  - » Maximum speed: 45 km/h.
  - » Autonomy: 70 km.
- 10 electric cars (Renault Zoe) used according to a "free floating" sharing model and recharged through public charging stations
- One seven-seater electric vehicle used for trips between the train station and the city center and recharged through public charging stations
- 4 electric boats, used for trips between downtown and the beach and recharged through public charging stations.

During the first phase of the pilot project (from July 2020 to October 2020), the electric mobility services (i.e., bicycles and scooters) achieved the following results:

- Total registered customers: 174
- Bicycle rental: 45
- Scooter rental: 43
- Bicycle usage: average rental time 9 hours averaging 23 km per bicycle
- Scooter use: average time of use - 15 hours
- The analysis of the preliminary data led to the following findings:
- The average rental time is rather high, probably due to the "in-station" type of sharing that was offered during the first phase of the pilot.
- The most active travel points provide a more complete understanding of service location, which is more revealing in densely populated areas and an important factor in the region's main tourist attractions.

ANNEX 8
ESTIMATION OF EMISSIONS BY POLLUTANT

OUAGADOUGOU

Table 8A.1

CO emissions by type of vehicle in Ouagadougou

Transport modes	Share in traffic	g CO / km		CO	
		Low	High	Low	High
Two-wheelers	71 percent	3.0	33.0	74 percent	75 percent
Three-wheelers	1 percent	3.0	35.0	1 percent	1 percent
Cars/taxis	17 percent	3.5	37.0	21 percent	20 percent
Trucks/buses/minibuses	2 percent	6.0	59.0	4 percent	4 percent

Table 8A.2

NMVOC emissions by type of vehicle in Ouagadougou

Transport modes	Share in traffic	gNMVOC / km		NMVOC	
		Low	High	Low	High
Two-wheelers	71 percent	0.008	8.2	74 percent	76 percent
Three-wheelers	1 percent	0.01	8.3	1 percent	1 percent
Cars/taxis	17 percent	0.01	8.9	22 percent	20 percent
Trucks/buses/minibuses	2 percent	0.01	10.0	3 percent	3 percent

Table 8A.3

NOx emissions by type of vehicle in Ouagadougou

Transport modes	Share in traffic	gNOx / km		NOx	
		Low	High	Low	High
Two-wheelers	71 percent	0.06	0.5	75 percent	28 percent
Three-wheelers	1 percent	0.06	4.0	1 percent	2 percent
Cars/taxis	17 percent	0.18	10.0	18 percent	54 percent
Trucks/buses/minibuses	2 percent	0.06	2.0	6 percent	16 percent

Table 8A.4

NH3 emissions by type of vehicle in Ouagadougou

Transport modes	Share in traffic	gNH_3 / km		NH_3	
		Low	High	Low	High
Two-wheelers	71 percent	0.001	0.002	76 percent	70 percent
Three-wheelers	1 percent	0.001	0.003	1 percent	1 percent
Cars/taxis	17 percent	0.002	0.004	18 percent	25 percent
Trucks/buses/minibuses	2 percent	0.001	0.002	4 percent	4 percent

Table 8A.5

PM2.5 emissions by type of vehicle in Ouagadougou

Transport modes	Share in traffic	gPM2.5 / km		PM2.5	
		Low	High	Low	High
Two-wheelers	71 percent	0.003	0.18	66 percent	69 percent
Three-wheelers	1 percent	0.005	0.22	1 percent	1 percent
Cars/taxis	17 percent	0.010	0.90	26 percent	20 percent
Trucks/buses/minibuses	2 percent	0.004	0.20	6 percent	10 percent

Table 8A.6

N_2O emissions by type of vehicle in Ouagadougou

Transport modes	Share in traffic	g N_2O / km		N_2O	
		Low	High	Low	High
Two-wheelers	71 percent	0.001	0.002	63 percent	38 percent
Three-wheelers	1 percent	0.001	0.005	1 percent	1 percent
Cars/taxis	17 percent	0.002	0.01	30 percent	45 percent
Trucks/buses/minibuses	2 percent	0.003	0.03	5 percent	16 percent

Table 8A.7

CO emissions by type of vehicle in Bamako

Transport modes	Share in traffic	g CO / km		CO	
		Low	High	Low	High
Two-wheelers	76 percent	3.0	33.0	70 percent	73 percent
Three-wheelers	1 percent	3.0	35.0	1 percent	1 percent
Cars/taxis	19 percent	3.5	37.0	21 percent	19 percent
Trucks/buses/minibuses	4 percent	6.0	59.0	8 percent	7 percent

Table 8A.8

NMVOC emissions by type of vehicle in Bamako

Transport modes	Share in traffic	gNMVOC / km		NMVOC	
		Low	High	Low	High
Two-wheelers	76 percent	0.008	8.2	73 percent	75 percent
Three-wheelers	1 percent	0.01	8.3	1 percent	1 percent
Cars/taxis	19 percent	0.01	8.9	21 percent	19 percent
Trucks/buses/minibuses	4 percent	0.01	10.0	5 percent	5 percent

Table 8A.8

NOx emissions by type of vehicle in Bamako

Transport modes	Share in traffic	gNOx / km		NOx	
		Low	High	Low	High
Two-wheelers	76 percent	0.06	0.5	71 percent	25 percent
Three-wheelers	1 percent	0.06	4.0	1 percent	1 percent
Cars/taxis	19 percent	0.18	10.0	16 percent	47 percent
Trucks/buses/minibuses	4 percent	0.06	2.0	11 percent	27 percent

Table 8A.10

NH3 emissions by type of vehicle in Bamako

Transport modes	Share in traffic	gNH_3 / km		NH_3	
		Low	High	Low	High
Two-wheelers	76 percent	0.001	0.002	74 percent	68 percent
Three-wheelers	1 percent	0.001	0.003	1 percent	1 percent
Cars/taxis	19 percent	0.002	0.004	17 percent	24 percent
Trucks/buses/minibuses	4 percent	0.001	0.002	8 percent	7 percent

Table 8A.11

PM2.5 emissions by type of vehicle in Bamako

Transport modes	Share in traffic	gPM2.5 / km		PM2.5	
		Low	High	Low	High
Two-wheelers	76 percent	0.003	0.18	63 percent	64 percent
Three-wheelers	1 percent	0.005	0.22	1 percent	1 percent
Cars/taxis	19 percent	0.010	0.90	24 percent	18 percent
Trucks/buses/minibuses	4 percent	0.004	0.20	11 percent	17 percent

Table 8A.12

N_2O emissions by type of vehicle in Bamako

Transport modes	Share in traffic	g N_2O / km		N_2O	
		Low	High	Low	High
Two-wheelers	76 percent	0.001	0.002	61 percent	33 percent
Three-wheelers	1 percent	0.001	0.005	1 percent	1 percent
Cars/taxis	19 percent	0.002	0.01	28 percent	39 percent
Trucks/buses/minibuses	4 percent	0.003	0.03	10 percent	27 percent